Navigating challenges and enhancing efficiency in production planning

A case study at Alfa Laval

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Lund, June 2024

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ACKNOWLEDGEMENTS

This master's thesis was written in the spring of 2024 as a final project of our master's degree in mechanical engineering at the Faculty of Engineering at Lund University. The thesis was a collaboration between the university and Alfa Laval AB.

We would like to thank the employees at Alfa Laval for participating in interviews and sharing valuable knowledge. Additionally, we would like to express our gratitude to our supervisor at Alfa Laval, Erik Ramström for his engagement and guidance.

Further, we would like to thank our supervisor at the Department of Mechanical Engineering Science, Jan Olhager, for his continuous feedback and dedication.

Lund, 2024

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ABSTRACT

Title	Navigating challenges and enhancing efficiency in production planning
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Background
A well-designed production planning system is the cornerstone of successful manufacturing operations, unlocking the full potential of a manufacturing process. By optimizing production planning processes, companies can achieve efficiency and meet customer demands, in order to stay competitive. This master's thesis explores the complexities and opportunities of production planning in the context of Alfa Laval's assembly factory in Lund.

Problem definition and purpose
Alfa Laval is currently undergoing significant changes in workshop and flow configuration, which are impacting the phenomenon of planning and control processes. These changes have led to noticeable symptoms. The planning process is perceived as time-consuming, and places strain on multiple resources. Therefore, the purpose of this thesis is to find improvement areas of the planning processes by identifying root causes affecting the issues related to production planning at Alfa Laval.

Methodology and Theoretical framework
To fulfill the purpose, a case study was conducted. The empirical data was collected through interviews, observations, internal documents and information systems in order to map the current planning process at the company. The literature review was divided into three main parts that are equivalent to production planning levels, Master Schedule, material and capacity plan, as well as production planning and control. In addition, various concepts impacting production planning was investigated into as well.

Conclusion
The thesis ultimately resulted in a list of recommendations to the company that covers all planning stages, which is believed to improve the planning process at Alfa Laval. The recommendations at the master scheduling level are in general about consensus and utilizing correct methods. A material and capacity plan was not found and is therefore recommended to implement a suitable one. Lastly, the recommendation at the level of production activity control was in general to refine existing processes.

Keywords
Production planning and control, master schedule, material and capacity plan, production activity control, manufacturing.

ABBREVIATIONS

CRP	Capacity requirement planning
CTO	Configured to order
ETO	Engineered to order
MRP	Material requirement planning
MTO	Make-to-order
MTS	Make-to-stock
OPT	Optimized production technology
PAC	Production activity control
S&OP	Sales and operation planning

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1. INTRODUCTION

The introduction to this thesis provides an overview of the background and context of the research. Specifically, the chapter will introduce the company investigated, outlining characteristics and relevance to the study. Additionally, the chapter will define the problem, purpose, and research questions that guides this thesis. Furthermore, it will outline the focus area and delimitations of the study, ensuring that the scope of the research is well-defined and manageable. Finally, the chapter will conclude with an outline of the structure of the thesis. Figure 1.1 shows an overview of the chapter and what sub-chapters it includes.

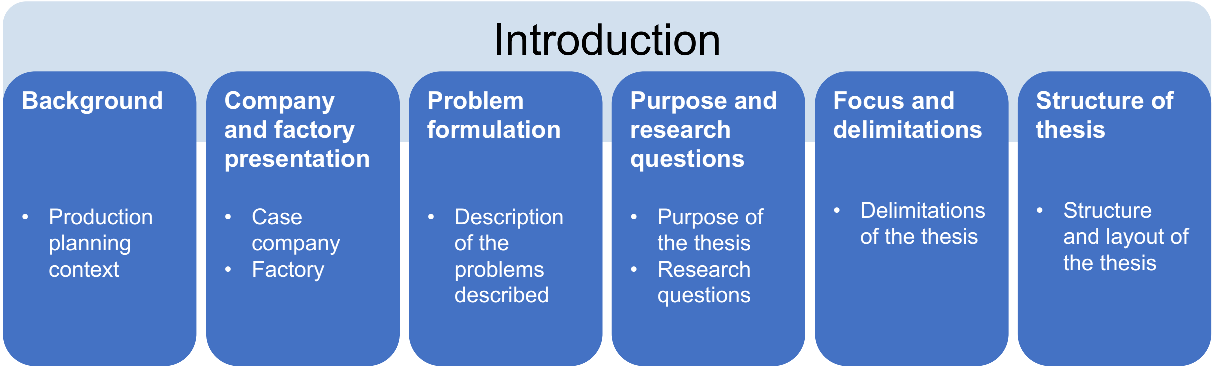

Figure 1.1. The structure of the following chapter 1. Introduction.

1.1 Background

In the ever-evolving landscape of manufacturing, there is a great need to stay competitive. According to Olhager (2022), this requires a strategic approach that combines strategy, production processes, planning, and control. Further, Mattsson and Jonsson (2008) describe that production logistics is a relatively recent field, where recognized theories have emerged since the 1950s. During this short period, many trends within the subject have emerged, swiftly driving competitiveness forward and influencing production planning (Mattsson and Jonsson, 2008; Olhager, 2013). Olhager (2013) elaborate that today, competitiveness entails excelling in quality, delivery, cost efficiency, and flexibility. This necessitates meticulous planning and control of operations which have grown in complexity due to shorter lead times, product life cycles, and the need for more efficient bottleneck utilization. Engwall (2020) describes the important difference between production planning and production control as linked to the horizons. Planning relates to the long-term horizon, while control relates to the short-term horizon. The author also asserts that the less meticulous planning, the more labor-intensive the control process becomes. Kiran (2019) explains that an efficient production planning system enables any manufacturing process to reach its full potential. According to the author, a production plan determines what and how much to produce, as well as required resources. It is argued that the benefits from a customer perspective are better quality of products and accurate deliveries, whereas for the manufacturer the benefits of production planning are optimized resources and improved decision-making, among others (Kiran, 2019). In light of these benefits, it is clear that production planning plays a crucial role in manufacturing operations. Therefore, it is argued that in essence, production planning serves as the backbone of manufacturing operations, driving efficiency, and enabling businesses to meet customer demands in an ever-evolving market environment. This master's thesis aims to explore the challenges and opportunities of production planning in a manufacturing context.

1.2 Company and factory presentation

The case company chosen for this thesis is Alfa Laval, a prominent global leader in providing energy-efficient solutions for heating, cooling, separation, and transportation of various products including oil, water, and chemicals (Alfa Laval AB, n.d.). The company has production facilities in several locations worldwide. The largest and most important presence is in Lund, Sweden, where they have manufacturing plants for component production and assembly operations of gasket heat exchangers (Alfa Laval AB, 2022). This thesis will be conducted at the assembly factory in Lund. Hereafter, when mentioning the company, factory or Alfa Laval in this thesis, the authors refer to the assembly factory in Lund. At the facilities in Lund, the company manufactures various kinds of gasketed heat exchangers, belonging to different lines, series and ultimately business units. In Figure 1.2, two different types of heat exchanges can be seen. The figure illustrates the sanitary series and a selection of the industrial line.

Figure 1.2. A selection of different gasketed heat exchangers produced at Alfa Laval's assembly factory in Lund. The sanitary series to the left and industrial line to the right (Alfa Laval AB, n.d.).

The aim of a heat exchanger is to heat or cool a medium by transferring heat between the medium and another medium (Alfa Laval AB, n.d.). In a gasket plate heat exchanger, the plates are equipped with elastomer gaskets that seals the channels and guides the mediums through alternating channels (Alfa Laval AB, n.d.). When assembling a heat exchanger, an upper carrying bar is attached to a frame plate. Thereafter, gasketed plates and a pressure plate are suspended on the upper carrying bar and fixed in position with a lower guide bar (Alfa Laval AB, n.d.). Lastly, the apparatus is tightened together with tightening bolts. Figure 1.3 illustrates the main components in a gasketed heat exchanger as stated by Alfa Laval AB (n.d), as well as some main parts of the heat exchanger that are deemed necessary to conduct this thesis.

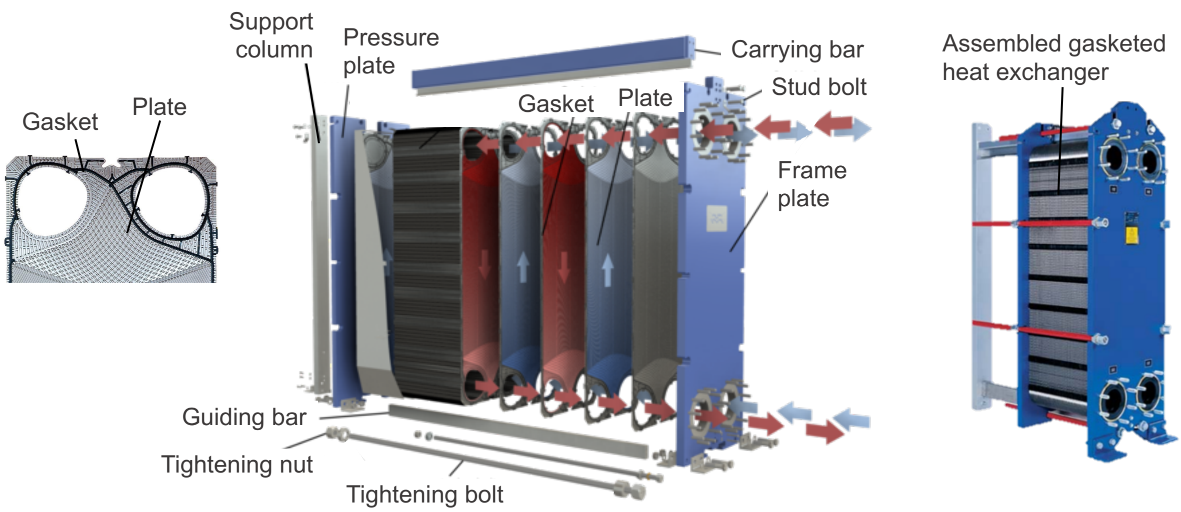

Figure 1.3. Gasketed heat exchangers main components relevant for this thesis (Alfa Laval AB, n.d.).

The factory consists of different assembly groups; small, medium, large, refrigeration, and sanitary. In the factory, products are produced once an order is received from a customer, adhering to a make-to-order (MTO) strategy. The size and the requirements of the products produced define the assembly groups. Each assembly group can accommodate two types of orders: configured to order (CTO) and engineered to order (ETO). The sanitary assembly group is organized differently as they are divided into base and frame, which represents the standardized and customized products. Figure 1.4 illustrates the assembly groups at the factory in Lund.

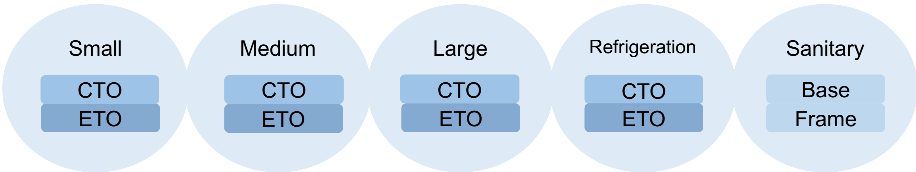

Figure 1.4. The assembly groups at Alfa Laval's factory located in Lund.

Additionally, a few components are manufactured in the factory. These are the painting of the front and pressure plates as well as the manufacturing of tightening bolts. The component manufacturing can be seen as an internal factory, inside the assembly factory. The operations at the assembly factory are illustrated in Figure 1.5.

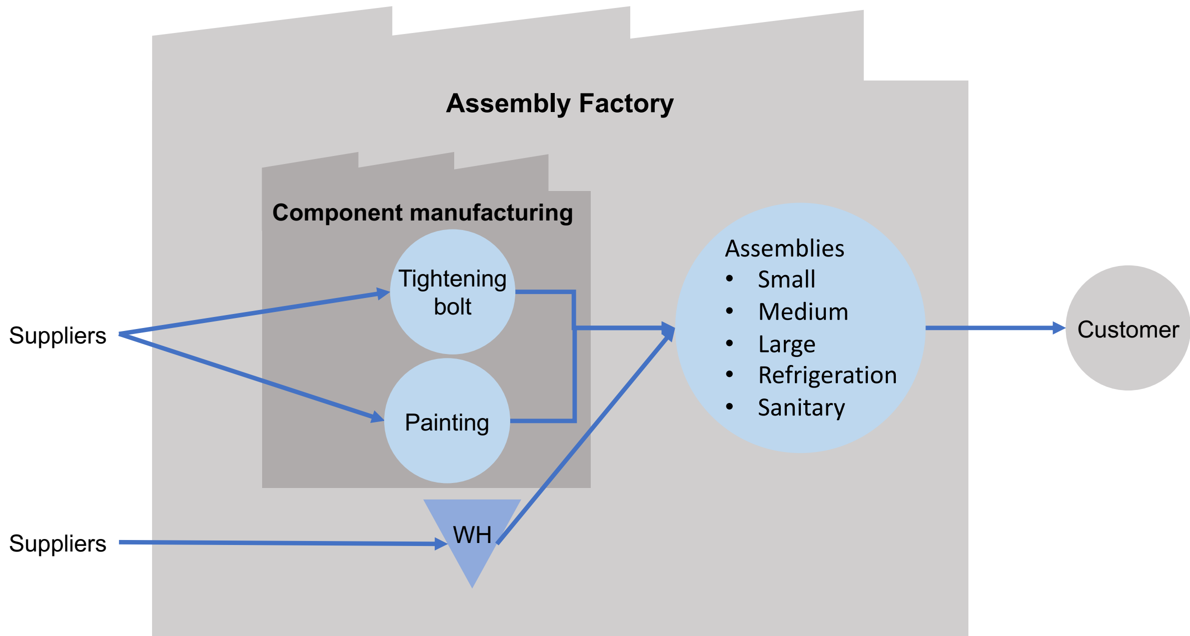

Figure 1.5. The operations at Alfa Laval's assembly factory located in Lund.

Currently, the production planning at Alfa Laval is divided between different actors. The sales and operation planning (S&OP) process is conducted globally across various factories. Thereafter, each individual plant further the planning process with master scheduling down to execution. In recent years, challenges in production planning and control have been acknowledged by Alfa Laval.

1.3 Problem formulation

Alfa Laval is currently undergoing significant changes in workshop and flow configuration, which are impacting the phenomenon of planning and control processes. These changes have led to noticeable symptoms, particularly an increase in extensive extra work within the Production Activity Control (PAC) processes. Currently, the PAC process is characterized by its iterative nature and is perceived as time-consuming, placing strain on multiple resources. As a result, manual planning tools have been introduced as temporary solutions. The underlying root causes of the resulting symptoms remain unidentified. Therefore, there is an urge to derive these root causes of the symptoms and find a more effective way to plan and control the production.

1.4 Purpose and research questions

The purpose of this thesis is to find improvement areas of the planning processes by identifying root causes affecting the issues related to production planning at Alfa Laval. To facilitate this purpose, the following research questions were developed.

RQ1: How are methods and principles used to conduct production planning processes in a manufacturing industry with a wide product range and MTO production?

The objective of this research question is to identify and analyze theories and methods that share similar characteristics with those of Alfa Laval. By investigating different approaches of production planning, the aim is to uncover underlying factors contributing to challenges in the production planning process at the company.

RQ2: What deficiencies or gaps are present in the production planning processes within the assembly factory at Alfa Laval?

This research question seeks to conduct an in-depth analysis of the production planning processes at Alfa Laval by comparing them with established theories and methods, to identify differences, similarities and gaps. By uncovering and understanding these gaps, the root causes of the production planning issues at Alfa Laval can be identified and addressed.

RQ3: What strategies can be implemented to improve the production planning process and address the identified root causes affecting production planning challenges in manufacturing industries with wide product ranges and MTO production?

This aim of this research question is to use the insights gained from identifying the root causes of production planning issues at Alfa Laval to develop strategies for improvement. By aligning these strategies with established theories and methods, recommendations for enhancing the planning process in similar manufacturing contexts will be suggested. The findings from this research will provide valuable guidance for companies facing similar challenges in optimizing their production planning operations.

1.5 Focus and delimitations

The S&OP process at Alfa Laval is integrated across multiple plants, making it a key factor for delimitation. As a result, the main emphasis will be on master scheduling, material and capacity planning, and PAC as illustrated in Figure 1.6. These planning levels will be further explained in chapter 3. Frame of reference. All functions and process controls highlighted in blue in the figure are located at the Alfa Laval factory in question. Further, the physical configuration of the production is given and cannot be changed. In addition, the product portfolio is considered outside the scope of the suggestion which means no portfolio management suggestions will be possible. Project orders are not being considered since they are planned by another department at Alfa Laval. As for the information system, Alfa Laval currently uses Jeeves ERP system, but plan to transition to a new system in the fall of 2025. No special consideration is taken to accommodate this change. Additionally, there is a time constraint as the research must be completed within 20 weeks.

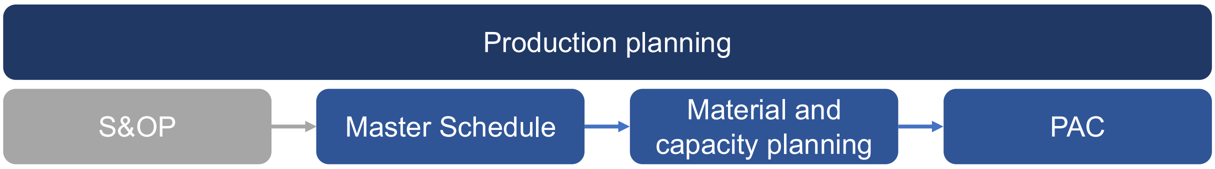

Figure 1.6. The planning process focus of this thesis.

1.6 Structure of thesis

The thesis consists of seven chapters. The initial chapter, 1. Introduction provides a general overview of the company and an introduction to the research. Subsequently, the methodology used for the thesis will be outlined in chapter 2. Methodology, including a discussion of research approach and design, as well as data collection and analysis, followed by an evaluation of research quality. Thereafter, relevant theories and concepts will be described in chapter 3. Frame of reference. It will include general concept considered to be relevant to the subject area, and methods for the three production planning levels master scheduling, material and capacity planning, and PAC. Thereafter, chapter 4. Empirical findings will present findings at the company in questions and a description of their production planning process. An analysis of the findings compared to the literature review is conducted in chapter 5. Analysis, before recommendations are discussed in chapter 6. Recommendations. The last chapter, 7. Conclusion summarized the thesis and the findings.

2. METHODOLOGY

The following chapter will describe the methodology used in the thesis. First, the research approach and design will be defined, followed by data collection and data analysis procedures that will be discussed. Thereafter, the research quality will be evaluated. Figure 2.1 illustrates an overview of the chapter and what sub-chapters it includes.

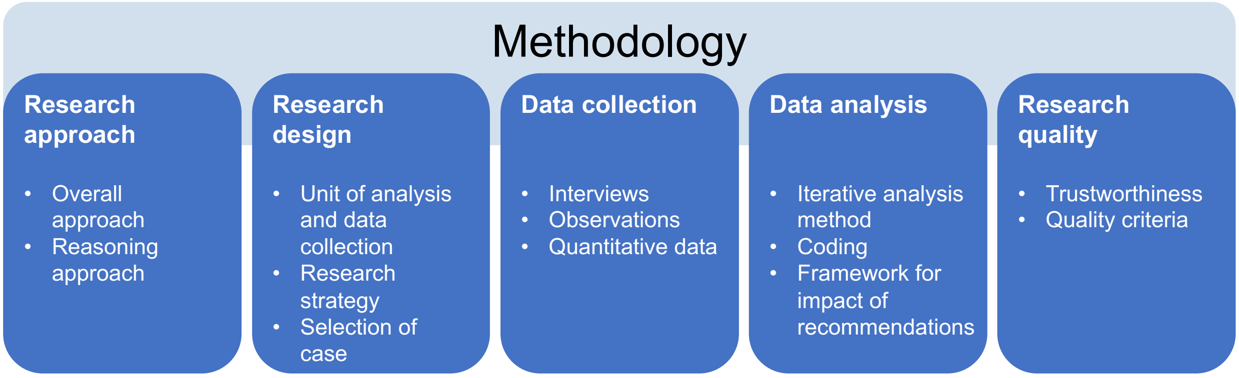

Figure 2.1. The structure of the following chapter 2. Methodology.

2.1 Research approach

The research approach serves as a guiding framework that shapes the methodology of this thesis. The main approaches used will hence be explained.

2.1.1 Overall approach

There are three different fundamental approaches in research; analytical approach, system approach, and actor approach, according to Björklund and Paulsson (2012). With an analytical approach, the aim is to describe reality as objectively and utterly as possible without considering subjective opinions, as stated by Björklund and Paulsson (2012). The authors explains that with this approach reality is seen as it can be divided into parts, and the sum of all parts equals the entirety. Arbnor and Bjerke (2009) further describe an analytical approach to be facts explaining the reality. A system approach on the other hand, is explained by Björklund and Paulsson (2012) as a way to describe reality objectively, similar to an analytical approach. Although, they describe that with this approach, the different parts and the relation between them are equally important. The authors mean that the sum of the parts does not necessarily equal the entirety. Arbnor and Bjerke (2009) add that with a system view, patterns, interactions, and irregular aspects are used to understand the reality. Meanwhile, an actor approach reflects on the research as a social construction that is both influenced by and has an impact on human beings, Björklund and Paulsson (2012) argues. They explain that this results in the research being dependent on the researcher's experiences and actions, which Arbnor and Bjerke (2009) agree with.

In this thesis, the focus was to describe reality as objectively as possible and break it down into parts. The relation between the parts was analyzed and were believed to be of great importance in the understanding of the production planning processes at Alfa Laval. With this in mind, a system approach was the overall approach in this thesis.

2.1.2 Reasoning approach

When conducting a study, there are three types of reasoning approaches; inductive, deductive, and abductive according to Saunders et al. (2019). Björklund and Paulsson (2012) describe an inductive approach to be when theory is formulated by empirical information. Saunders et al.

(2019) adds that theory is based on the data rather than the opposite. The opposite would be a deductive approach, where a theory is used to predict the empirical findings and is verified with collected data (Björklund and Paulsson, 2012). When both of these approaches are used back and forth, it is called an abductive approach, Björklund and Paulsson (2012) explains. Golicic et al. (2005) states that choosing only one approach, inductive or deductive, delimits the scope, and thereby the ability for information to contribute.

The authors of this thesis started with an inductive approach to get an overall understanding of the company and problem. Thereafter, a deductive approach was used to gather relevant theories and information regarding the area investigated. After this stage, the authors of this thesis had an iterative process between these two. This describes an overall abductive approach and is explained in Figure 2.2.

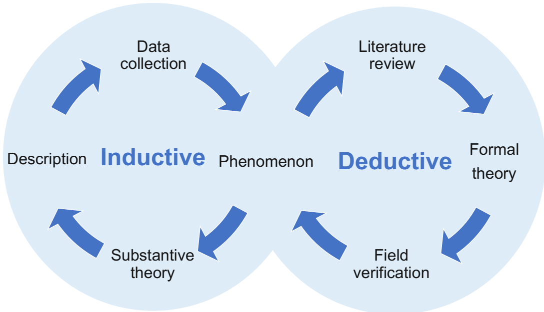

Figure 2.2. Inductive and deductive approach, inspired by Golicic et al. (2005).

2.2 Research design

This chapter will discuss and explain the unit of analysis, research strategy and method of this thesis. To conduct this thesis, the following research design was developed, see Figure 2.3. The design was based on Kembro and Norrman's paper (2019) in combination with Yin's (2018) framework for multiple case studies, which was adapted to suit this thesis.

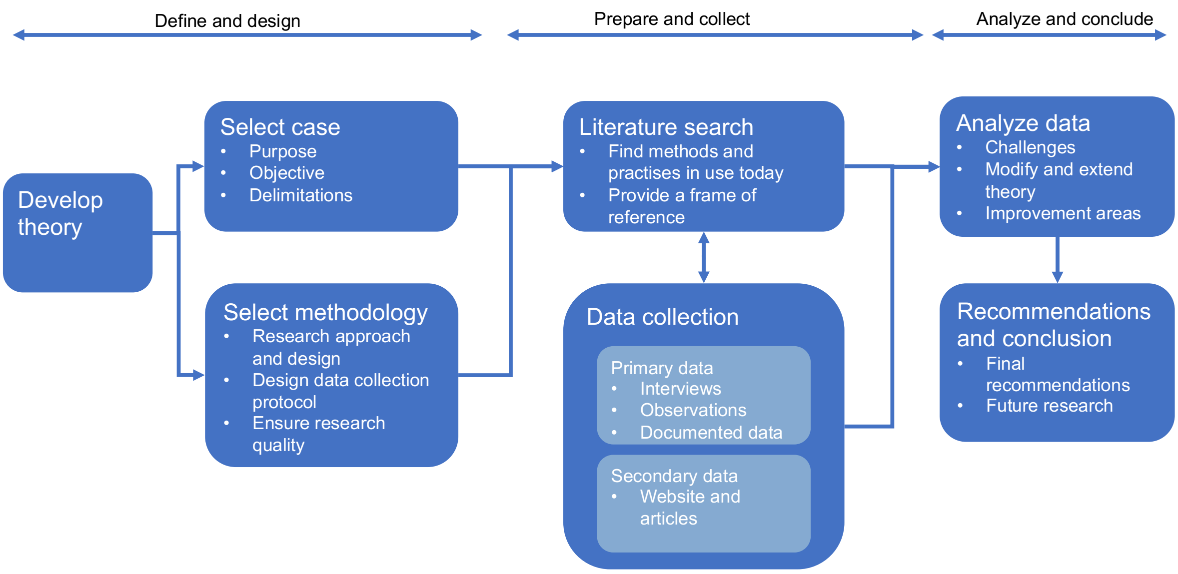

Figure 2.3. The research design, inspired by Kembro and Norrman (2019) and Yin (2018), adapted to a single case study.

2.2.1 Unit of analysis and data collection

The selection of unit of analysis is crucial as it determines the scope of study, what relevant data to gather, and at which level the phenomenon will be examined (Yin, 2018; Da Mota Pedrosa et al., 2012). In this thesis, the unit of analysis was the factory at Alfa Laval and its production planning processes. By adopting this specific unit, the study aimed to provide a comprehensive analysis of the current state within the factory and identify potential areas for improvement. Moreover, Yin (2018) defines the unit of data collection as the sources from which data will be gathered during a research study. Given the thesis's objective of identifying root causes and improvement opportunities within production planning, as well as the unit of analysis, the unit of data collection consisted of interviews, observations, and quantitative data. Conducting interviews with personnel from both administrative and operational departments, along with observational studies, was considered important for obtaining valuable insights into existing processes. Additionally, quantitative data was used to confirm the information obtained from interviews and observations, an essential part of the abductive approach.

2.2.2 Research strategy

Choosing a research strategy that aligns with the research questions will facilitate the collection of relevant data, necessary to address the research's purpose, according to Yin (2018). The author argues that three conditions should be considered when selecting a research strategy, as shown in Table 2.1. The absence of a need for control over behavioral events in the research, together with the thesis focusing on contemporary events, supports the suitability of a case study (Yin, 2018). Further, a case study suits the nature of the purpose, as the main objective is to find a solution on *how* to design the planning processes in the future. In accordance with Gammelgaard (2004), the choice of case study also aligns with the systematic approach of the thesis. Therefore, a case study was chosen as the research strategy.

Table 2.1. Relevant situations for different research methods (Yin, 2018).

Methods	Conditions: Form of research questions	Requires control of behavioral vents?	Focuses on contemporary events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
Case study	**How, why?**	**No**	**Yes**
History	How, why?	No	No

Yin (2018) describe there to be four different designs of case studies, depending on a holistic or embedded unit of analysis, as well as a single or multiple-case design, see Figure 2.4. A multiple-case study is often seen as a stronger option as it is considered more robust, according to Yin (2018). However, multiple-case studies are considered resource-intensive and time-consuming. As this thesis deals with a single unit of analysis, type one and three as seen in Figure 2.4, are suited. Given the need for a comprehensive understanding of the root cause within a limited timeframe, a single case study was selected to provide the necessary depth of analysis.

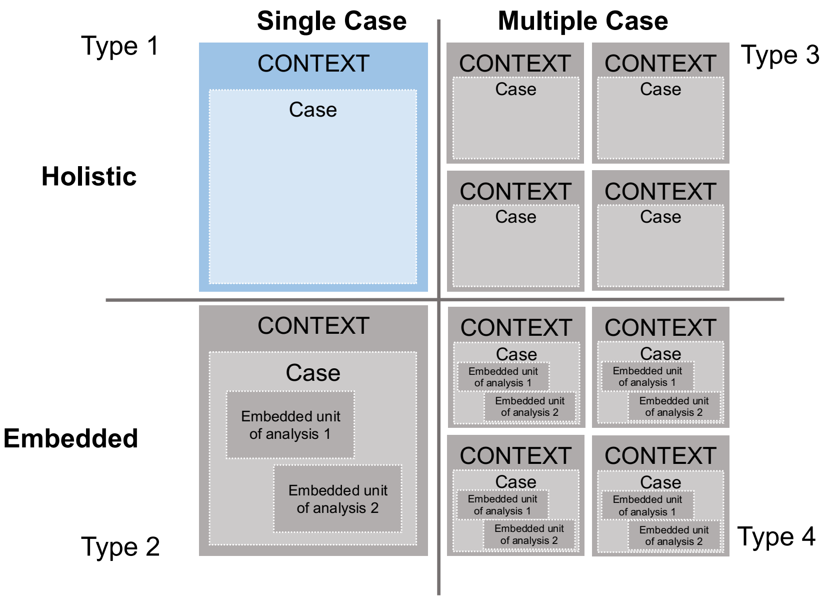

Figure 2.4. The different designs of case studies (Yin, 2018). The chosen design highlighted in blue.

2.2.3 Selection of case

There are countless of possibilities for the selection of case for this thesis, as there are a wide range of combinatorial options. Therefore, the selection of the case study was done in two steps which will be described below. The selection was a collaborative effort involving the authors of this thesis, company representatives, and the supervisor from Lund University.

Initially, three different case configurations were formed to distinguish between the various available combinations, see Figure 2.5. One possibility involved selecting a case according to an assembly group: small, medium, large, refrigeration, or sanitary. Another option was to choose between CTO or ETO categories. The third option was to combine these factors, such as selecting small CTO, medium ETO, or refrigeration CTO case. However, after consulting with the company, it became evident that segregating CTO and ETO cases would not be practical since they are produced in the same assembly groups and utilizes the same resources, thus being planned simultaneously and within the same processes. Therefore, it was not suitable to choose between CTO or ETO cases and revealed the limitations of selecting a combined option. When comparing the selection of case based on assembly groups or a combination of both assembly group and CTO or ETO, it was concluded that assembly groups had the most significant impact of generalizing findings. As a result, assembly groups were chosen as the preferred option.

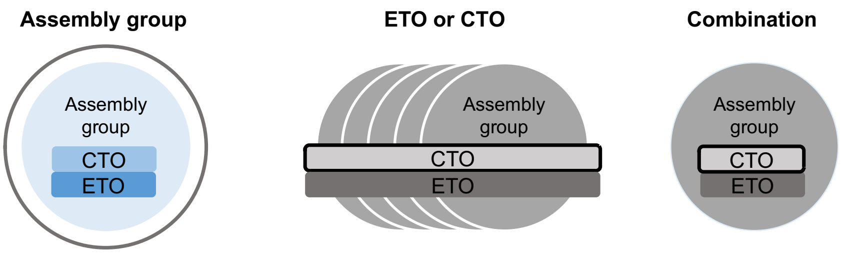

Figure 2.5. Alternatives to selection of case. The chosen alternative marked in blue.

Further, there were several alternatives available to determine which assembly group would be selected as case. Several aspects and selection criteria were taken into consideration to find the best alternative for a case. One selection criterion was that the case should represent a large part of the planning processes. Furthermore, it was deemed important to cover essential contextual factors. An additional consideration was whether the component manufacturing, painting, and tightening bolt, could be selected or not.

The component manufacturing has different value-adding activities and could be planned differently from assemblies. Given that the assembly processes were identified as the core activity of the factory, the component groups were not selected as case. The assembly groups refrigeration and sanitary were described to have more complex production processes which differs from small, medium, and large, as well as other requirements. Further, company representatives described these product groups as having lower production volume than the other assembly groups. The characteristics and restrictions, together with the lower volume, signify that conclusions drawn from this segment might not have transferability to other assembly groups. Therefore, it was decided that they were not chosen as cases in this thesis.

The choice was thereafter between the assembly groups small, medium, and large. The difference between small and large products was described as significant by company representatives. From this aspect, products in the medium assembly group were perceived as a compromise between the two extremes. A similar rationale was applied to the manufacturing processes required for production assembly. These processes vary among the assembly groups, with small and large having little in common, while medium embodies aspects of both. To cover as much of the production planning process as possible, the medium assembly group was chosen, as it encompasses more complexities. The aim was to later enable leverage conclusions from medium to both large and small assembly groups. In summary, the medium assembly group was chosen as the case for this thesis, as highlighted in Figure 2.6.

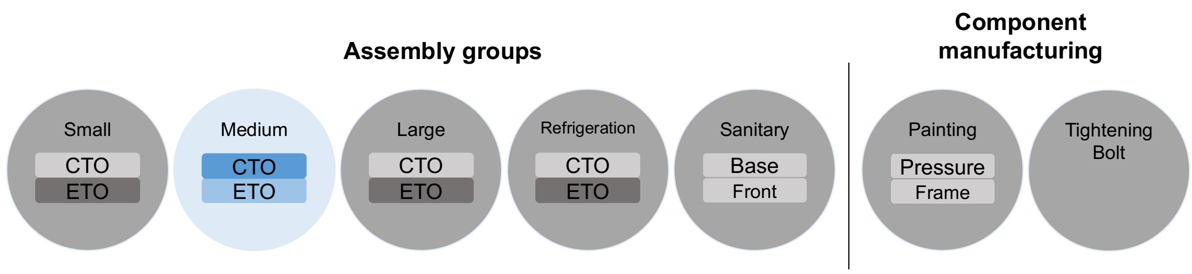

Figure 2.6. Alternatives of case based on assembly groups. The chosen case marked in blue.

2.3 Data collection

The sampling of data within the case was done repeatedly to observe and analyze local configurations in a more detailed manner. Initially, unstructured interviews were conducted to get an understanding of how the factory and different processes work and relate to each other. To gain knowledge of a specific problem, occurrence or situation, qualitative data can be used (Björklund and Paulsson, 2012). The qualitative data in this study was based on interviews and observations. The interviewees were chosen to shed light on the planning process at different levels, enabling the identification and understanding of challenges within the chain more effectively. Kallio et al. (2016) claims a well-designed semi-instructed interview guide enhances the objectivity and trustworthiness of research studies and makes the result more credible. Therefore, the interviews conducted was semi-structured. In Table 2.2, information of what interviews were conducted can be found. The interviews were chosen to cover all interactions with planning in the factory. All data collection was done jointly by the authors of this thesis. In addition to interviews, weekly meeting with the supervisor at the company was conducted. In Appendix A, the semi-structure interview guides used can be seen.

Table 2.2. Qualitative data obtained from semi-structured interviews.

Title of interviewee	Purpose	Number of interviews	Date	Total duration
Unit manager of production Unit manager of logistics	What role the production planning has on a management level and how it affects daily operations.	2	1/3-2024, 6/2-2024	1h 45 min
Master scheduler	Overview of the Master Schedule processes and how it interacts with other production planning processes.	3	26/2-2024, 21/3-2024, 8/4-2024	2h
Team managers of logistics - order handler Team Managers of logistics – planning	Understanding the different part of the production planning processes.	2	19/3-2024, 8/3-2024	2h
Scheduler - medium	How the production planning is conducted for the case.	1	8/3-2024	1h
Team manager of production - medium	How the production planning affects the operations for the case.	1	7/3-2024	1h
Team leader of production - medium ETO Team leader of production - medium CTO	How the execution of the planning is done.	2	21/3-2024, 11/4-2024	1h

Observations were made to increase understanding of processes and production. In Table 2.3, the purpose of the observations, as well as other information, can be found.

Table 2.3. Qualitative data obtained from observations.

Observation	Date	Purpose	Source
Tour of production	17/1-2024	Current state of production and initial understanding of it as well as problem identification.	Unit manager of production
Capacity meeting	Weekly 17/1-2024 – 15/5-2024	Observing the weekly issues related to the planning process.	Join meeting of logistics team and operations teams
Status board meeting	12/3-2023	Understanding what problems in the workshop are caused by production planning.	Joint meeting for the medium assembly group

Quantitative data can be used to complement the qualitative information (Yin, 2018). The data used in this study can be found in Table 2.4.

Table 2.4. Quantitative data obtained.

Document	Description	Information obtained	Source
Forecast of expected sales	Excel	Share of volumes produced.	Master scheduler
Assembly groups	Excel	Devotion of what product types goes through what flow in production.	Master scheduler and Unit manager of production
Split_CU24	Excel	Historical data of number of units produced in ETO and CTO assembly flows over the last 12 months.	System support, Finance
March Monthly Supply Plan	Excel	Forecasts for March 2024.	Master scheduler
March 2024- Local Assembly Lund	Power Point	Summery from the Local supply review meeting of Manch 2024	Master scheduler
Qlik view extract	Excel	Overview of product produced, containing modules and articled and in which assembly flow	Company supervisor

The literature review was conducted with the use of online databases, including *Web of Science* and *LubSearch*. Furthermore, physical books were searched and gathered from various libraries to supplement the online search and gather relevant information.

2.4 Data analysis

The objective was to conduct a comprehensive analysis of the chosen case by integrating both qualitative and quantitative methods to achieve a thorough understanding. Initially, the focus was on examining the specific assembly group, followed by deriving findings that could be relevant and beneficial for broader assembly contexts.

The data analysis process involved a series of iterative reviews between the literature and the collected data, ultimately enhancing the overall understanding. During the analysis, the goal was to identify similarities and differences between the realities observed at Alfa Laval and relevant theories to identify root causes and propose improvement areas. To facilitate this process, a case-oriented strategy was adopted. At a later stage, the findings were analyzed to develop more generalized explanations, in accordance with (Miles et al., 2020). However, it is important to acknowledge that findings derived from a case-oriented approach may present challenges in terms of generalize findings.

The analysis of interviews used a combination of coding systems. The first cycle of coding primarily consisted of initial in vivo coding, supplemented with elements of other coding types, all aimed at summarizing segments of the data (Miles et al., 2020). The second cycle of coding involved pattern coding, which summarized the first cycle of coding to identify a broader theme of the information gathered, as suggested by Miles et al. (2020).

To analyze recommendations, a matrix was utilized to grade the benefit and effort associated with each recommendation. The matrix was inspired by a risk matrix constructed by Norrman and Jansson (2004). The authors explains that it assesses the risk of an event to occur by estimating the probability and consequence of the event. In this thesis, the factors analyzed were instead benefit and effort, see Figure 2.7.

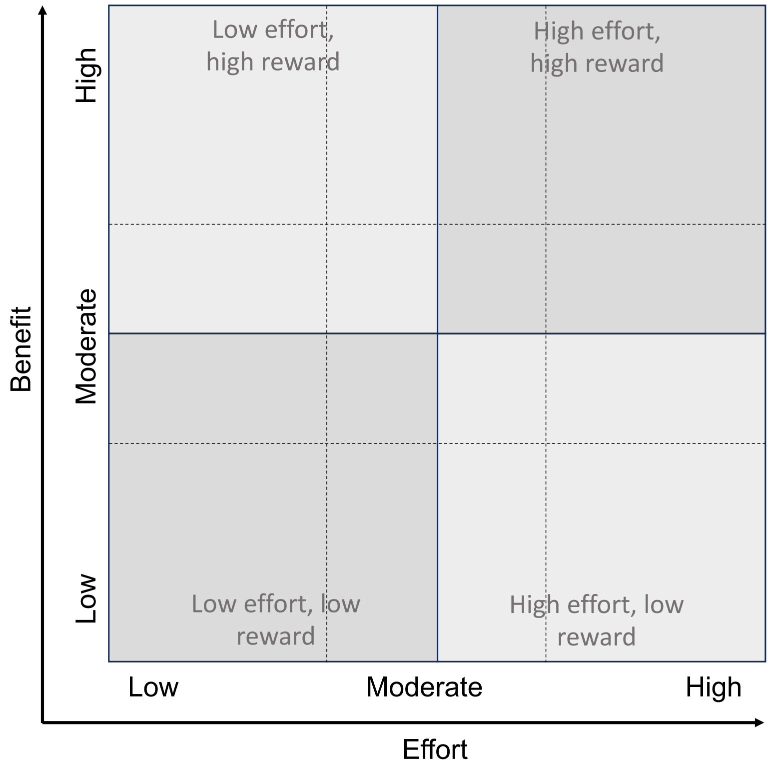

Figure 2.7. A benefit-effort matrix used for evaluating recommendations. Inspired by Norrman and Jansson (2004).

2.5 Research Quality

The concepts of validity, reliability, and objectivity are essential for assessing the trustworthiness of a study, explained by Björklund and Paulsson (2012). Validity, as defined by the authors, refers to the extent to which a study accurately measures what it is intended to measure. Reliability, on the other hand, is described as the consistency of measurement equipment. Objectivity is defined as the degree to which personal values or biases may influence the study (Björklund and Paulsson, 2012). According to Björklund and Paulsson (2012), high reliability indicates that the results are consistently gathered, while high validity suggests that the results closely align with the study's objectives,

To increase the validity of a study, questions during interviews should be clear and direct formulated, as well as considering different perspectives by using triangulations, according to Björklund and Paulsson (2012). The authors explain that triangulation can be either different data source, using different theories or different examiners of the material used. By using triangulation, the reliability also increases. Additionally, control questions can be used during interview to increase reliability (Björklund and Paulsson, 2012). Björklund and Paulsson (2012) describe that by motivating and clarifying the choices done in the study, the objectivity of the study increases since the reader can make their own decision based on the result of the study. Therefore, this thesis aims to explain the findings thus making is possible for the reader to draw their own conclusions.

The quality of a case study can be measured using the criteria of transferability, traceability, and truth-value (Da Mota Pedrosa et al., 2012). These criteria consist of various indicators that must be met to ensure the overall quality of the study. According to Da Mota Pedrosa et al.

(2012), the four indicators of transferability include the theoretical aim, unit of analysis, justification of cases, and number of cases. Compliance with these indicators signifies that transferability has been achieved. Furthermore, Da Mota Pedrosa et al. (2012) motivates that for a case study to be considered traceable, it should include a case study protocol or database, guidelines for data collection, informant selection criteria, and the number of informants. In terms of truth-value, Da Mota Pedrosa et al. (2012) argues that an article must address aspects such as coding, comparison, iteration, and refutation to ensure truth-value is upheld. These three criteria are addressed in previous sections, as well throughout the report.

3. FRAME OF REFERENCE

This chapter will disclose relevant theories related to the planning horizon as well as relevant concepts. The structure of the coming chapter is illustrated in Figure 3.2 and follows the different planning stages.

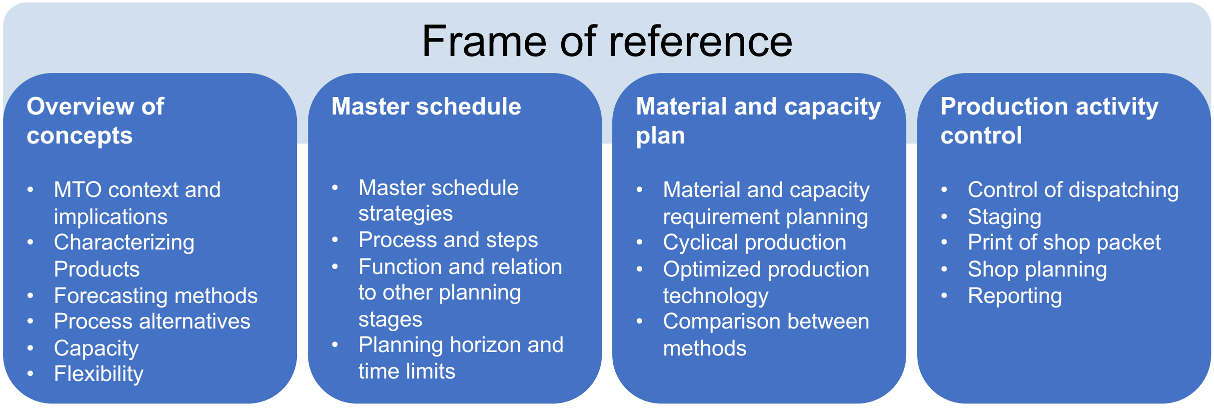

Figure 3.1. The structure of the following chapter 3. Frame of reference.

The selection of governing principles and methods for a comprehensive control system is a strategic decision including S&OP, master scheduling, material and capacity planning, and PAC (Olhager, 2022). The production planning process advances through various stages, beginning with S&OP, which then breakdowns into the Master Schedule. Bozarth and Handfield (2019) define S&OP as resource level planning, and master scheduling as end-item production planning. A material plan further refines the Master Schedule into specific item production requirements (Olhager, 2022). It is followed by PAC, which determines the production order timing and thus is the transition from planning to execution (Bozarth and Handfield, 2019; Olhager, 2022). A framework was used to illustrate the relationships between the different planning processes, see Figure 3.2. The framework is used as a reference in this chapter to explain the planning stages.

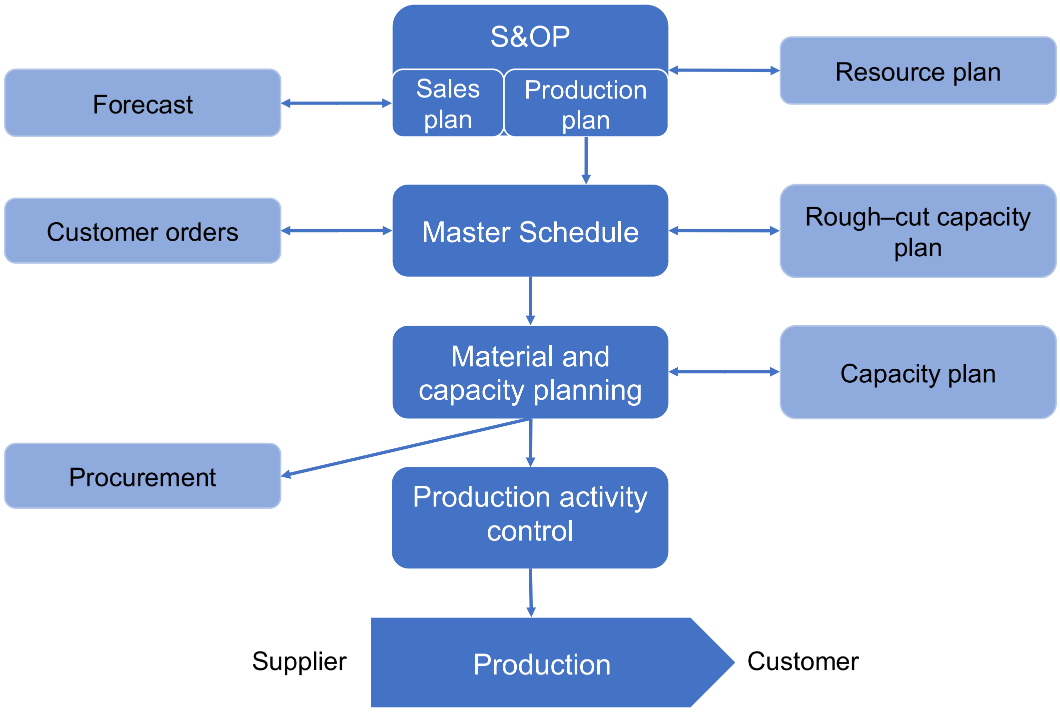

Figure 3.2. The relationship between different planning processes. Inspired by Mattsson and Jonsson (2008) and Olhager (2022).

3.1 Overview of concepts

To effectively plan operations for each assembly process, it is necessary to provide an overview of various concepts, variables, and primary data in order to characterize and comprehend the assembly flows and overall operations. In this sub-chapter, the implications of a MTO strategy will first be discussed, followed by an evaluation of alternatives for characterizing products. Thereafter, forecasting methods are presented as well as process alternatives. Lastly, the concepts of capacity and flexibility will be described.

3.1.1 MTO context and implications

The strategy a company uses lays the foundation for what issues and complexities requires to be addressed. In MTO, raw materials and components are kept in stock, and production first begins when a customer places an order (Engwall, 2020). This type of production usually occurs on a one-piece or small-batch basis and depends on varying demand as well as the supplier's production planning Engwall (2020) explains. In an MTO context, it is harder to apply a one size fits all when managing and making universal planning and control tools, compared to in a make-to-stock (MTS) context (Simchi-Levi et al., 2013; Stevenson et al., 2005). An MTO company is at a higher risk of making a costly error when selecting an unsuitable system, Stevenson et al. (2005) claims. Additionally, Simchi-Levi et al. (2013) describe that many global companies underperform due to differences in business needs and supply chain configurations, such as planning. One example of this is when companies aim to achieve operational efficiency and reduce costs, yet also strive to enhance speed, order fulfillment, and service levels for greater responsiveness. MTO companies face challenges in accurately predicting customer demand, organizing material acquisitions, and planning production in advance (Stevenson et al., 2005). Additionally, unique material and production requirements of each job within the factory, together with a lack of standardized articles and varying job routes, makes it difficult to efficiently plan and manage production processes, as described by Stevenson et al. (2005).

The primary operational challenges for MTO companies include capacity planning, order acceptance or rejection, and achieving high on-time delivery rates. Capacity planning should be managed at various stages, with a particular emphasis on the initial customer inquiry stage, as this is crucial for the MTO industry (Soman et al., 2004). The challenges to plan and schedule tasks at an operational level is described by Hadas and Cyplik (2007) and Kiran (2019) to be one of the basic features of MTO manufacturing.

3.1.2 Characterizing products

Today the dynamic reality puts increasing demands on an effective link between product and process design Olhager (2022) states. The author explains that to align market demands with production capabilities, it is essential to have a thorough understanding of the variety of product options available and the volume of demand. Therefore, these concepts will be addressed in this sub-chapter. Additionally, to get an overview of the products produced, the product structure and material profile characterization is first explained.

Product structure and material profile

The product structure shows the components of the product in the form of constituent materials (Olhager, 2022). These materials are divided into various levels corresponding to the successive completion of a product, see Figure 3.3 for an illustration. All physical products can be described in this manner Olhager (2022) claims. The width and depth of the structure tree vary among products and indicate the product's complexity. Olhager (2022) continues to explain that the product structure is always viewed from the end product perspective. Further the author argue that finished products and spare parts are needed regardless of market demand, while other items' requirements are based on the requirements of higher-level product structures.

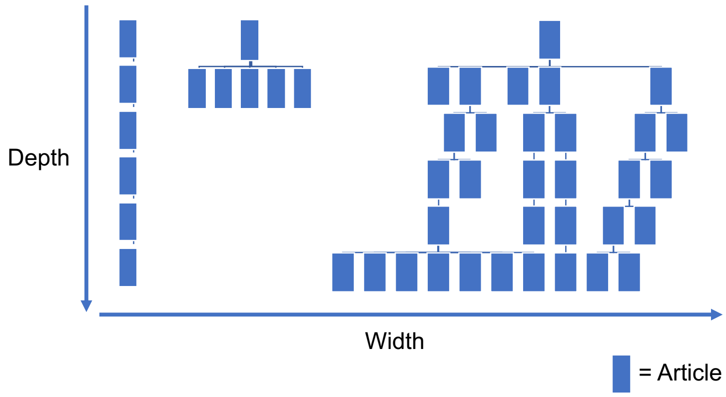

Figure 3.3. Product structures (Olhager, 2022).

To better understand how the total number of articles within a company interact, a material profile can be created (Olhager, 2022). A typical material profiles consists of three levels: end product, semi-finished goods and raw material and components. Engwall (2020) and Bellgran (2005) supports the theory and argues, in line with Olhager (2022), that there are four characteristic shapes of a material profile: A, V, T and X profile, see Figure 3.4. A-profile is common in production to forecast or to stock (Olhager, 2022). The production process of this converging material profile is complex and several activities need to be coordinated Engwall (2020) explains. The V-profile is common in MTO productions, Olhager (2022) states, and entails a diverging production flow (Engwall, 2020). The T-profile is common in companies with a late customer order point, such as in MTO and assembly to order productions. It illustrates a production in which the products are given their specific design just before delivery to the customer (Bellgran, 2005). The X-profile is common in assembly to order productions.

The main purpose of a material profile is to determine where the profile waist is, which is the point where the number of items is the smallest. Olhager (2022) continues to state that this point is often critical for planning and forecasting and should be the object for planning.

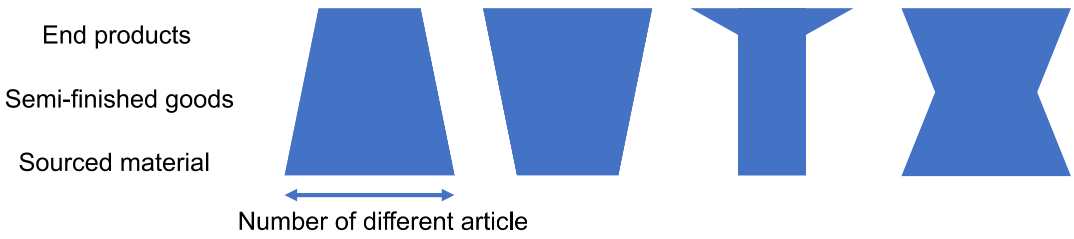

Figure 3.4. Different material profiles, based on Olhager (2022).

Variety of product options

There are several methods possible for the configuration of the product variety, according to Olhager (2022). The author mentions standardization and modularizations, among other, as possible ways to describe and organize the products produced. Hence, these types will be explained.

Standardization refers to creating uniformity regarding various characteristics (Olhager, 2022). Reducing variation and implement standardization are often considered positive from a manufacturing perspective, Baldwin and Clark (1997) explains. Standardization on finished product level limits the customer wishes and therefore created a limited mix of product produced by the company, Olhager (2022) describes. Segerstedt (2018) explains that on the level of article, standardization refers to reduce unnecessary and expensive variations of components. The aim is to create as many finished products as possible using a limited number of raw materials or sourced components (Olhager, 2022). Olhager (2022) states that standardization of a product in some form also enables flexibility since in the short run, certain components can be better used where they are needed.

Modularization, as a structural design principle, simplifies complexity by breaking down the product structure into modules (Baldwin and Clark, 1997; Barbosa et al., 2017). The idea behind modularization is to create a final product that consists of a combination of predefined sub-systems or building blocks, called modules, Olhager (2022) describe. Baldwin and Clark (1997) explain that modularization creates economy of scale, inventory savings, and decreased complexity of material flow and planning.

3.1.3 Process alternatives

The layout of the shop floor is a key factor that influences the suitability of PAC methods (Stevenson et al., 2005). Generally, it is important that the choice of production process and the arrangement of its equipment to be as optimal as possible, considering the products that will be manufactured (Kiran, 2019; Olhager, 2022). There are five types of production processes according to Olhager (2022), and these are fixed position, job shop, flow shop, assembly line, and continuous production. In addition, Olhager (2022) describes mass customization as an alternative production strategy. In the so-called product-process matrix, introduced by Hayes and Wheelwright (1984), different types of product volume and standardization are matched with production processes. The choice of production system based of the product's degree of standardization and the demand volume are illustrated in Figure 3.5.

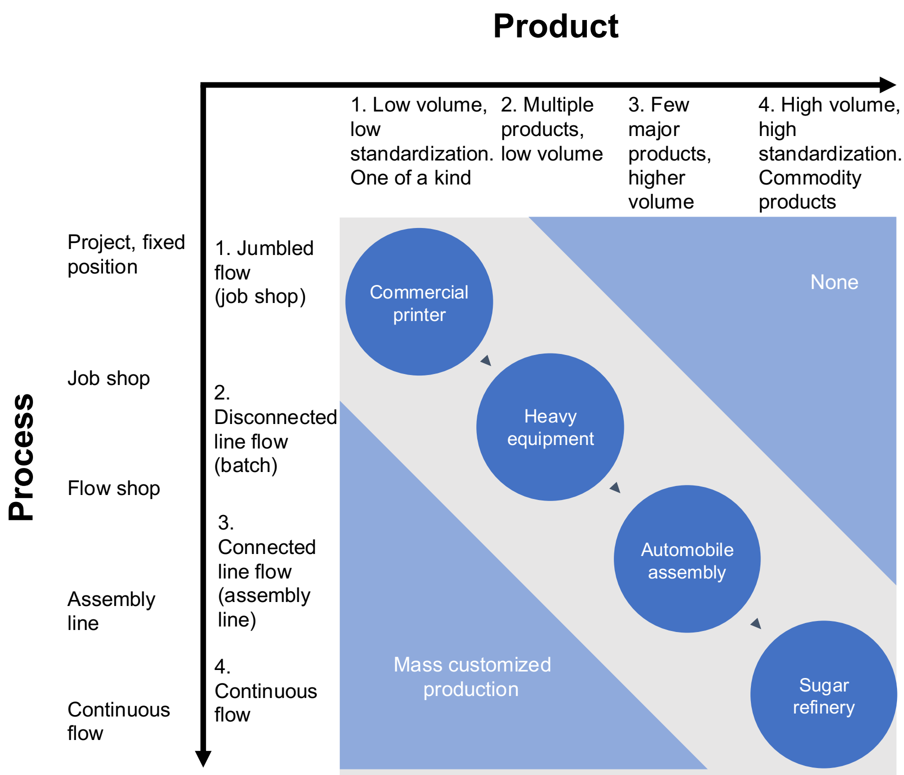

Figure 3.5. Process choices based on product characteristics by Hayes and Wheelwright (1984) and further inspired by Olhager (2022).

Due to the manufacturing context and the company in question, job shop, flow shop, and assembly line will hence be described as well as mass customization. In a job shop, the operations are performed in a restricted area and the materials are transported between stations (Lumsden, 2012; Olhager, 2022). It is characterized by its aim for high machine utilization, Lumsden (2012) explains. The products produced are discrete items, meaning that products are specified in units, unlike in continuous process manufacturing (Olhager, 2022). Stevenson et al. (2005) describe a general job shop to typically allow for routing in multiple directions, although there is usually one main flow direction. Yeh (2000) continues by stating that the importance of having detailed, realistic, and flexible production plans in MTO manufacturing when having a job shop configuration. A job shop is ideal for companies that supply components to larger companies, where demand fluctuates in terms of both content and size (Olhager, 2022; Zijm, 2000). Olhager (2022) describes the companies' products being produced in different versions, limited only by the capabilities of the machinery. The author explains that both machinery and personnel can be constraints of resources, leading to a focus on maximizing utilization in the workshop by ensuring that all resources are constantly engaged in processing materials. However, there is an uncertainty about the existence of a pure job shop, as real-world scenarios typically exhibit a dominant flow direction (Stevenson et al., 2005).

Meanwhile, flow shops have been developed from job shops to shorten throughput time, and simplify planning, are considered as one planning point, Olhager (2022) describe. Further, the author elaborate that the products produced are discrete items, meaning products are specified in units. The primary distinction between the job shop and the flow shop lies in the direction of material movement (Lumsden, 2012; Stevenson et al., 2005). Flow shop entails grouping machinery necessary for production of a certain product group in flows, according to Lumsden (2012). Detailed planning and ongoing work allocation take place within the group, which means expanded tasks and greater independence for group members, Olhager (2022) states. The author adds that in many cases, the operator can move between different processing steps, reducing the dependency between the individual and the machine. A manufacturing order per batch is used for the entire flow shop, and Olhager (2022) describe that this should be compared to one order per operation in a functional workshop.

Assembly lines are common when mass producing standardized products and it was made famous by Henry Ford (Bellgran, 2005; Hopp and Spearman, 2011). With a high and constant demand for a product or product group with a limited product range, there is a logic to design the production equipment to fit the certain production range, Olhager (2022) explains. In an assembly line, the main characteristics are that the manufacturing is mainly parallel in all manufacturing steps and is common in the process industry (Mattsson and Jonsson, 2008). Products are manufactured and assembled according to a fixed routing, facilitated by paced material handling systems, Hopp and Spearman (2011) states. Olhager (2022) argues that the problem of designing a production line is called line balancing where two reoccurring methods are normally present: shortest operations time first and position weight method.

There is a strive to increase flexibility in production systems, Olhager (2022) explains. This strive is symbolized in the Hayes Wheelwright bottom-left corner and is called mass customization. The goals of the production process to enable production of different products in small volumes effectively in a flow-oriented production process, Olhager (2022) describe. The author further elaborates that in essence, one seeks a combination between flexibility and productivity so that the company can offer customers a large variety at the price of a standardized product. Through product development techniques like modularization, different product configurations may exhibit similar product characteristics, facilitating their smooth integration within a unified, flow-oriented production system (Olhager, 2022). To achieve optimal customer alignment, short setup times and flexible personnel are essential for managing a diverse array of products and product configurations. In contrast, (Bozarth and Handfield, 2019) state that this position in the product process matric is a mismatch of production system and product and creates an inflexible process.

3.1.4 Forecasting methods

The demand is often forecasted since it lays the foundation for dimension of production system and facilitates a foundation for decisions (Kiran, 2019). Demand and its forecasts serve as the foundation for resource allocation decisions (Johnson et al., 2018; Kiran, 2019). Additionally, Kiran (2019) states that forecast are also utilized for material planning as well as description of the correlation between customer demand and various products. As described by Simchi-Levi et al. (2013), when a company offers endless of configuration possibilities it results in poor forecasting of configurations. They argue fewer configuration possibilities to result in drastically improved forecast accuracy.

Demand models and forecasting models

There is a difference between demand model and forecasting method, Olhager (2022) explains. The author further elaborates that demand models describe the underlying process that generates demand, based on historical data. In contrast, forecasting methods aim to predict the upcoming demand. Olhager (2022) further states that the choice of forecasting method is based on what type of demand is present. Mattsson and Jonsson (2008) adds that there are other factors that affect how well a forecasting system performs. The authors describe these to be the length of the forecast period, the foundation of forecasting, horizon, frequency, aggregation, and forecasting unit.

There are different types of demand models according to Olhager (2022). The author explains that a time series of demand data can be divided into five fundamental components, called time series components, which are referred to as decomposition. The five parts are: trend (T), seasonality (S), cycle (C), level (N), and coincidence (E). Olhager (2022) stated that there are two general calculations of how the time series components are combined. A multiplicative model views demand as a product of the components, while an additive model sees the components as a sum, as the following calculations show.

Multiplicative model: $Demand = T \cdot S \cdot C \cdot N \cdot E$
Additive model: $Demand = T + S + C + N + E$

Similar to demand models, there are several methods for forecasting (Chambers et al., 1971; Mattsson and Jonsson, 2008; Olhager, 2022). According to Olhager (2022), time series methods are founded on the assumption that the underlying demand structure in the future is already present in the data. The methods the author describes are moving average, exponential smoothing, exponential smoothing with trend, trend projection, seasonal index, and exponential smoothing with trend and season. Chambers et al. (1971) on the other hand describes five basic techniques for time series analysis and projection. The authors describe and compare moving average, exponential smoothing, Box Jenkins, X-11, and trend projection. Moreover, Mattsson and Jonsson (2008) describes the moving average and exponential smoothing as forecasting methods. All authors mention moving average, exponential smoothing, and two the articles mention trend projection. Therefore, these three will hence be explained.

Moving average is described as the simplest form of non-conditional calculation methods is to simply assume that the next period's demand will be the same as the last period's, (Mattsson and Jonsson, 2008). When using a moving average, each data point in a time series represents the arithmetic or weighted average of a specified number of consecutive data points within the series, Chambers et al. (1971) explains. They elaborate that the number of data points selected is adjusted to mitigate the impact of seasonal variations, irregularities, or both. The method is described as relatively poor in the short term of zero to three months and poor in the medium term of three months to two years (Chambers et al., 1971).

Moreover, exponential smoothing is a widely used forecasting technique that involves the calculation of weighted averages of past observations (Kiran, 2019; Mattsson and Jonsson, 2008). Unlike moving averages, where each observation is given equal weight, exponential smoothing assigns exponentially decreasing weights to past observations. Exponential smoothing is described as good for capturing short term horizon, zero to three months, relatively poor in the medium horizon of three months to two years (Chambers et al., 1971) .

Trend projection on the other hand involves fitting a mathematical equation to a trend line, which is then used to forecast future values (Chambers et al., 1971). There are several variations of this approach, including the slope characteristic method, polynomial regression, logarithmic regression, and others (Chambers et al., 1971). According to Chambers et al. (1971), the method is very good in the short term of zero to three months and good in the medium term horizon of three months to two years.

Errors and control of forecasts
Forecasts are often imperfect and deviates from the actual outcome (Mattsson and Jonsson, 2008; Olhager, 2022). Therefore, it is crucial to monitor and evaluate errors of the forecasts to ensure the errors fall within acceptable margins, as Axsäter (2006) describe. This is especially

important when using automated forecasting techniques like moving average and exponential smoothing, where the potential loss of control of the forecast can lead to negative consequences, Mattsson and Jonsson (2008) explains. Measuring forecast errors is essential for error analysis and the primary objective is to distinguish between random and systematic errors (Mattsson and Jonsson, 2008; Olhager, 2022). Forecast errors are calculated on a period basis and is defined as the difference between the forecasted and actual demand. Mattsson and Jonsson (2008) explains two common methods for reporting forecast errors: mean absolute deviation and mean error. The authors states that the mean absolute deviation calculates the error using absolute values, disregarding whether errors are positive or negative relative to actual demand, and it serves as a measure of the scatter of the forecast. On the other hand, mean error determines whether the forecast is consistently biased, Mattsson and Jonsson (2008) clarifies. They continue to explain that a low mean absolute deviation and mean error indicate high forecast quality, requiring both metrics to be low for an accurate evaluation. Another common method for evaluate errors of forecasts is mean squared error as described by Lantz (2015). The author explains that mean squared error consider absolute values, similar to mean absolute deviation, and the method signifies large errors rather than small ones.

There are two types of tests to analyze errors, demand and forecast tests (Mattsson and Jonsson, 2008). Demand tests are essential to identify and prevent errors in demand values that significantly deviate from expected values, as explained by Mattsson and Jonsson (2008). These tests automatically inspect all recently actual demand values to ensure data accuracy and reliability (Mattsson and Jonsson, 2008; Olhager, 2022). Conducting these tests is crucial to address anomalies like unexpected large orders impacting short term demand or production issues causing sudden spikes in delivery volumes, which can lead to inaccurate forecasted results, as Mattsson and Jonsson (2008) and Axsäter (2006) states. These events should not affect the forecasts, which mean the values should be adjusted or eliminated. Moreover, one approach to conducting demand tests involves comparing the actual demand values with the most recent forecast, Mattsson and Jonsson (2008) describes. By using the latest forecast as a reference point, the system can flag any deviations exceeding a specified factor multiplied by the mean absolute deviation, the authors and Olhager (2022) explains. They add that differences that surpass this threshold are flagged for review and potential adjustment, ensuring accuracy of the overall forecast. The selection of an appropriate threshold factor should be based on the desired level of confidence in the forecast process (Mattsson and Jonsson, 2008; Olhager, 2022).

Forecast tests on the other hand are crucial for evaluating the accuracy of forecasts, as emphasized by Mattsson and Jonsson (2008). Periodic controls are conducted to ensure that the average forecast error is within acceptable limits, they explain. The authors argue that these predefined thresholds are represented as a factor multiplied by the mean absolute deviation. Selecting the appropriate factor involves balancing the need for manual intervention to correct errors and the tolerance for systematic errors in forecasts (Mattsson and Jonsson, 2008). Therefore, different factors may be chosen based on the significance of the article being forecasted, with higher factors used for less critical articles and lower factors for more important article to establish effective control boundaries. Axsäter (2006) explains that one reason for forecast errors to be outside the acceptable margins could be the utilization of an inadequate forecasting method. If it would result in it to always be a systematic error (Axsäter, 2006).

3.1.5 Capacity

Capacity plays a pivotal role in manufacturing (Martínez-Costa et al., 2014). In a manufacturing context, capacity is viewed as one of about seven decision categories for which manufacturing companies must establish policies (Olhager et al., 2001). According to (Lantz, 2015), failure to maintain sufficient and efficiently utilized capacity in a system can result in a company losing competitive advantages. Effective capacity management is essential to meet demand and sustain competitiveness in manufacturing companies Olhager et al. (2001) explains.

Capacity dimensioning

Capacity can be dimensioned in various ways depending on the demand, Olhager (2022) explains. Further, the author elaborates that a company can dimension its capacity based on maximum, mean or minimum demand. If the capacity is obtained based on the maximum demand, the company will be able to produce all products at all times (Olhager, 2022). However, during periods of time there will be overcapacity, which result in the possibility to produce products for other companies. Lantz (2015) describes that the disadvantages of this dimensioning method to be the insufficient load and high capital costs. On the other hand, if a company's capacity is determined by the mean demand, in theory, it could produce all products in-house, assuming that products can be stored, Olhager (2022) states. The author explains that products could then be manufactured to stock beforehand, assuming that the products are relatively standardized. If the products are not standardized, the company must rely on sub-contracting part of the production in periods of time. Another alternative to be that the capacity could be obtained from the minimum demand (Olhager, 2022). This means that all demand variations must be cover with the use of sub-contracting. Additionally, if the demand cannot be met due to the dimensioning of capacity, there could be long-term consequences (Lantz, 2015). Olhager (2022) concludes that if the aim is to achieve high resource utilization, the company tends to dimension its capacity from minimum or mean demand. If there is a high need on delivery precision and short delivery cycles in a customer order-driven production, the total capacity tends to exceed the average capacity need and lean toward the maximum demand. With this method to decide the capacity, there is a trade-off between overcapacity and additional revenue, which can be obtained by having good flexibility for short and secure deliveries, towards the cost for storing that occurs with early production (Olhager, 2022). Martínez-Costa et al. (2014) mean that there is a constant development of mathematical models to optimize capacity dimensioning.

Capacity planning methods

There exist multiple methods for planning capacity. Mattsson and Jonsson (2008) mentions five methods which are summarized in Table 3.1. They differ on several aspects such as scope, which parameters are being addressed, planning level, as well as what type of capacity is being planned.

Table 3.1. Comparison between methods for capacity planning (Mattsson and Jonsson, 2008).

Independent variable \ Methods	Production units	Capacity planning factors	Load profile	Capacity requirement profiles	Capacity requirements planning
Primary planning objects	Production plan	Production plan	Production plan Customer order	Production plan Customer order	Manufacturing order
Object scope	Individual article Article group Article structure	Individual article Article group Article structure	Individual article Article group Article structure	Individual article Article structure	Individual article
Regards inventory	No	No	No	No	Yes
Regards lead time	No	No	No	Both lead time offset and distribution	Both lead time offset and distribution
Primary planning level	S&OP Master Schedule	S&OP Master Schedule	S&OP Master Schedule	S&OP Master Schedule	Material planning Production activity control
Capacity grouping	Entire company	Department Foreman	Department Foreman	Entire company Individual production group/machine	Individual production group/machine

Capacity at different horizons

Capacity management in manufacturing firms is frequently segmented into three or four stages, spanning from long term capacity planning to short term capacity control and execution, Olhager et al., 2001) describe. The authors adds that intermediate capacity management is linked to rough-cut capacity planning, which is tied to the Master Schedule. Additionally, intermediate capacity management is connected to capacity requirements planning, which in turn is related to the material requirements plan (Olhager et al., 2001). The demand for a product dictates the need for capacity (Olhager, 2022; Martínez-Costa et al., 2014). The field of operations management literature distinguishes between tactical and strategic capacity planning (Martínez-Costa et al., 2014). Tactical capacity planning, typically covering a one-year timeframe, involves overseeing production and inventory management and potentially adjusting staffing levels and work hours, through overtime, without modifying equipment capacity, Martínez-Costa et al. (2014) describe. They add that in contrast, strategic capacity planning focuses on facility changes over the long and medium term, typically spanning multiple years. Mattsson and Jonsson (2008) explain and summarize the link between options for action and the planning horizon, see Table 3.2. The authors divide the actions into five groups that they refer to as reallocate and adapt capacity, increase or decrease capacity and its requirements, as well as reallocate capacity requirements. The actions are then divided between the horizons of medium and short term, which Mattsson and Jonsson (2008) clarifies as belonging to the planning levels of master scheduling or lower.

Table 3.2. Different actions to alter capacity and capacity requirements with regard to planning horizon (Mattsson and Jonsson, 2008)

Horizon

Type of alternative

	Medium term	Short term
Increase/decrease capacity	New employment/Temporary layoff New machines Number of shift/short-term week Sub-contracting	Sub-contracting Extra shift
Increase/decrease capacity requirements	Change production plans Increase/decrease inventory	
Reallocate capacity	Transfer between departments	Transfer between departments
Adapt capacity		Overtime Put off maintenance
Reallocate capacity requirements	Seasonal storage Change delivery cycle	Advance/postpone order Change order quantity Alternative production groups Lap phasing/order splitting

The type of alternatives has different action linked to them according to Mattsson and Jonsson (2008). Theses action will hence be explained based on Mattsson and Jonsson (2008) definition.

There are several actions linked to the increase and decrees of capacity in both medium term and short term. In the medium-term horizon, to increase capacity, one can hire new personnel and utilize temporary employment if the capacity shortage is not expected to persist. Therefore, this action should be considered a medium-term action. Oppose action would be to temporary layoff personnel. Additionally, there may be opportunities to invest in new machinery or other production equipment to some extent. Changing the number of shifts is another option to increase capacity. This alternative involves increasing machine utilization while keeping labor utilization constant. Extended shift operations can, for example, be achieved by transferring personnel from less busy production sections or through new hiring. Additionally, capacity can be increased by outsourcing. This involves allowing external suppliers to take over a certain part of production for shorter or longer periods. An oppose action to decrease capacity is to bring back previous outsourced work. In the short-term horizon, the action of sub-contracting is still considered to alter the capacity. However, in terms of shift, the action is referred to as extra shifts. This involves adding an extra shift where the labor utilization constant and capacity utilization of for example machinery is increased.

Further, there two actions described that aims to either increase or decrees the capacity requirements. Both are linked to the medium-term horizon. The actions change production plans and increase decrease inventory are based on deliberately letting production plans target lower or higher volumes than demanded in the market.

Another type of alternative is to adapt capacity which is done by transfer between departments. This action is available in both horizons. It can be achieved by transferring production personnel from underutilized departments to departments with overutilization. However, it is only feasible in the short term either for low-skilled types of work or if it involves a previously multi-skilled and trained workforce.

The final type of alternative is to relocation capacity requirement which involves several different available actions in both horizons. In the short-term horizon, one action is to advance or postpone orders which is seen as a primary alternative for relocate capacity requirements. It is achieved though altering the start and due dated for planed manufacturing orders. However, to enable advancement of orders the material needed has to be available sooner than originally planned. This further leads to extra capital tied up since they are manufactured and ready before the need. Postponement of orders can result in shortages of material during the final manufacturing or assembly process. Postponement in relation to companied with a MTO strategy is described to have the effect of increasing delivery timed to costumers. Another option is to relocate the capacity requirement by using alternative production groups. The action involves temporarily not utilizing the production resources that the manufacturing setup is optimized for, which would typically be the most economically optimal for production. A third option to relocate capacity requirements is to decrease or increase the order quantity. In this case, the overall demand must be managed while changing the order quantities of certain production lines. Lap phasing or order splitting is an additional action available in the short term. Lap phasing refers to a practice where a completed portion of the order quantity is transported to the next operation before the entire order quantity is finished. While order splitting or parallelization of operations involves work with executing *one* processing step to two or more production groups. Order splitting involves a different relocation of capacity by distributing the manufacturing process in between different machines.

3.2 Master Schedule

The Master Schedule is an essential tool that is developed based on a breakdown of the S&OP and actual customer orders (Grimson and Pyke, 2007). Its primary goal is to align market demand with production capabilities and serve as a mutual agreement (Olhager, 2022). Figure 3.6 demonstrates how the Master Schedule interacts with various planning processes. The Master Schedule establishes production plans for product families or individual products to accommodate changing demands, as noted by Bagheri et al (2022) and Zäpfel and Missbauer (1993). One of the key objectives of the Master Schedule is to effectively coordinate and manage the material flows within the company, from input to output (Mattsson and Jonsson, 2008; Segerstedt, 2018).

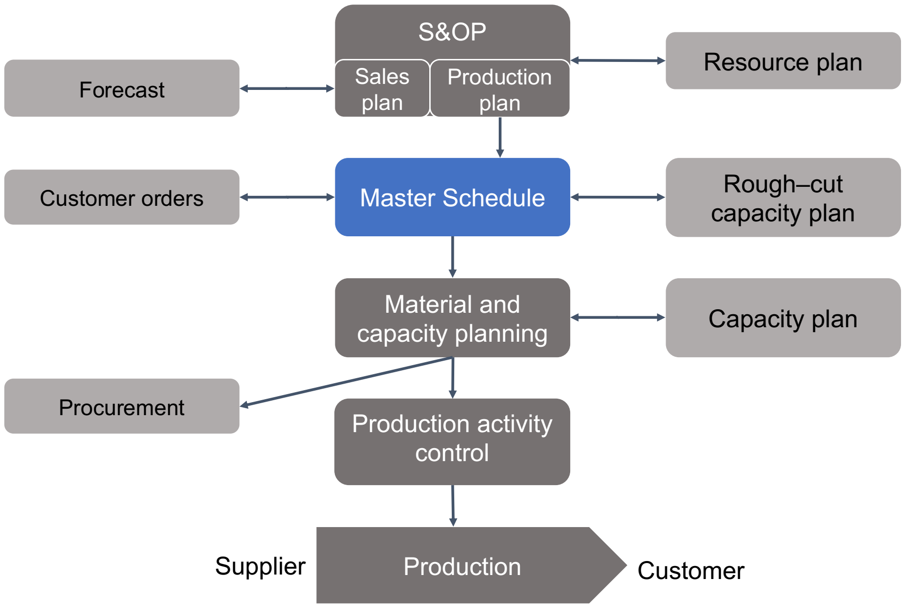

Figure 3.6. The interaction between Master Schedule and other planning processes. Inspired by Mattsson and Jonsson (2008) and Olhager (2022).

Master scheduling practices vary across organizations depending on market competitiveness and firm strategy, such as MTS or MTO, and other mixed strategies for master scheduling (Zäpfel and Missbauer, 1993). The authors mean that organizations may adopt different approaches to master scheduling depending on their competitive position in the market, their overall business strategy, and how they manage inventory and production processes. There are two main strategies for the breakdown from S&OP, according to Olhager (2022). The object level can vary depending on strategy but is generally critical components or raw materials in an MTO context (Olhager and Wikner, 2000). Additionally, Simchi-Levi et al. (2013) states that when there is high demand uncertainty, there is a need to regard confirmed customer orders.

3.2.1 Process and steps

The Master Schedule process is described by Mattsson and Jonsson (2008) to consist of five steps. These are shown in Figure 3.7 below, as well as the interactions between them. The process and steps differ depending on the manufacturing type, MTO or MTS, the authors explain. In this section, the MTO process will be explained. This section is based on Mattsson and Jonsson (2008) if other is not stated.

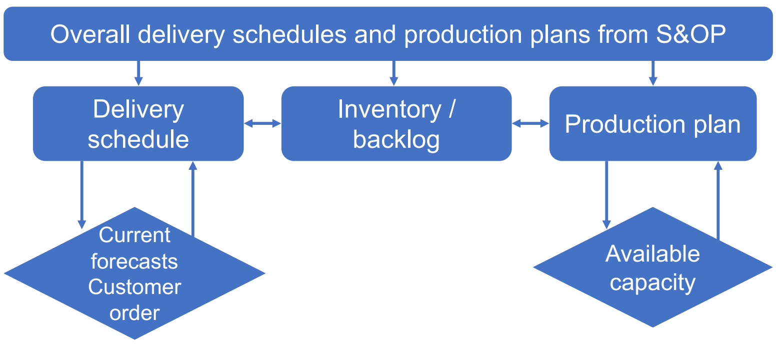

Figure 3.7. The process of master scheduling (Mattsson and Jonsson, 2008).

Step 1: Forecast of future demand based on S&OP
The forecast of future demand is based on product types. Product types refer to the general or basic construction of a product that may undergo modifications later on. Forecasting by product types reduces the number of objects to forecast, enabling manual handling. These forecasts form the basis for creating the delivery schedule, which must cover the entirety of the Master Schedule horizon. Therefore, it is essential to consider trends, seasonality, economic conditions, and other factors when forecasting. Simchi-Levi and Timmermans (2021) explains the importance of all parties coming to a consensus on the dataset used for forecasting to prevent the need for individuals to navigate conflicting forecasts and instead rely on intuition to determine the most accurate course of action.

Step 2: Create a preliminary delivery schedule using the forecast and backlog data
The level of customization in a customer order determines how this step can be done. There are essentially three different approaches to consider.

For orders with limited customization, where product types can be used for planning purposes, the process of establishing a preliminary delivery schedule is similar to that of an assemble-to-order context. In this scenario, forecasts are based on product types, and customer orders are customized using these predetermined types. Both the forecast and customer orders in the delivery schedule are specified in quantities of product types, ensuring all variations of customer orders correspond to an equivalent product type. Since deliveries in such companies occur with lead times, adjustments to forecasts must be made based on orders received, ensuring forecast consumption is considered even in this setting.

In some cases when customizations of customer orders are limited, some companies produce product types to stock them awaiting customization when a customer order is received. When the stocked product type is retrieved, it is customized to the customer specification. Developing the delivery schedule involves reconciling elements against inventory, a practice common in MTS companies.

When the level of customization is high, the process of assembling a delivery schedule is done differently and specific to the business. In such cases, detailed plans similar to those in the S&OP process may be necessary, or relying on existing backlog could be crucial.

Step 3: Develop a preliminary production plan using the preliminary delivery schedule and considering current and desired inventory levels and order sizes
The preliminary delivery schedule serves as the basis for developing the preliminary production plan, with the level of customization determining the approach taken for this step.

When customization is moderate, the process is similar to an assemble-to-order company, as mentioned previously. The preliminary production plan originates from the creation of the delivery schedule, typically carried out within an ERP system. In this scenario, a customer order is equivalent to a manufacturing order for a specific product variant. In the short term, the production plan consists of manufacturing orders, while forecasted quantities feature in the long term, resulting in a complex medium-term mix. Various approaches exist for managing this mix. In cases of high customization, challenges arise as the products are to a large extent unknown, with material and production requirements uncertain. Therefore, capacity planning accuracy at the Master Schedule level must account for the uncertainties inherent in current order backlogs. Capacity requirements must therefore be determined using load profiles or capacity requirement profiles since they calculate quantities, as explained in section 3.1.4

Forecasting methods. Following the calculation of capacity requirements using the production plan, a comparison with available capacity is conducted, leading to necessary adjustments.

Step 4: Reconciliation of the developed plans
A comprehensive reconciliation is performed between the existing delivery schedule and production plan developed compared to the plans generated in the S&OP process. In an MTO context, the alignment between the delivery schedule and production plans is less evident and not as easily quantifiable as in an MTS context. This discrepancy arises due to the more uncertain and less detailed nature of the information underlying these plans.

Step 5: Finalize the developed plans
Lastly, both the production plan and delivery schedule require finalization. This typically involves a meeting attended by several of the company's production managers, supply managers, and market managers. This process aims to validate the practicality of the Master Schedule (Bagheri et al., 2022; Bozarth and Handfield, 2019; Olhager, 2022).

3.2.2 Function and relation to other planning stages

In companies with MTO production, the production plan is primarily focused on ensuring capacity in the medium term, rather than material flows (Mattsson and Jonsson, 2008). It is essential that material supply is partially based on material planning methods that do not require pre-defined connections between products and their constituent parts, according to Mattsson and Jonsson (2008). The authors explain this as becoming crucial when dealing with articles that have supplier lead times exceeding lead times to the customer. Mattsson and Jonsson (2008) further elaborate on differences between production plans in various time horizons. They describe that in companies with MTO production, the differences between the production plan and final manufacturing plan are more prominent compared to an MTS environment. The final manufacturing production plan is always based on released manufacturing orders for specific product variants, which are directly linked to customer orders.

The master scheduling production plan is on the product level and is closely connected to the plans created for final manufacturing processes (Mattsson and Jonsson, 2008). However, these plans are often not identical. According to Mattsson and Jonsson (2008), the main difference is that the production plan in the Master Schedule is derived from both forecasts and customer orders, whereas the plans in the PAC processes are solely based on customer orders. Additionally, the authors suggest that in the latter scenario, the final manufacturing component is integrated into the material plan or inventory management structure.

One output of the Master Schedule is a rough-cut capacity plan. The preliminary capacity plan converts the Master Schedule into resource capacity requirements and assesses them against the existing capacity of each resource (Bozarth and Handfield, 2019; Olhager, 2022). This process is used to validate the practicality of the Master Schedule (Bagheri et al., 2022; Bozarth and Handfield, 2019; Olhager, 2022).

3.2.3 Planning horizon and time limits

The planning horizon of the Master Schedule must be longer than the accumulated lead time for the product with the longest lead time (Mattsson and Jonsson, 2008; Olhager, 2022). Bozarth and Handfield (2019) further explain that the planning horizon should align with the lead time required for sourcing and manufacturing the product. For more complex products, a longer horizon of several months may be necessary, while products with shorter lead times may only require a few weeks. Typically, the planning horizon normally ranges from six months to a year (Bagheri et al., 2022).

When materials are purchased in larger lot sizes, it is essential to consider adjusting the procurement lead time within the planning horizon of Master Schedule, Olhager (2022) explains. The author describes that aside from the accumulated lead time, the Master Schedule's timeframe typically includes a few extra periods to offer some planning visibility. The time perspective in master scheduling is further complemented by specific time limits, namely a demand time limit and a planning time limit. The demand time limit signifies the period during which production is considered fixed, as clarified by Olhager (2022). For final product assemblies featuring significant customizations, it is logical to assemble based on actual customer orders, aligning the fixed planning period with the final assembly timeframe. Moreover, Olhager (2022) defines the planning time limit as the point at which, when combined with the total production lead time, a production order is initiated at the lowest product structure level once the order exceeds this limit, including any procurement lead time for materials ordered. This decision is influenced by the active planning required for orders beyond this threshold. To summarize in an MTO context, the Master Schedule is defined by several key features according to Olhager (2022). These include aligning the planning horizon with the accumulated production lead time, establishing the demand time limit based on the customer order point, and making delivery promises based on the ability to commit to specific timelines.

3.3 Material and capacity plan

In a MTO context, it's crucial to plan materials carefully to meet delivery deadlines and keep production running smoothly, according to Olhager (2022). The Master Schedule is broken down into a material and capacity plan with the use of a product structure (Bagheri et al., 2022). The purpose of material and capacity planning is to balance supply and demand to withhold cost effective material flows, high customer service and streamline costs regarding capacity utilization, Mattsson and Jonsson (2008) describe. There are multiple methods to conduct material and capacity planning. In this section, three methods will be described. First, material requirement planning (MRP) will be described, followed by cyclical production, and lastly optimized production technology (OPT), as Olhager (2022) mentions as three different methods. The outputs of the material and capacity planning are a purchasing order and a manufacturing order (Olhager, 2022). In Figure 3.8, the interactions of the Master Schedule with other planning processes are shown.

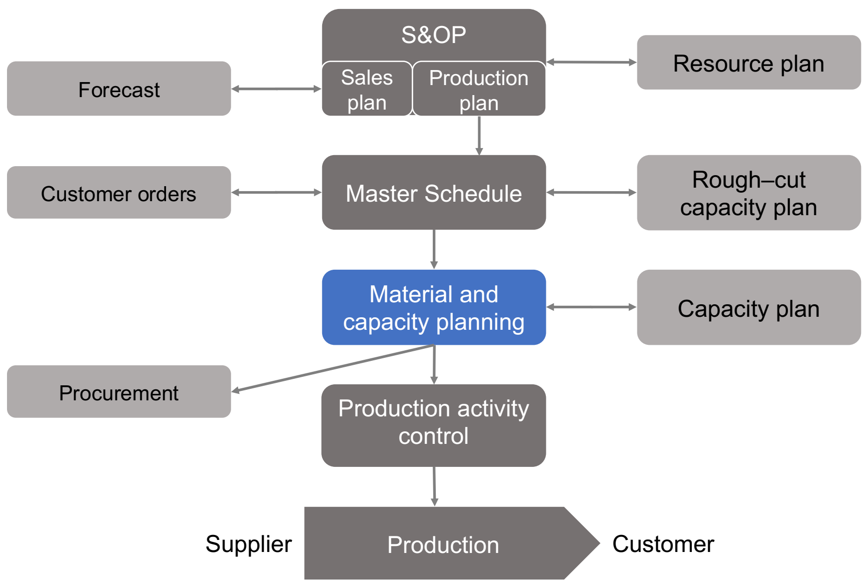

Figure 3.8. The relationship between different planning processes. Inspired by Mattsson and Jonsson (2008) and Olhager (2022).

3.3.1 Material and capacity requirements planning

In the 1970s, the introduction of MRP gained rapid and widespread acceptance (Olhager, 2013). Today, MRP is a widely known method for planning multiple-step production, according to Olhager (2022). Additionally, Benton and Shin (1998) describe MRP as intended to oversee the movement of materials, components, tools, and relevant information, and acts as a central coordinator that translates the overall production plans into specific steps necessary to carry out the planned production process. The information flow of a MRP is illustrated in Figure 3.9. The entire manufacturing system, from procurement to shop floor management, can be regulated using MRP (Benton and Shin, 1998). Stevenson et al. (2005) argue MRP provides numerous benefits, including improved customer service, streamlined production scheduling, and reduced manufacturing costs. MRP is a method that can handle different customer orders with different parts, to produce the right product, in the right quantity, at the right time (Benton and Shin, 1998; Olhager, 2022). However, Hung et al. (2013) claim this method is commonly used in MTS manufacturing and Stevenson et al. (2005) highlights the challenges with MRP, explaining that it is a method that suits large companies with low product variation. Additionally, Mattsson and Jonsson (2008) describe MRP as a complex method that can pose challenges in comprehension.

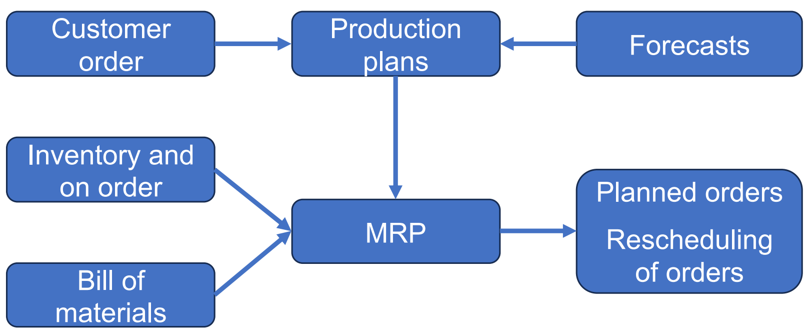

Figure 3.9. The information flow of a MRP (Mattsson and Jonsson, 2008).

MRP operates by taking the Master Schedule output and breaking it down the requirements for finished products and other planned items into detailed needs for all items, regardless of the production structure level they are found on (Greeff and Ghoshal, 2004; Olhager, 2022). During the breakdown, if inventory on hand, open order, lead times and lot sizing roles are taken into consideration, the method is called net requirement planning (Olhager, 2022). If they are not taken into consideration, it is called gross requirement planning. The breakdown of the Master Schedule is done with consideration to bill of material which shows the relation between the parent article and the child article (Olhager, 2022). A key issue with MRP, described by Benton and Shin (1998), is its underlying assumption that the actual production parameters, such as lot size and delivery cycle, can be predetermined. Further the authors explain precise estimation of lead times and optimization of lot sizes as crucial factors for ensuring the effective functioning of the MRP, which Bozarth and Handfield (2019) confirm. In Figure 3.10 below, the process of a MRP is illustrated.

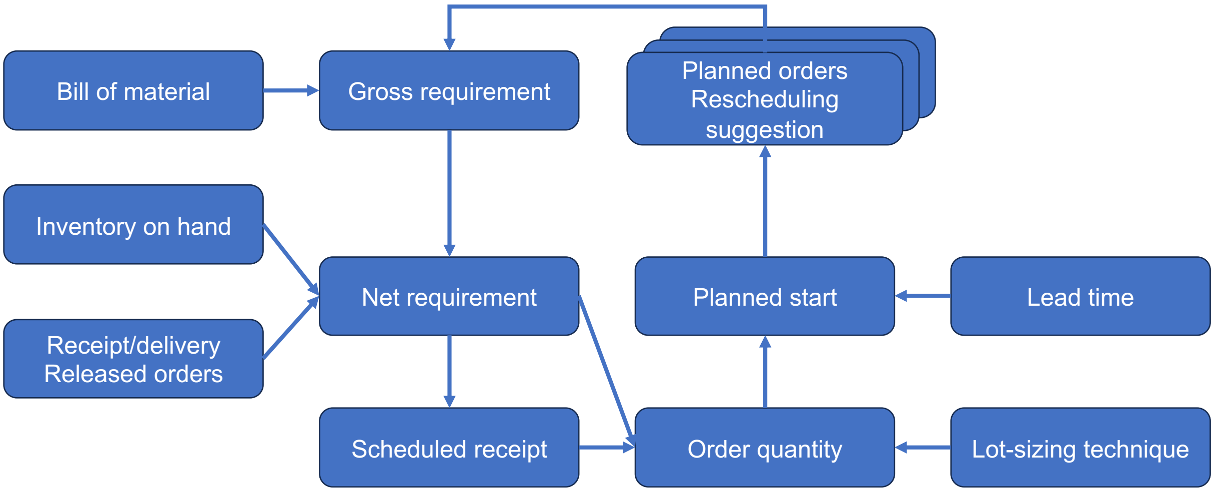

Figure 3.10. The process of an MRP (Mattsson and Jonsson, 2008).

MRP is often used to derive capacity requirements (Olhager, 2022). The MRP can be translated to a capacity requirement planning (CRP) to evaluate if the plan is executable or not regarding available capacity (Hung et al., 2013). CRP verifies the feasibility of capacity required at work centers for each time period by considering actual lead times and other information derived from the material requirements plan (Zäpfel and Missbauer, 1993). Olhager (2022) states that the CRP always works with the actual capacity need, both setup times and processing times, which is the reason for why the actual lot sizes is required for the calculations.

3.3.2 Cyclic production

Cyclic production is a rate-based planning system and is a combined material and capacity planning method (Olhager, 2022; Segerstedt, 2018). The method is suitable if the demand is stable, production capacity is limited, and the product range is established over a longer period (Mattsson and Jonsson, 2008; Olhager, 2022). In cyclic production, the primary focus is on capacity, with materials taking a secondary role, in contrast to MRP, where it is the opposite (Mattsson and Jonsson, 2008). Olhager (2022) points out that capacity planning focuses on the most constrained resource in the production system. The author further elaborate that it is crucial to constantly keep this resource supplied with materials to make the best use of it. The products are placed in a cyclical production sequence, which is repeated a determined number of times per year, in periods of constant time, Segerstedt (2018) explains. All products return with the same constant interval or multiples of this interval (Segerstedt, 2018). Mattsson and Jonsson (2008) describe that the method aims to create a more even flow of material, resulting in shorter queues. Olhager (2022) and Segerstedt (2018) adds that the overall purpose of cyclic production is to control and manage the queuing at workstations. The queue time is normally the dominating part of a product's lead time, according to Olhager (2022). Cyclic planning results in constant arrival intervals for the products at the working stations (Segerstedt, 2018). Since the product sequence is determined, the production, material movement, and queues are controlled at the same time as the resource utilization is even out. Thereby, control over capital tie-up, stock levels, work in process, and thought-put times are created (Olhager, 2022). Figure 3.11 illustrated the information flow in cyclic production during the planning process.

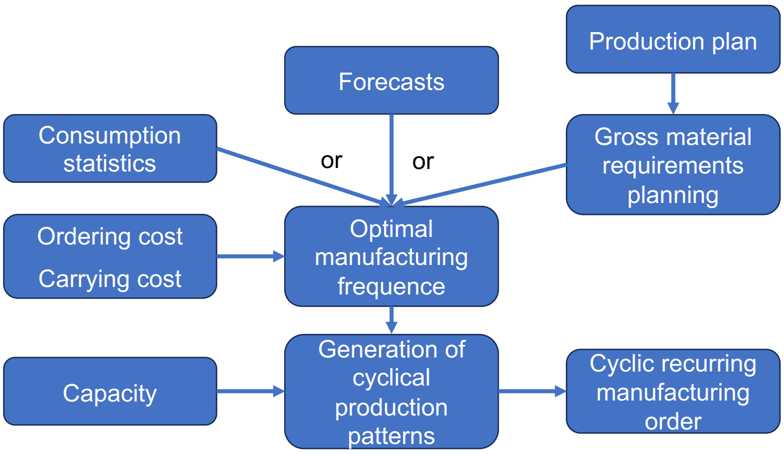

Figure 3.11. The information flow in a planning system of a cyclic production (Mattsson and Jonsson, 2008).

To efficiently generate cyclic production patterns, access to system support is important, Mattsson and Jonsson (2008) describe. The authors also explain cyclic production being a shop planning method, where the sequence of orders and operations is predetermined by the cyclic production pattern. The result of the predetermined sequence is that customers have no control over delivery cycles and must adhere to the manufacturing schedule set in place (Mattsson and Jonsson, 2008). By utilizing the cyclic production pattern, a connection between the bill of material of various products can be established, as described by Mattsson and Jonsson (2008).

3.3.3 Optimized production technology

OPT is a software program that is designed to optimize production capacity by identifying and managing bottlenecks in the production process (Olhager, 2022; Stevenson et al., 2005). It is based on the theory of bottlenecks which is called theory of constraints (TOC), and it was developed by Goldratt and Cox in 1984. One key aspect of TOC is the identification of bottleneck resources, which determines the overall performance of the production system (Storhagen, 2011). By aligning production processes with the requirements of these bottleneck resources, companies can improve efficiency and productivity (Olhager, 2013; Stevenson et al., 2005). OPT allows for dynamic demand and can be applied in both flow and job shop environments, as explained by Olhager (2022).

OPT is described by Olhager (2022) and Storhagen (2011) to have two components: nine OPT rules for handling bottlenecks in production chains and the program software for planning and sequencing production activities. The nine OPT rules guide companies on how to effectively identify and plan around bottlenecks in their production systems. In Table 3.3 the nine OPT rules are shown. When utilizing OPT, lead times are not fixed, as in other planning systems. Instead, the lead times are determined through load simulation, with the aim of maximizing the utilization of bottleneck resources (Olhager, 2022; Storhagen, 2011). This approach allows for flexibility in lot sizes, with larger batches preferred for bottleneck resources and smaller batches for resources with lower occupancy rates. A potential disadvantage of OPT is the lack of transparency in the technical details of the system and the algorithms used, according to Olhager

(2022). This can make it challenging for companies to fully understand how the software is optimizing their production processes.

Table 3.3. A description of the nine OPT rules (Storhagen, 2011; Yenradee, 1994).

OPT Rule	Comment
1. Balance flow, not capacity.	Capacity dictates, but flow should be maximized. A non-bottleneck does not require high utilization.
2. Utilization rate of a non-critical resource is not determined by its own potential but from another constrain in the system.	All plans for non-critical resources are based on the bottleneck in the system.
3. Utilization and activation of a resource is not synonymous.	Utilizing a non-bottleneck means that it complements the bottleneck. Activating production beyond the bottleneck's capacity leads to unnecessary inventory buildup.
4. A lost hour at a bottleneck is a lost hour for the total system.	Set-up time should be minimized in the bottleneck to maximize flow.
5. A saved hour in a non-bottleneck is a mirage.	Extra changeover can be done since there is free time.
6. Bottlenecks govern both material flow and inventory in the system.	It is important that the bottleneck is utilized 100 % and disturbances are avoided.
7. The transfer batch may not, and many times should not, be equal to the process batch.	The process batch in the bottleneck can be divided up in sub-batches that are further transported.
8. The process batch should be variable, not fixed.	Large batches are produced at the bottleneck to achieve low setup times and small batches at non-bottlenecks.
9. Schedules should be established by looking at all constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined.	Actual lead times depend on capacity utilization, lot sizes, setup times, etc.

3.3.4 Comparison between methods

To summarize the previous sub-chapter, Table 3.4 below is used for comparison of MRP, cyclic production and OPT.

Table 3.4. Comparison between planning systems for material and capacity planning (Olhager, 2022).

Characteristics	MRP	Cyclic production	OPT
Material planning system	Yes	Yes	Yes
Regards product structure?	Yes	-	Yes
Regards capacity?	Yes	Yes	Yes
Rate-based or discrete demand	Discrete	Rate	Discrete
Order initiation	Material plan	Material plan	Material plan
Order quantity	Fixed/Variable	Fixed/Variable	Variable
Time between orders	Variable	Fixed	Variable

In essence, MRP, cyclical production, and OPT all involve developing a material plan, but they differ in their approaches. While MRP can evolve into CRP, cyclical production and OPT incorporate capacity constraints into material planning (Olhager, 2022). MRP and OPT both utilize the product structure to establish links between material and capacity requirements across various articles (Olhager, 2022). In MRP, this structural linkage is established through materials, whereas in OPT, there are operational structural connections aimed at analyzing and prioritizing bottlenecks and their capacity.

Olhager (2022) describes that MRP and OPT allow for variation in both quantity and time between orders. In contrast, cyclical production relies on fixed production intervals, assuming a consistent demand over a longer time horizon. The batch size also remains relatively consistent in cyclical production (Olhager, 2022). Rate-based planning systems take advantage of the stability of demand to maintain either a fixed quantity or time between orders, resulting in a structured production, as described by Olhager (2022).

MRP and OPT accommodate varying demands and create material and capacity requirements based on the current order situation Olhager (2022) states. Further, the author describe that these methods are therefore more generally applicable since they do not put limits on the characteristics of the demand. Additionally, Plenert (1999) compares TOC theory with MRP, suggesting that OPT with TOC performs better in situations with dominant bottlenecks, while MRP is more effective for highly customized products. However, determining the superiority of one system over the other remains challenging (Plenert, 1999). In Table 3.5 below, a comparison between MRP and TOC is shown.

Table 3.5. Comparison of MRP and TOC (Plenert, 1999).

Characteristics	Methods: MRP	Methods: TOC
Scheduling flexibility	High	Good
Production lead time	Very long	Medium
Resource efficiency focus	Labour	Bottleneck
Inventory levels	Large	Medium
Setup times	Averaged	Adjusted
Production batch size	Large	Vary

According to Plenert (1999), the main difference between MRP and TOC, and thereby OPT, lies in the priorities. MRP focuses on labor efficiency, whereas TOC concentrates on addressing bottlenecks. Furthermore, the approach to managing setup times varies between the two systems. MRP relies on average setup times, whereas TOC uses adjusted setup times.

3.4 Production activity control

The role of PAC is to facilitate the shift from planning to execution (Bozarth and Handfield, 2019). The objective of PAC is to decide when a production order should be processed based on the available capacity (Olhager, 2022). In essence, the PAC is where planning meets processes (Hopp and Spearman, 2011). Figure 3.12 illustrates the interactions between PAC and other planning processes.

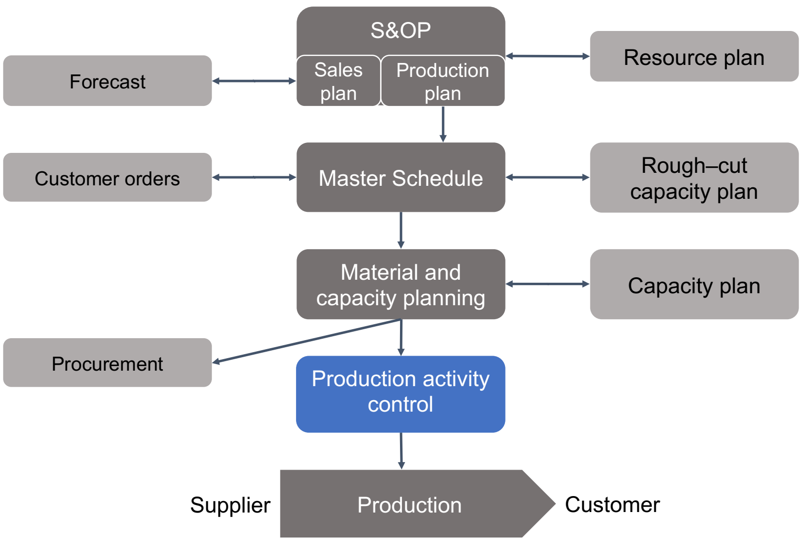

Figure 3.12. The relationship between different planning processes. Inspired by Mattsson and Jonsson (2008) and Olhager (2022).

PAC planning process involves detailed planning and execution, as well as follow-up of manufacturing orders that have been created in the previous planning processes (Mattsson and Jonsson, 2008). Mattsson and Jonsson (2008) describe the eight main stages of the PAC planning process, which are illustrated in Figure 3.13. In this sub-chapter, these stages and their principles and methods will be described. Manufacturing order is viewed as an input variable in the PAC planning process and not described in this sub-chapter. Control of dispatching, staging, and printing of shop packets, although considered part of dispatching according to Mattsson and Jonsson (2008), will be discussed separately due to the application of various methods and strategies. The print of shop packet is often an automatic process used to relay information and describe in short. Additionally, the stages and methods for shop planning and reporting will be outlined.

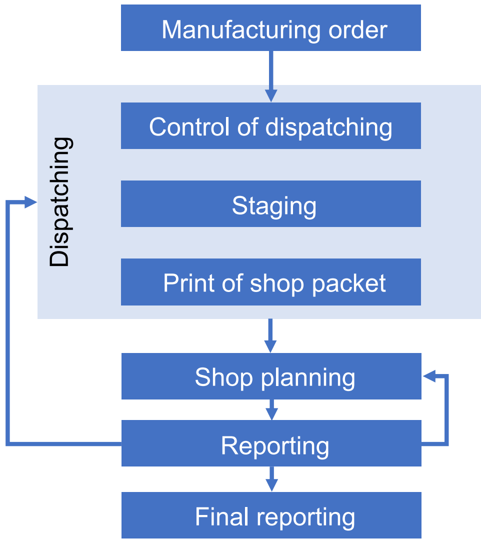

Figure 3.13. The PAC planning process main activities (Mattsson and Jonsson, 2008).

3.4.1 Control of dispatching

Control of dispatching involves determining which orders are to be released to the workshop to be executed according to Mattsson and Jonsson (2008) and Segerstedt (2018). Mattsson and Jonsson (2008) further emphasize that a crucial starting point lies in the determination of the start and due dates, established in prior planning stages, while also considering the actual workload. The scheduling of dispatching is viewed as a complex problem both theoretically and practically (Hopp and Spearman, 2011). There are two fundamental principles for releasing an order in the workshop according to Mattsson and Jonsson (2008). They describe one principle relating to available capacity and involves releasing an order because there is sufficient capacity, even if there are no material-related reasons to do so until later. This approach can improve capacity utilization but may result in higher capital investment, Mattsson and Jonsson (2008) argue. Further, they explain the other principle being related to the material needs that prevent an order from being initiated. The order's due date then takes precedence over available capacity when scheduling the release, and the order is planned based on the completion time without considering capacity constraints (Mattsson and Jonsson, 2008).

There are three main methods to control dispatching: dispatching based on planned start dates, regulated order dispatching, and capacity controlled dispatching (Mattsson and Jonsson, 2008). These are illustrated in Figure 3.14 below.

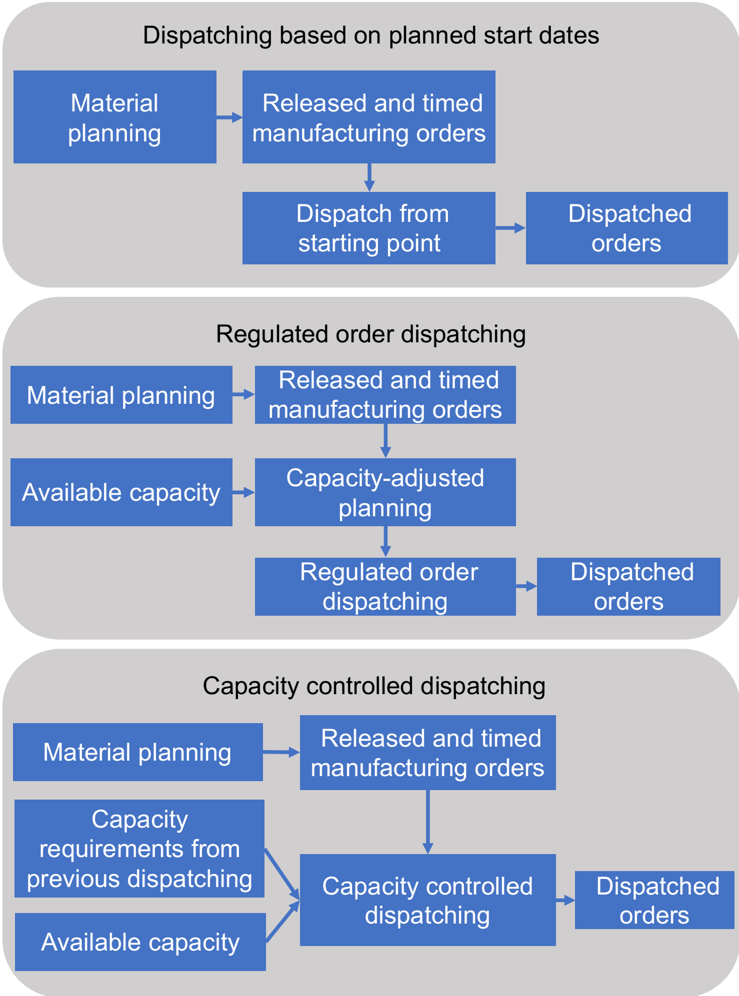

Figure 3.14. Methods for control for dispatching (Mattsson and Jonsson, 2008).

When deciding to dispatch an order, two main factors typically come into play: available capacity and material requirements, as outlined by Mattsson and Jonsson (2008). If an order is to be dispatched based on available capacity, the methods used needs to be able to consider current capacity utilization and the capacity demand of the order, the authors explain. Further, Mattsson and Jonsson (2008) describe that when material requirements are considered, an order is dispatched based on the material plan, to be delivered in time. This is done even if there is not enough capacity available. Dispatching can be done for one period at a time or sequentially (Mattsson and Jonsson, 2008). If done sequentially, it is often done based on some sort of prioritization or rules, Mattsson and Jonsson (2008) argue. The last parameter considered during dispatching is reporting dependency, the authors explain. The dispatching being reporting dependent means that there is a need to update continuously the number of finished orders. Mattsson and Jonsson (2008) explains that the information could describe if there is room to dispatch another order or not. Table 3.6 below compares the different methods of dispatching based on the different dimensions presented.

Table 3.6. Comparison of the different methods for dispatching (Mattsson and Jonsson, 2008).

Variable	Methods: Dispatching based on planned start dates	Regulated order dispatching	Capacity controlled dispatching
Regard to capacity	No regard to available capacity	Regard to available capacity	Regard to available capacity
Type of dispatching	Sequence dispatching	Sequence dispatching	Period dispatching
Reporting dependency	No reporting-based dispatching	Reporting-based dispatching	Reporting-based dispatching
Regard to material requirement	Regard material requirement	Regard material requirement	No regard to material requirements

Dispatching based on planned start dates is appropriate to utilized in combination with level loading methods such as cyclic production (Mattsson and Jonsson, 2008). Additionally, even demand is preferred in order for the method to be suitable. Regulated order dispatching on the other hand is suited where there are limited opportunities to vary capacity, according to Mattsson and Jonsson (2008). Furthermore, the authors argue that the method is difficult to use in environments with complex product structures and a high number of operations. They elaborate that planning difficulties increase nonlinearly with growing complexity, making it harder to analyze the effects of rescheduled operations. This includes assessing the impact on material supply for other orders and items, as well as managing capacity problems in different production groups (Mattsson and Jonsson, 2008). The method capacity-controlled dispatching is described by Mattsson and Jonsson (2008) to be easier to utilize than regulated order dispatching since it does not require an as advanced system support that enables analysis of rescheduling of orders.

3.4.2 Staging

The aim of this process is to ensure that dispatched orders for manufacturing have all material available, as Mattsson and Jonsson (2008) describe. Staging can also be described as pulling material from inventory before it is required for an order which is a common practice aimed at identifying shortages (Blackstone and American Production and Inventory Control Society, 2013). The cause of shortage of material can have various reasons but will force corrective measures such as forcing material, delaying orders, compromising lead times, decrease order quantity.

There are three types of methods: staging by physical reservation, staging by control of inventory, and staging by control of available inventory. The methods are visualized in Figure 3.15.

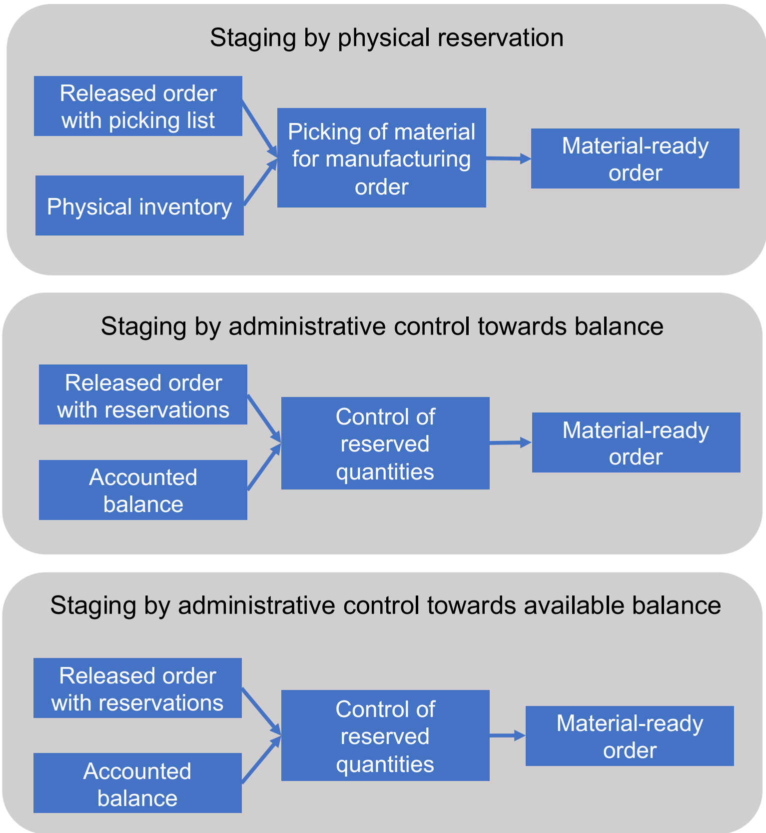

Figure 3.15. Information flow with staging using different methods (Mattsson and Jonsson, 2008).

According to Mattsson and Jonsson (2008), the variables that characterize the different staging methods include the type of balance, physical or administrative control, time displacement, and scheduled receipt. They explain that the type of balance varies depending on whether the control of the balance is directed towards inventory on hand or available inventory on hand, where the quantity is based on either what is in stock or what quantity is available without compromising other orders. Physical or administrative control refers to how the control of the balance is conducted, with the use of an inventory accounting system considered as administrative control (Mattsson and Jonsson, 2008). Mattsson and Jonsson (2008) indicate that if the administrative controls are correct, they should correspond to the physical control. Furthermore, they state that time displacement refers to whether the staging should be done in connection to the withdrawal of material or a few days prior. Finally, the authors divide staging methods into those that consider scheduled receipt and those that do not consider it. Table 3.7 compare the three methods for staging, considering these characteristics.

Table 3.7. Comparison of the methods for staging (Mattsson and Jonsson, 2008).

Variable	Physical reservation	Administrative control towards balance	Administrative control towards available balance
Type of balance	Inventory on hand	Inventory on hand	Available inventory on hand
Physical or administrative control	Availability checks of on-hand balance	Availability check of administrative inventory	Availability check of administrative inventory
Time displacement	Appropriate for staging without time delay	Appropriate for staging without time delay	Appropriate for material staging beforehand
Scheduled receipt	No regard	No regard	Can regard scheduled receipt

Physical reservation is described by Mattsson and Jonsson (2008) to be a suitable method when there is no system support. The difference between the other methods is that administrative control towards available balance puts higher demand on the accuracy on the data in the system, especially accurate bill of materials (Mattsson and Jonsson, 2008).

3.4.3 Print of shop packet

At the dispatching stage, the order receives the status as a released order, marking it ready for manufacturing, according to Mattsson and Jonsson (2008). The necessary information for executing a manufacturing order is then communicated to the shop floor through a print of shop packet, which includes a variety of production cards (Segerstedt, 2018). These cards typically consist of an operations list, job ticket, shop traveler, material requisition, tool card, and move card (Mattsson and Jonsson, 2008; Olhager, 2022; Segerstedt, 2018). The specific cards utilized by a company may vary based on the nature of production and the products being manufactured, as explained by Segerstedt (2018). These cards ensures that materials, tools, and production capacity are available, facilitating effective reporting throughout the manufacturing process. The print of shop packet can be in the form of either paper-based documentation or integrated documentation within the ERP system (Mattsson and Jonsson, 2008; Segerstedt, 2018).

3.4.4 Shop planning

The main purpose with shop planning is to ensure that orders dispatched for manufacturing are produced with regards to delivery performance and throughput time, with appropriate order sequence (Mattsson and Jonsson, 2008). Establishing a set of guidelines on how to address queues and potential delays in meeting deadlines is essential, as explained by Olhager (2022) and Segerstedt (2018). Olhager (2022) further describes that in manual systems, priority control is typically managed by foremen. Shop planning can be executed manually or through computerized systems, but either way it consistently relies on a set of rules, which may vary in strictness (Olhager, 2022; Segerstedt, 2018).

There are five main principles for shop planning: foreman overseen shop planning, general prioritization rules, planning based prioritization rules, prioritization-based shop planning, and rate-based shop planning, see Figure 3.16 for the process steps.

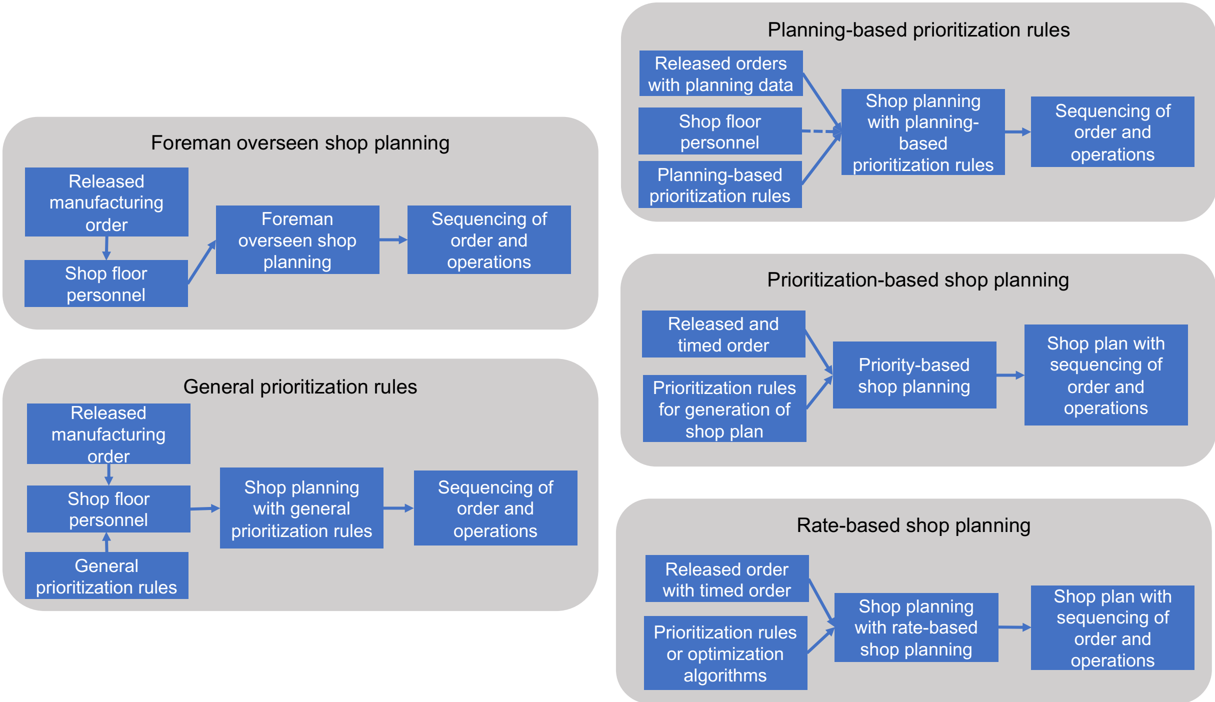

Figure 3.16. Information flow in shop planning using different methods (Mattsson and Jonsson, 2008).

There are several parameters that characterize the different methods for shop planning, Mattsson and Jonsson (2008) states. One key factor is capacity consideration, which can range from not considering available capacity at all, to considering capacity within the production group where operations will take place, or even considering capacity in previous and subsequent production groups (Mattsson and Jonsson, 2008). Another factor is the sequence of operations, which can be determined by a planning department, an ERP system followed by production employees, or general rules and policies provided by the planning department for employees in production to follow, Mattsson and Jonsson (2008) explain. Alternatively, employees in production may determine the sequencing without input from the planning department, the authors describe. They also highlight timed sequence as a key differentiator, with sequencing based on start or due dates varying among methods. The connection to the material plan is described as another difference, with some methods considering the material situation as planned and others not. Lastly, reporting dependency varies, with simpler methods requiring reporting once operations are completed, while more complex methods necessitate updated times as well. Table 3.8 compares the methods for shop planning.

Table 3.8. Comparison of the alternatives for shop planning (Mattsson and Jonsson, 2008).

Variable \ Methods	Foreman overseen shop planning	General prioritization rules	Planning-based prioritization rules	Prioritization-based shop planning	Rate-based shop planning
Regard to capacity	In own production group	No	No	No	In own or multiple production groups
Sequencing of operations	No effect of planning function	Indirect effect of planning function	Indirect effect of planning function	Direct effect of planning function	Direct effect of planning function
Timed sequence	Sequencing not defined by start/due dates	Sequencing not defined by start/due dates	Start/due dates define sequencing	Start/due dates define sequencing	Start/due dates define sequencing
Material planning connection	No regard	No regard	Regards the material situation	Regards the material situation	Regards the material situation
Reporting dependency	No	No	No	Finish reporting needed	Time and finish reporting needed

Each planning method is described by Mattsson and Jonsson (2008) to have some sort of rules or policies as basis for sequencing except for foreman overseen shop planning. They further explain the last-mentioned method to be suitable for small shops and is the simplest of the methods to conduct. Additionally, it often results in an increase of motivation of employees due to them having responsibility. Both general and planning-based prioritization rules are suited for flow shops and line assemblies, where the physical layout indirect determines the order of operations (Mattsson and Jonsson, 2008). Due to that the method planning-based prioritization rules do regard the material plan, it is also suited to use in a job shop, according to Mattsson and Jonsson (2008). Prioritization- and rate-based shop planning on the other hand are considered to applicable to all configurations of shops the authors explain. They elaborate that utilizing a prioritization-based shop planning method puts demand on the accuracy of the duration of operations for the method to be effective. Lastly, Mattsson and Jonsson (2008) describe the rate-based shop planning method differ compared to the other methods since it plans ahead and require a comprehensive system support for the finite capacity planning of operations. Otherwise, it is considered an easy method to use by the authors.

3.4.5 Reporting

Changes compared to the plan is inevitable in PAC, Mattsson and Jonsson (2008) states. To be able to follow the execution of a manufacturing order and take corrective actions when needed, reporting is required (Segerstedt, 2018). Reporting is also to follow up on actual operation durations, Segerstedt (2018) explains. Another purpose of reporting is to enable a perception of available resources and a third aim is to provide information about actual resource consumption (Mattsson and Jonsson, 2008; Segerstedt, 2018). There are two types of reporting according to Mattsson and Jonsson (2008): order reporting and operations reporting.

Reporting of orders

Order reporting may have relevance throughout various stages of a manufacturing order, but only delivery is deemed essential, according to Mattsson and Jonsson (2008). The authors continues and states that different types of cards in the shop packet, as well as workshop terminals and specialized reporting systems linked to the ERP system, can facilitate order reporting. Figure 3.17 below illustrates the potential reporting points for an order. In planning contexts where material withdrawal is reported, the status of orders is often automatically updated (Mattsson and Jonsson, 2008). However, there may still be a necessity to update an order status even if material withdrawal is not reported. Reporting of order status is considered crucial in planning environments with long cycle times (Mattsson and Jonsson, 2008).

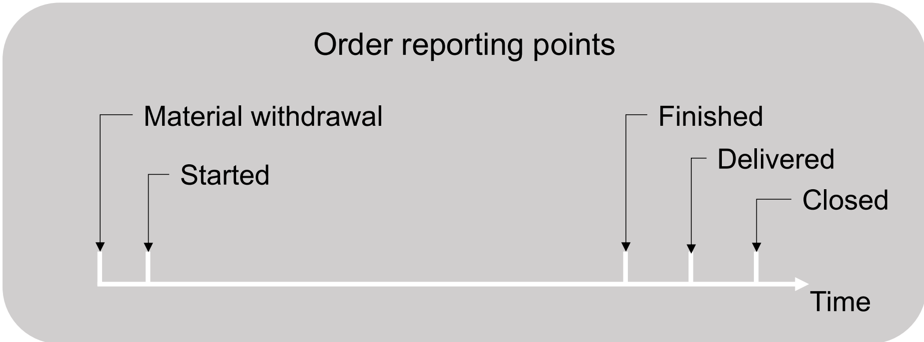

Figure 3.17. Reporting points for a manufacturing order (Mattsson and Jonsson, 2008).

Reporting of operations

When reporting on operations, the simplest level involves reporting once the operation is completed, with the option to additionally include details on the quantities produced and discarded, according to Mattsson and Jonsson (2008). The authors adds that if material requirements are tied to specific operations, an automatic update of material balances can occur when all operations are reported as completed. For accurate conclusions of operation durations, it is crucial to report the actual operation durations (Mattsson and Jonsson, 2008). This reporting can take place directly within the ERP system or through a separate reporting system. In long term planning, with extended operation durations and rate-based shop planning, there may be a need to gradually report actual operation durations, Mattsson and Jonsson (2008) explains. This approach ensures that operations with capacity constraints are planned more precisely to reflect the actual capacity requirements. Other shop planning methods that primarily focus on sequencing between released operations do not encounter the same challenges, as described by Mattsson and Jonsson (2008). The authors continue to explain that when utilizing prioritization rules in shop planning methods, reporting operation starts is essential to prevent any delays, as halting an operation is typically undesirable. Reporting on operations can be facilitated through the use of a printed shop packet or directly within the ERP system.

4. EMPIRICAL FINDINGS

This chapter contains the empirical findings which aims to describe the company's reality based on the data collected. First, a description of the medium case will be presented, including information of the products and process. The following chapter discusses capacity at the company before the process of ensuring the right material is presented. Lastly, the process from an order perspective is explained. In all sections of this chapter, the information is based on interviews, observations, and quantitative information, as mentioned in section 2.3 Data collection, if nothing else is stated. Figure 4.1 illustrates an overview of the chapter, its sub-chapters and what it includes.

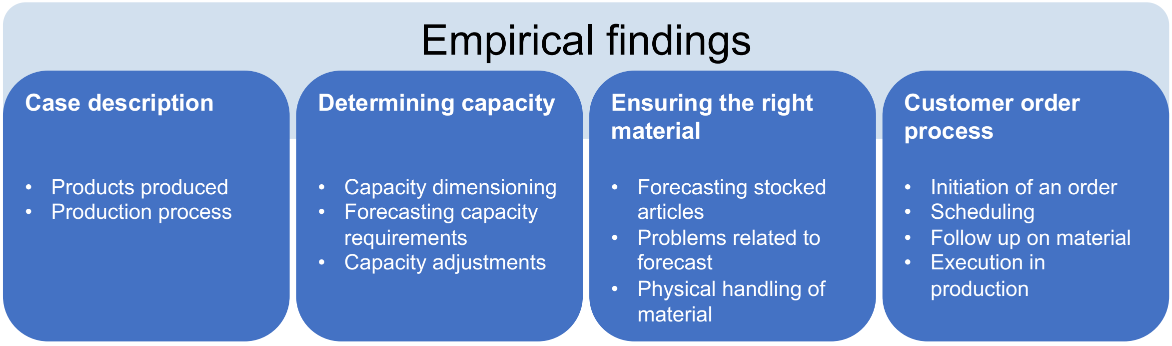

Figure 4.1. The structure of the following chapter 4. Empirical findings.

4.1 Case description

Information of the products produced in the chosen medium assembly group is described in this sub-chapter, as well as the production process for medium orders.

4.1.1 Products produced

There are various ways to group and define products, and constituent articles at the company. In this thesis, the definitions of product group, product type, end products, modules, and articles used in this thesis are illustrated in Figure 4.2. T15 is an example of a product produced in the medium assembly group.

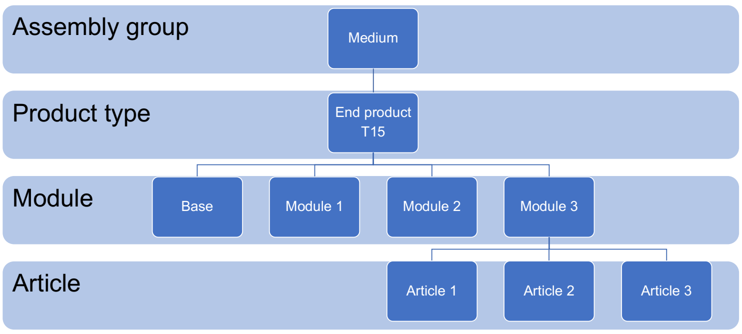

Figure 4.2. Definitions of product groups, product type, module and article illustrated.

The products produced in medium assembly group is comprised of nine product types, according to data collected. Although, these products are not only considered medium product types. This is a result of assembly groups becoming overloaded, leading to product types being manufactured in alternative assembly groups than initially planned. For example, it was described by interviewees that two product types that are large product types, currently are manufactured in the medium assembly group. In Table 4.1, the number of products that has been produced in each assembly flow the last year is shown in combination with what assembly group it initially belonged to. It is based on historical data of how many products of each product type have been produced for one year, in combination with which flow each product type is produced. However, even though there are information of how many product types are produced each year, interviewees have not described the demand of product types to be either rate-based or discrete.

Table 4.1. The number of product types and their original assembly group and the assembly group they are produced in. Numbers are altered with a factor but display the relations.

Produced in assembly group	Original product type allocation	Sum of CTO	Sum of ETO
Large	Large	410	1074
	Medium	110	28
Medium	Large	138	1424
	Medium	3910	1276
Small	Medium	3486	1104
	Small	369	1700
Total sum		**8423**	**6606**

One order can consist of multiple products, even though it is most common with one product per order. The products on the order can in turn be of various product types. The product types consist of multiple modules, which in turn consist of various articles. Interviewees disclose that if an order consists of multiple products, the order is automatically assigned to the ETO flow. In the medium assembly group, there were 133 different modules produced the previous year. One important module is the base module that defines the main structure of each product type. Further, interviewees explained that more complex customization can be added by removing and swapping different modules and of the heat exchanger, thus creating endless configuration options. An example of regular customization is described as the number of plates, the thickness of the gaskets, and the pattern of the plates. The number of plats is further described by interviewees as the main customizations leading to extra time in production and thus causing problems. The original product type mainly defined by the base module, more specifically the size of the product type, determines primarily which assembly group the product will be produced in, and each module and specific configuration options dictate if it will be produced as an ETO or CTO.

The assortment of product types manufactured within the medium assembly group, both ETO and CTO, are illustrated in Figure 4.3. It reveals that the majority of product types processed are T15 and TL10. Notably, the figure encompasses all products assembled in the assembly groups, including those of larger sizes. It is important to recognize that these are product types. The potential customization of within each product type is not considered.

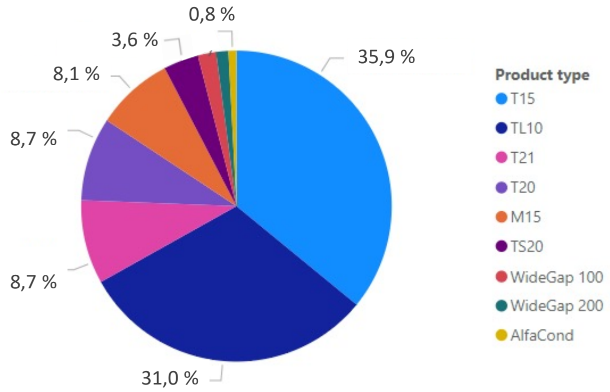

Figure 4.3. The share of the product types produced in the medium assembly group. Based on data provided by system support at Alfa Laval.

In the medium assembly group, there were 62 % CTO orders and 38 % ETO orders manufactured last year. The general rule of thumb is that the more complex the order is, the more likely it is an ETO order whereas more standard orders are often labeled CTO. The medium assembly group can produce some product types belonging to the small and large product groups. However, all orders, both ETO and CTO, have some level of customization, for example for the number of plates. ETO orders are described extra prone to encounter complications such as material shortages, discrepancies in drawings, and time-consuming certifications and inspection requirements. The complexity of ETO orders is cited by the majority of interview participants as the primary obstacle in effective planning. Project-based orders are planned by a freestanding project order department but are produced together with other ETO orders and are not considered the scope of this thesis. The product types produced in the medium assembly group, and in which flow it was produced in last year can be seen in Figure 4.4.

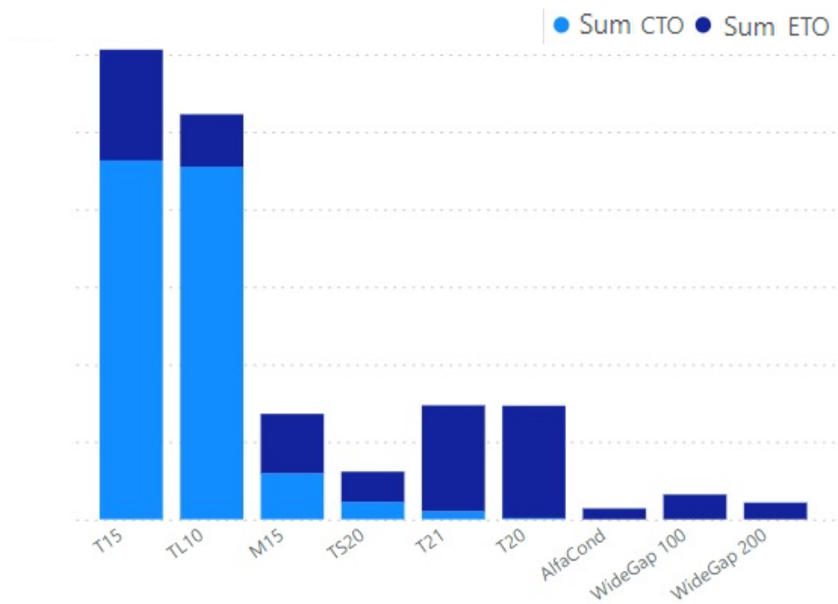

Figure 4.4. The share of product types produced in CTO and ETO medium assembly flow. Based on data provided company supervisor extracted from QlikView.

4.1.2 Production process

Various production processes were observed within the factory. The print of shop packet was observed as an automatic process. In the medium assembly section, it was observed that the products physically move around the workshop during production. There are two assembly flows in the workshop floor, one for CTO orders and one for ETO order. CTO orders allow for a quicker and more efficient production process. On the other hand, ETO orders present a challenge with varying production lead times as customizations varies, each one requiring specific manufacturing processes. Thus, the previously mentioned product differentiation between ETO and CTO orders is important since there are designated flows for each type of orders, as described by interviewees. Additionally, two primary categories of operations were identified within the assembly flows called *gasketing* and *assembly* where each displaying distinct characteristics. All orders involve both operations, but they are not always executed sequentially or by the same operators. It is typical for certain personnel to specialize primarily in gasketing, while others focus mainly on assembly tasks. No bottlenecks in terms of machines are described present in the medium assembly group. The process step of gasketing, which involves placing gaskets on plates, is characterized as both simple and time-consuming. However, a relatively short learning curve is associated with this task. Figure 1.3 illustrates the gasket and plate. Gasketing of plates requires personnel to work in pairs. It is performed in the same physical area for both CTO and ETO orders within the medium assembly group, although in separate sections within that zone. At the gasketing stage, operators remain stationary, utilizing consistent tools. Additionally, this phase serves as preparatory work, and the gasketed plates are temporarily stored in pallet racks before the assembly process begins. The aim of this process is to facilitate a smooth assembly process.

Moreover, the assembly process is described by the company representatives as a flow shop. The general assembly process is done in the steps of rising, plate installations and tightening, pressure testing, and parceling as well as steps related to customizations, such as inspections. Each operation step in the assembly process has a designated area, which is illustrated in Figure 4.5. The first step in the assembly process is to rise the heat exchanger by lifting the body of the product. Thereafter, it is moved to the next operation where plates are installed and tightened. Then, the apparatus is moved to pressure testing to ensure that there are no leaks. These apparatuses are then relocated to a designated area, known as the inspection area. The inspections can be conducted by Alfa Laval’s own quality department or by external classification society. Subsequently, the apparatus is moved to a parceling and staging area in preparation for shipping. The primary operation steps remain the same for both ETO and CTO flows. However, in the ETO flow, certain apparatuses may need to be diverted from the standard flow for various reasons, such as for inspections. The layout of production is adapted based on the production processes, resulting in a difference between the ETO and CTO flow. The products manufactured can only flow in one direction.

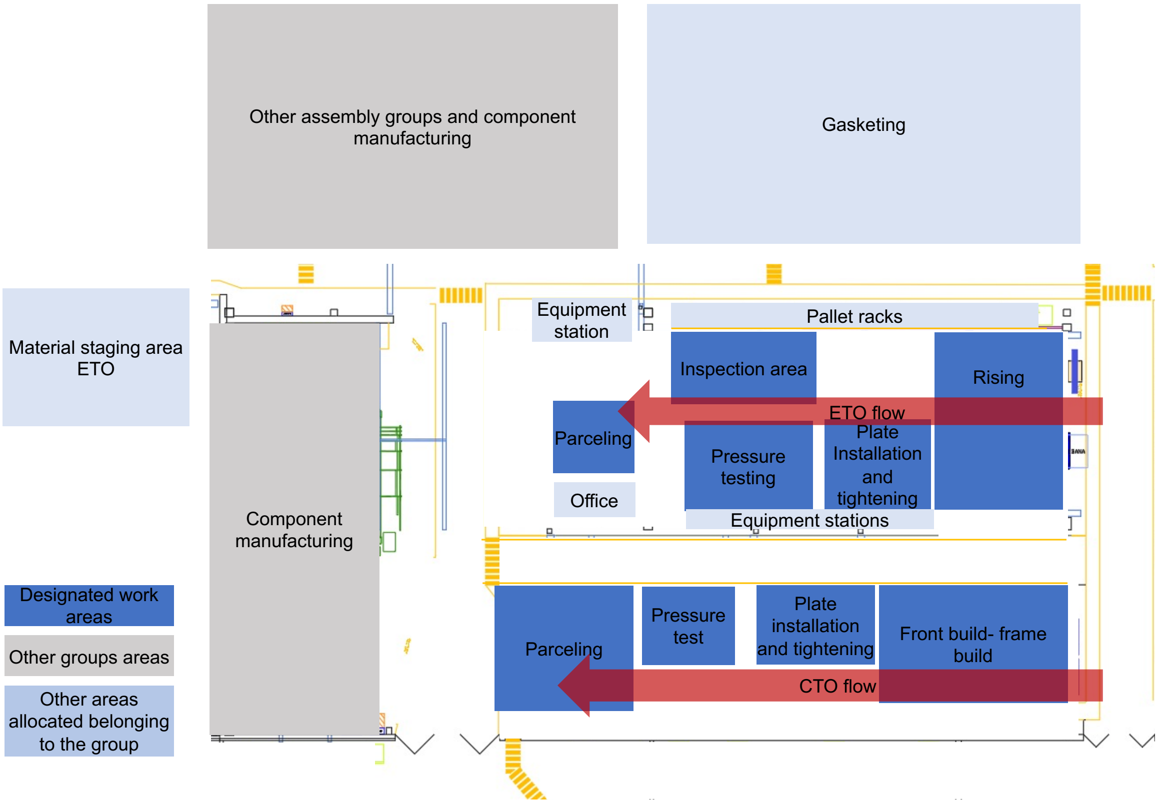

Figure 4.5. Layout of the medium assembly group with areas marked for specific operations. Note that the factory continues in some directions that is not stated in this map.

The CTO flow in the medium assembly group is described to be rate-based with a rate of 70 minutes and in the ETO flow the time between orders vary. In the CTO flow, it is stated that an average of eleven products can be built daily, while for the ETO flow, the average is five products. However, it might vary depending on the level of customization and, consequently, the complexity of the production assembly process required. These limitations stem from a combination of the time needed to assemble the products and space constraints. One factor that is described to disturb the rate in the CTO flow is the number of plates on an order. When the number of plates exceeds the normal limit, it is considered an ETO order, since it results in longer manufacturing time when putting the gaskets on the plates and also during the assembly phase when plates are installed. Due to the fact that products are produced in another assembly groups than initially planned, as describe previously in section 4.1.1 Products produced, it results in ETO orders sometimes having to be assembled in the CTO flow. It is described to then disturbs the flow since it cannot keep the rate of 70 minutes per station. As a result, the rate of 70 minutes is not always followed.

The medium assembly group is organized into two sub-groups, ETO and CTO, each with their respective gasketing forces. These sub-groups are overseen by different team leaders, who allocate daily tasks among workers. The workforce of approximately 22 full-time employees has the flexibility to transition between gasketing and assembly operations. Typically, the same operators accompany an apparatus throughout the assembly process, although there are instances where specific tasks, such as lifting, are handled by one operator before transferring the apparatus to another. The tasks vary in skill level and experience required, with gasketing being a simple operation that has a short learning curve compared to other operations. In contrast, the assembly process requires more experience and training. As a result, knowledge and experience are considered important factors in allocating work among production groups.

4.2 Determining capacity

This section outlines how the appropriate capacity is determined at the company. At Alfa Laval, capacity of existing resources is considered during the planning phases, with man-hours at the shop floor as the primary object. Manufacturing orders and operations are allocated reference hours, forming the basis for predictions. The capacity is dimensioned jointly by different actors for the assembly groups. The capacity is dimension and addressed by the master scheduler and team manager of the production.

4.2.1 Capacity dimensioning

When discussing capacity dimension with interview participants, no one is able describe how the entire process is conducted throughout the horizons. The capacity required is a prediction taken from the forecast done on a Master Schedule level. Both reference hours and the approximation of utilized man hours per worker per day is an average approximation. This is evident in the joint tool QlikView, where both forecasts, actual capacity and customer orders can be viewed, see Figure 4.6. Here the green line demonstated the forecasted value of the capacity, the red line the man hours capacity available and the staple is the actual customer orders. The capacity forecast is uppdated monthly thus changing the green line.

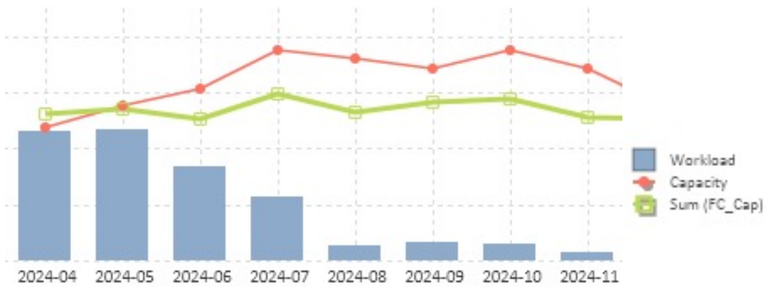

Figure 4.6. The medium assembly group's capacity over the past few months, featuring actual customer orders (blue), forecasted capacity (green), and actual available capacity (red). Extracted from QlikView 2024-04-09.

4.2.2 Forecasting capacity requirements

Capacity is addressed at two horizons at Alfa Laval. The first one is conducted by the master scheduler who does a forecast in order to plan capacity. The forecast at this stage is described to not consider seasonality, trends, current backlog or inventory and lead time.

The forecast of the capacity is based on an aggregated forecast from the S&OP process, conducted across multiple factories. The S&OP forecast consists of the number of units that is expected to be produced of each product type. The capacity forecast is done in terms of man-hours for the whole factory, as well as for the different assembly groups. The conversion from units to hours is based on reference hours. The reference hours denote the average time required to manufacture a product, divided into CTO and ETO assembly flows. The reference hours are based on an average over twelve months, which is based on historical data. The process of conversion is done using Excel and it is described to be time-consuming as it involves reviewing historical production data to determine the capacity requirements. The reference hours are updated quarterly or upon request by the finance department at the company. The forecast is further translated into gasketing hours since there is a wish for it by company representative. This is also done with the reference hour, that are based on the gasketing operations. The forecasting process views the factory as an entire resource. It was described that no special consideration to capacity limits of resources is done in the process. The accuracy of the reference hours is described as questionable for certain product types, leading to forecast inaccuracies. Moreover, there is minimal feedback in the systems when a product is produced in a different production flow than intended, such as when a product is produced in the large assembly flow rather than the medium one. The minimal feedback is due to the limitation of the reporting possibilities, especially when orders are being transferred between assembly groups. Interviewees noted that the ERP system, where the reporting takes place, does not allow an order to change assembly group from their originally planned location. Nevertheless, the ERP system correctly document the hours spent by the assembly group where the product is actually being manufactured. This is described to affect the reference hours, making them incorrect.

The goal of the forecast is to optimize personnel utilization by adjusting available capacity in terms of man-hours. Interviewees describe the time horizon of the capacity forecast to be three to 15 months or up to 18 months. Although, in documents the horizon is described to be three to twelve months. Additionally, the current forecast is used as a prediction in the upcoming weeks. The forecast is used in the time horizon one month as it is used to adjust capacity in this time period.

To align capacity with forecasts at the Master Schedule level, Alfa Laval aims to maintain a flexible workforce comprising both permanent and temporary employees. The primary focus was described to mitigate the impact of summer holidays on staffing levels. Adjusting the capacity based on the forecast has been done previously, as described by interviewees. It was unsuccessful since the forecast predicted a lower demand than the actual outcome turned out. It is described to have caused no trust in the forecast and since then they have been careful to adjust the capacity based on the forecast as it is seen as uncertain. As a result, no indication of systematic hiring based on the capacity forecast was indicated to be done, apart from temporary summer hires. Additionally, the number of shifts can change when having high order intake for a longer period. Currently, the CTO flow utilizes extra shifts for periods of four weeks at a time. This was described to be done due to the lack of space. The staff remains constant in numbers but divided in a day shift and an evening shift.

The forecasted capacity from the Master Schedule aims to be within a range of +/- 20 % for all assembly groups. Where deviations under this range are noted to have varying impacts. Interviewees describe that it is harder to manage and reduce staff compared to hiring, which occurs when the forecast is higher than the actual outcome. In addition, the monthly updates of the forecast are reported to pose challenges for capacity influencing actors to manage effectively. They experience that it is hard to follow the forecasts since it is chancing constantly.

In essence, the capacity forecast on Master Schedule level unites historical data that gives the reference hours with the S&OP production plan forecast to create a capacity plan. On monthly meetings called *local supply review meeting*, the forecast is evaluated, both in terms of accuracy but also predictions and the forecast is finalized. To the understanding of the authors of this thesis, the aim of the local supply review meeting is to handover and establish the forecasts monthly.

4.2.3 Capacity adjustments

After the Local supply review meeting and the adjustment of personnel, capacity is not addressed until the shorter horizon of one or two weeks. When addressing capacity at this level, Alfa Laval relies solely on confirmed customer orders. At the horizon of one to two weeks, the final allocation of personnel at the workshop is done. The process involves comparing the expected workload, based on the planned number of products to be manufactured and on the reference hours required for each product, with the scheduled available capacity. This is done in QlikView with data from the ERP system, see Figure 4.7. The first graph illustrates the workload in hours during upcoming weeks as well as the available capacity. Thereafter, a graph illustrating hours required on a daily basis with available capacity is shown. The number of units during the upcoming weeks on a daily basis are illustrated in the last graph. The figure illustrates some of the planning problems with balancing orders over weeks but also between days. Various factors, such as unforeseen absences due to illness, can impact the availability of planned capacity during this period. If there is a gap between the workload and available capacity, there is an ambition to close it to maximize the available capacity. The aim is to maximize the available capacity, resulting in time and energy being spent on ensuring this to be fulfilled optimally.

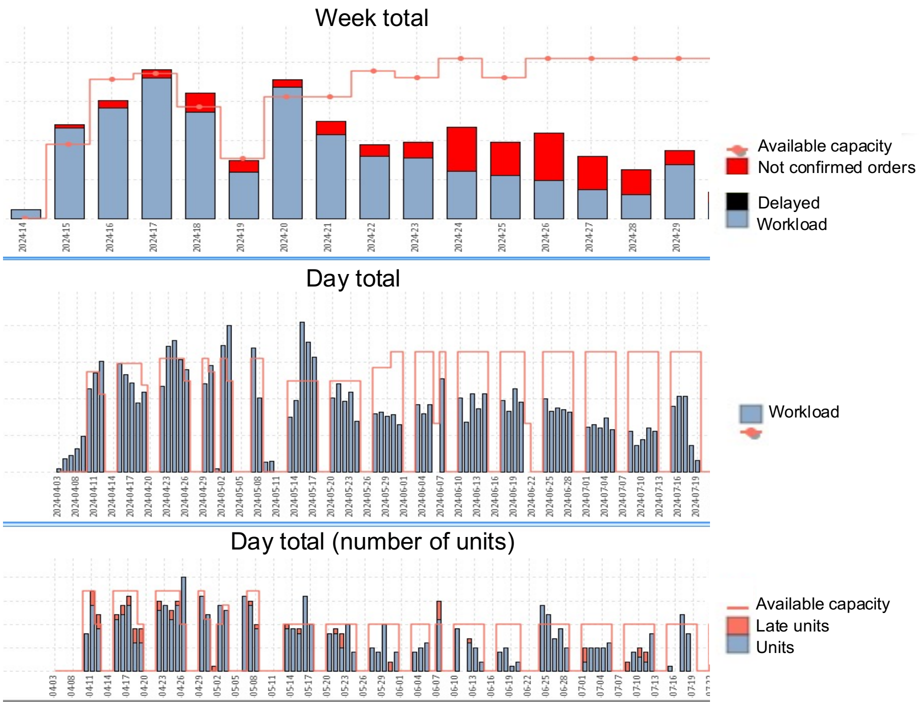

Figure 4.7. Confirmed customer orders and available capacity at a weekly and daily level. Extracted from QlikView 2024-04-09.

There is an aim to view the man-hour capacity within the assembly groups as a collective resource at the factory level. The company holds weekly Thursday meetings with all relevant stakeholders, including schedulers, top management, and purchasers, to address capacity gaps within the factory. Prior to this meeting, a preparatory meeting is conducted to discuss potential actions. One common approach involves transferring personnel between assembly groups to balance workload, with daily transfers between departments being made with the weekly meeting serving as a deciding point. Another action is to delay maintenance, although differing opinions on its implementation were observed. The meetings also discuss the advancement and postponement of orders, which are prepared by schedulers and discussed at the meeting. Additionally, the company frequently transfers orders between departments, a common practice that does not impact delivery dates.

The plans to adjust capacity often change from day to day. The aim is to view the entire factory resources as one, although there are no formal prioritization rules of how to distribute personnel. In addition, the process of transferring resources can be complicated by variations in operational efficiency based on individual experience levels. The company is actively working to shift away from a siloed mindset and instead view the entire factory as a single resource. Moreover, during meetings where capacity adjustments are discussed, decisions are made collaboratively by all stakeholders, with few decisions being made by individual employees. The team manager of production for the medium assembly group is responsible for managing all personnel in production and thus has a critical role in adjusting capacity.

To further bridge capacity gaps, the company also utilizes overtime and outsources certain operations to subcontractors. Overtime is described to be scheduled on Saturdays when the factory has high order intake but not enough to change the number of shifts. If the production has had delays during the week it also results in the need for overtime to keep the due date. To adjust the capacity further, sub-contracting is a common action in the factory. There is a close working relationship with a sub-contractor for the gasketing operation, but the extent of the practice is unknown. There was some evidence that this action was carried out. During one meeting another action to bridge capacity gaps was discussed: putting of maintenance. During the meeting, the long-term consequences of putting it off were addressed.

4.3 Ensuring the right material

This sub-section aims to relay the details the material planning process at the company. At the company, 2475 articles are stocked as of March 2024, and a constant flow of material bought order unique. The inventory levels are described as large by company representatives. Articles are sourced both from external suppliers and in-house suppliers, such as Alfa Laval's own component factories. Only the stocked material is planned with a forecast. Order unique material is not forecasted and purchased for each costumer order. No information on the extent of the use of order unique material has been found. The main factors influencing material supply planning are the master scheduler, operational purchasers, and system support functions. There is no explicit material plan identified during the empirical study. Interviewees referred to the ERP system as the main function of controlling the material, where each employee can moderate and control some of the parameters to some extent. Although, how the ERP system controls material is unknown to the interviewees and it is described that no one is in charge of this function. In the ERP system, bill of materials for orders can be found, including modules and articles.

4.3.1 Forecasting stocked articles

A forecast is created for all stock articled by the master scheduler. The forecast of future material withdrawal is based on historical data of material use. The horizon of the historical data depends on what method of forecasting is employed. It is described that the reason the forecast is not based on the same data as the capacity forecast is that the S&OP forecast has historically not been accurate enough. The S&OP is described to be accurate on a larger context covering the number of units being produced at the factory. The material forecast however requires it to be accurate on what product types to be produced as well.

The material forecast is done in Excel and is based on data provided by the system support at the finance department. In the Excel file, automatic calculations are done using moving average, exponential smoothing, as well as an in-house method called the *Ö-vägen method*. Exponential smoothing is used for multiple articles. Moreover, moving average is described to be used for trend-sensitive articles. What articles to be calculated with which method is based on predefined rules in the Excel, although at Alfa Laval, no one is familiar with the process behind this, yet it is unquestionably relied upon for its accuracy. It is described problematic since there is limited control over the forecast. Although, there is a plan to create a new Excel with new rules and methods. It will be a single method used for all stocked items in the future; a moving average on a horizon of three or 15 months. The reason for this method to be employed is described to be due to the trend sensitives.

The material demand forecast for each stocked article is entered into the ERP system and are used by the operational purchasers. To deal with uncertainty, the safety stock values of articles are changed rather than change the forecast of the predicted demand. No explicit considerations are taken to trends such as seasonal demand, as described by interviewees. However, there is lack of information on the basis for the ERP system's recommendations for purchases. It is unclear if the system considers factors such as gross or net requirements, cyclic patterns, or whether recommendations are based on current inventory levels or forecasted demand.

It is expressed that there is limited information of the materials, how they are connected, and characteristics. An additional factor that complicates forecasting is that new stocked materials originating from new products have a different process in regard to forecasting. Then the forecast is based on what the business units expects to sell of the products, including how much of each article. Further, large fluctuations of material demand are described as problematic, since it results in an uneven material demand to suppliers, causing a bullwhip effect. Noteworthy is that the introduction of new modules does not automatically trigger a change in forecast even though new models often use the same material as older models, thus increasing the demand on certain articles. The processes of forecasting demand are iterated monthly, and the forecast is updated monthly. The time constraints are expressed as the main obstacle for continuous improvements or analysis of the forecasting process.

Similar to the capacity forecast, the accuracy of the material demand forecast is evaluated on the local supply review meeting with factory management. Although, it is described to be no feedback from the purchasing department on the accuracy of the forecast, which makes follow ups difficult.

4.3.2 Physical handling of material

Once the materials arrive at the factory, they undergo a goods receiving inspection to ensure they meet the right quality and quantity standards. Some materials are refined inhouse and thus have different processes that does not include the same quality control. After receiving, they are stored in various locations. However, space limitations have led to the use of several warehouses. There is one main warehouse, several tents, decreasing space in the yard, and an additional storage area at another site called Ö-vägen. Material sorting and storage locations are not discussed in this thesis. The withdrawal of material is managed through the ERP system by each assembly group before assembling and gasketing starts. Orders receive different statuses in the ERP system based on material availability, without considering various warehouses and stock locations. The ETO manager notes that sometimes materials are ready but stored at Ö-vägen, requiring extra time for staging. It is a significant problem when ordered material is not ready as planned, leading to rescheduling of orders. Safety buffers, like checking materials before assembling starts, are in place to ensure the right material is received. However, interviewees report discovering damaged or incorrect materials during production, causing delays. Comparing the two production flows of CTO and ETO, most of the issues related to material occurs with ETO orders. It is described to be due to the customizations of orders and thereby the order unique materials. The manager of the ETO flow describes how there are often material issues detected in the middle of assembly processes that are related to the material being constructed falsely in some way. Further, they explain that this often happens with order unique material due to the specifications that are required for these types of material, which in turn further complicates the handling of these issues. Additionally, the repurchasing of order unique material result in long delay of production due to the longer lead times compared to stocked material, as describe by interviewees. This is also an issue when the material is damaged. Other issues related to material of ETO orders is described to be connected to the drawings. It could be incorrect information and specifications, as well as incorrect following of the drawings. Additionally, the many locations for storing material is explained as a reason for material to be delayed and not be ready on time. In contrast, problems related to stocked materials are easily resolved through good communication between in-house suppliers and warehouse personnel. Therefore, CTO orders do not face material issues as the primary planning concern.

4.4 Customer order process

This sub-section described how an order is planned and handled from the point of order to execution in production. The section describes the planning process from a different perspective of the planning process with the order in focus. The actors in this process are order handler, scheduler, team manager, and team leaders.

4.4.1 Initiation of an order

Orders are received from various sales companies around the world and are sent to the assembly factory. An order may consist of multiple heat exchangers. Depending on the complexity and customizations of orders, it is directed to either the project order department or the order handling team. The included modules and articles determine the most suitable assembly flow for production.

The order handler starts by validating each order to ensure its accuracy and that the information is complete. This involves verifying that the heat exchangers ordered contain the specified articles and modules, and that all necessary information is provided. Once all essential details are confirmed, the order is broken down into a sales order for further processing. The breakdown into a sales order is automated through the ERP system, and the desired delivery date from the customer is added to the sales order. Next, the sales order is converted into manufacturing orders which correspond to production steps. These are thereafter planned to meet the desired delivery due date.

The desired delivery due date might be altered if it cannot be fulfilled. Alfa Laval is working towards establishing fixed lead times for certain products in their assortment. It is described to enhance planning stability and provide reliable promises to customers. This involves setting specific production lead times from order initiation to customer delivery. It is currently focused on CTO orders, where assembly processes must be adaptable in terms of materials and resources within the fixed lead time. For CTO orders with medium configurations, fixed lead times of two, five, or ten weeks are being enforced. The lead time of a product is determined by the lead times of its constituent modules, with the module containing the article with the longest lead time dictating the overall lead time. Further, it is described that this system aims to standardize orders and allow customers to modify modules to shorten lead times. Additionally, orders must be booked within the fixed lead time, requiring the necessary capacity adjustments to accommodate order bookings during the freeze period. Orders are automatically assigned the fixed lead time unless specified otherwise by the customer, allowing for flexibility in accommodating varying customer needs and preferences. Customers can also request longer lead times if necessary, ensuring that their requirements are met. Currently, a project is underway to assess the capacity adjustments needed to enable fixed lead time.

The order handler first plans the order based on the desired due date. Whether the order can be scheduled within the fixed lead time is primarily determined by the load and capacity of the production. The production capacity is assessed through QlikView that displays the total capacity of all assembly groups in production. If there is not enough time to complete the order within the fixed lead time, the order is passed on to the scheduler. The scheduler will rearrange existing orders to accommodate the new order within the fixed lead time, sometimes requiring an iterative approach to accommodate all orders within the lead time window. Thus, this process is a collaborative effort between the scheduler and order handler. The balancing of orders is done by day and with focus on the horizon of one to two weeks for the medium assembly group.

Once the order has a preliminary delivery due date, and all necessary validations have been conducted, purchase orders are issued to the suppliers for the required materials and parts. Upon receipt of approval from the suppliers confirming their ability to deliver order unique materials on time, the purchasing department notifies the order handler. In case the suppliers are unable to meet the delivery timeline, the planning process revisits the order until all requirements are met, occasionally necessitating additional iterations for resolution. The rescheduling may result in the order being finished before the scheduled due date. In such instances, the completed products are stored until they are ready to be shipped.

Upon approval of all manufacturing and purchasing orders, involving internal and external stakeholders, the customer is issued a confirmation of the order, along with a specified delivery date. The goal is to provide customers with order confirmations within a three-day timeframe.

4.4.2 Scheduling

It is described that previously, team leaders in the production had more control of the planning process at the company but in recent years there has been a wish to move the control of planning up the chain. Therefore, a planning department was created, where schedulers are responsible for rescheduling orders and the product mix to be manufactured on a daily basis.

The composition of the product mix for production is described to be crucial, partially since the contrasting complexities of orders causing them to have varying times. As the start date of an order gets closer, the scheduler is in charge of balancing the production flows of the planned orders to optimize the production. Figure 4.8 illustrates an example of an action that is done to smoothen the production phase. Generally, this process is carried out with a one- to two-week foresight, although occasionally a longer one-month horizon is considered to gain a comprehensive overview of forthcoming operations. The balancing is done based on available capacity, with physical production space being a critical factor in the planning of the medium assembly group, as there are constraints on simultaneous manufacturing. An additional challenge during scheduling is the booking distance; as the company adheres to fixed lead times, not all available capacity can be booked, thus impeding the planning of new orders within these fixed lead times. If adjustments cannot be made to balance the flow, orders may be reassigned to an alternative assembly group. However, the orders cannot be transferred within the ERP system. Although, the hours spent on the orders are transferred to the assembly group conducting the manufacturing. This discrepancy is described to impact the statistical analysis of production output across different assembly groups.

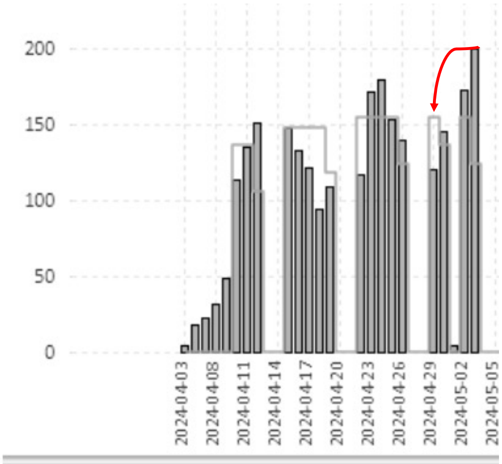

Figure 4.8. Example of balancing between days for the medium assembly group. Extracted from QlikView 2024-04-10.

As previously mentioned, the product mix plays an important role in maintaining a smooth production flow. However, the complexity is described to arise from the unrestricted ability to customize products, making it challenging to understand the impact of customizations on production time accurately. All current schedulers within Alfa Laval have prior experience working in production, and it is explained as a strength when it comes to determining the product mix and understanding the different customizations, especially since there are no set prioritization rules or policies to facilitate this otherwise.

Furthermore, manual tools are utilized for order scheduling, such as a step ladder in Excel functioning as a Gantt chart. This method is employed for some assembly groups but not all. Although this method is time-consuming, it is considered essential for order planning. Additionally, adjustments are sometimes made to the time between the due date and delivery date to expedite scheduling, requiring alterations to certain parameters.

The primary challenges encountered during this phase are explained to revolve around material issues, the complexities of ETO orders, and the flexibility afforded to customers in altering their orders. Material-related problems encompass incorrect requirements, not the right quality, and delayed deliveries. The complexity of ETO orders is described to pose challenges due to errors in drawings, discrepancies in purchased materials, and mishaps in the manufacturing process. Furthermore, customers' flexibility in modifying orders extends to the point of shipment, allowing changes to be made even after production has started.

4.4.3 Follow up on material

An order handler checks the status of the required material of an order two weeks prior to the preliminary start date. If there is a problem, such as material has not arrived at the factory or the delivery is delayed, there are primary two actions to be taken. If the problem is not urgent, they convey it to the purchasing department which then follows it up and solve the issue. If it is urgent, the problems are escalated to a daily meeting with management where immediate issues are notified and solved.

4.4.4 Execution in production

At Alfa Laval there is a described difference between product mix and sequencing. The aim of sequencing and ensuring a production mix is to optimize the flow in production. This includes ensuring that the production rate is maintained, and that the workforce is evenly distributed throughout the day and week. The sequencing and product mix is done based on due date, as well as the complexity of the products. That means that orders with time consuming customizations is balance with simpler orders to obtain an efficient flow. It is possible for orders to have their start dates adjusted, as long as the due date can still be met. Worth noting is that the due date and delivery due date to the customer are not always the same; there is often a gap between them. This is to ensure the orders are finished when the delivery due date is, and the scheduler determined what due date to set. The product mix provided by the scheduler is matched with the workforce to determine the sequence of orders that will be produced. The team leaders of the medium assembly group are then responsible for sequencing orders. The team leaders only sequence orders with the aim at managing the due date. The expertise of the workforce is carefully assessed since orders can have customizations that require special knowledge. However, conflicting information describe the sequencing not to be based on the product mix in a large extent since it might not always work to manufacture due to them being time-consuming. It is described that the team leaders can change the product mix and thus also the sequencing. This is done within a varying time frame.

To initiate an order, the availability of physical space and planned time in production is verified. Since it is the team leader who handles dispatching, sequencing, and reporting, there is no formal reporting back at this stage. Control of the material is also conducted through the ERP system, where orders are assigned a status based on the availability of materials in stock, if it is in transit, or in case of shortages. The control of the balance is described to be done towards inventory on hand. The inventory levels displayed in the ERP system do not consider scheduled receipts. Once an order reaches the highest status, the staging process can be completed, and the material requisitioned. This is described to happen in different time intervals depending on which assembly flow it is, but with the aim to do it with an even rate. In general, there is a desire to call for materials a few days before an order is scheduled to be assembled, as this allows for gasketing and flexibility in the mix distribution between days. The pursuit of achieving a lean flow contradicts this, and therefore materials are called for as close to the point of use as possible. In practice, this provides, for example, the CTO flow with materials for two to three days ahead of assembly. Orders are at this staged accompanied by a of shop packed. The shop packet is transformed throughout the production process and relays for example materials and tools needed. The shop packet is in paper form.

After the material is requisitioned, warehouse personnel have approximately three hours to collect the material and deliver it to the designated location for staging. Here the material is stored till production is initiated. It is described that a designated individual known as a water spider ensures the accurate delivery of the correct quantity and quality of material, confirming its condition is neither damaged nor incorrect. It is during this phase that potential errors are typically detected. If the material is order unique, reordering may be necessary. Furthermore, there may be instances where the material is stored in a separate warehouse, causing delays of up to two days in initiating the order. The majority of material-related issues tend to be associated with ETO orders due to their unique requirements and features. There are instances where the material is not ready even though production is scheduled to begin, leading to planning issues. According to interviews, in such cases, orders need to be replanned. This requires coordination between the planner and production but also the order handler which has the final decision to move the order. This process can be time-consuming, as it involves assessing material shortages, meeting customer demands for affected orders, and maintaining production efficiency. Some material issues are described as being resolved through sequencing adjustments and reordering by the team leader.

If there are no issues with the materials, the order is initiated in production. The production process involves two main stages: gasketing and assembly. Typically, gasketing precedes assembly, with the gasketed plates produced and stored to then be assembled into the apparatus. However, there are instances where gasketing and assembly occur simultaneously, and the gasket plates are installed directly from the gasketing station to the apparatus. Additionally, when gasketing capacity is exceeded in one group, it can be carried out by another production group. Reporting is conducted in the ERP system for both gasketing and assembly, although sub-operations within these stages are not separately tracked. Any production issues are verbally communicated to the relevant parties for resolution

5. ANALYSIS

The structure of this chapter can be seen in Figure 5.1. First the deepened problem formulation will be described. Then, an analysis of the products produced will be carried out, followed by an analysis of the production process, all in the sub-chapter 5.2 Factors influencing planning. Thereafter, three sub-chapter named 5.3 Master Schedule, 5.4 Material and capacity plan, and 5.5 Production activity control will follow. In these sub-chapters differences and similarities between Alfa Laval and theories will be discussed. Additionally, the issues and possible improvements will be discussed in these sub-chapters.

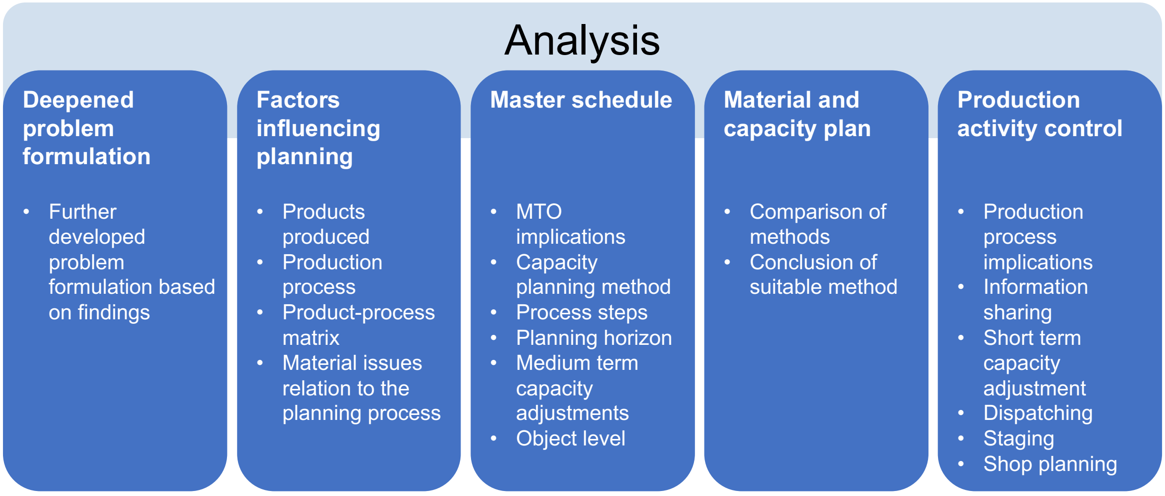

Figure 5.1. The structure of this chapter 5. Analysis.

5.1 Deepened problem formulation

The empirical findings show that it exists processes and methods for planning the production at Alfa Laval at mainly two horizons. These horizons were described as spanning one to two weeks and three to 15 months respectively. Compared to theories, these horizons can refer to PAC and master scheduling. However, there is a gap between these horizons. When asked about the existence of a material plan, interviewees stated that it does not exist. Some interviewees referred to the ERP system but could not explain how it was involved in the planning of materials. The response was similar when asked about a capacity plan. They then referred to the capacity forecast and the process of allocating personnel between departments, which neither is an actual plan. A conclusion is that material and capacity planning at the company is not conducted and is therefore missing. The theoretical framework illustrated in Figure 3.2 describe different planning levels and the interaction between them. The mapping of the company production planning process in this framework is seen in Figure 5.2.

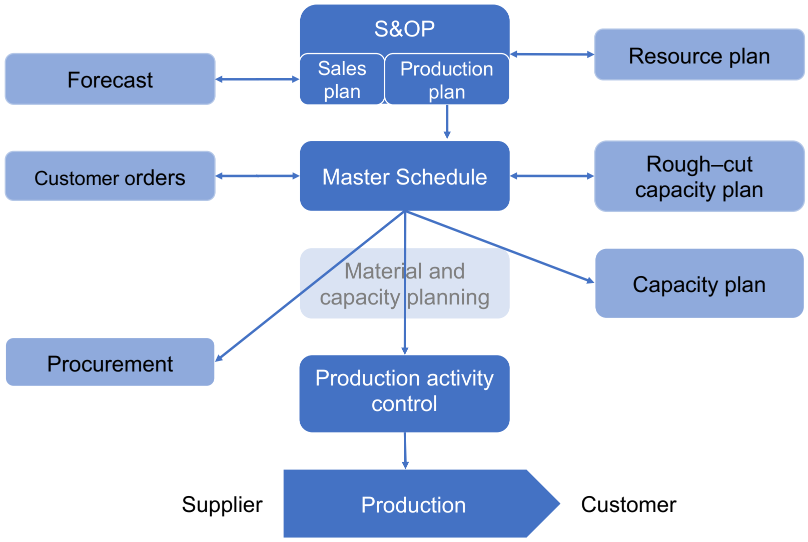

Figure 5.2. The production planning process at Alfa Laval.

The difference between the original framework and the one found in Figure 5.2 is mainly the lack of material and capacity planning as well as the interaction of capacity plan and procurement with the other planning levels. According to theory, the interaction of procurement to the planning process should be with the material plan but at Alfa Laval this interaction occurs with the Master Schedule in the shape of the material forecast. The capacity plan should be generated through the material plan. Although, at the company the only thing that could be seen as a capacity plan is the capacity forecast, even though it is not an actual. The lack of a material and capacity plans results in the analysis in this thesis regarding this area will focus on presenting alternatives and what the pre-requisites of these alternatives are. In contrast, at the levels of master scheduling and PAC, established frameworks together with empirical findings will facilitate the mapping of these processes. The objective is to assess these processes and methods, and where necessary, propose improvements. Moreover, the empirical study provided limited insights into the order unique material flow, and the current forecasting procedures on a Master Schedule primarily focus on stocked items. Consequently, this analysis primarily concentrates on stocked items.

The aim of the thesis was to identify the root causes of the experienced issues. However, due to the absence of a material and capacity plan, this proved challenging. The connection between the levels was deemed difficult to analyze. Another complicating factor was the constraints and time limitations. As a result, there were no time to ensure that it was the root causes that were found. Therefore, the focus moving forward was to identify issues and potential causes instead.

5.2 Factors influencing planning

In this sub-chapter, products manufactured will be analyzed, followed by an examination of the production process in which they are manufactured, aiming to characterize it within the product-process matrix. Subsequently, material issues will be discussed and analyzed.

5.2.1 Products produced

All products produced at the company include several articles and therefore, is it of interest to analyze the connection between the product types and articles. To better understand how the total number of articles within the company interact with the products produced, an approximate material profile for the medium assembly was created, see Figure 5.3, based on the different material profiles illustrated in Figure 3.4. The different points of the material profile could be defined differently, but the authors of the thesis argue that the importance is to illustrate the relation between the different stages and highlight an overall shape. Therefore, the end products were chosen as the number of product types produced in the medium assembly group, which are nine different types. In this thesis, semi-finished goods correspond to modules and the number of modules in total for the nine product types are 133. Regarding the number of articles, only the total stocked number of articles at the factory could be extracted from the collected data, not the number of articles for the medium assembly group. Additionally, there is no data on how large percent of the articles are ordered unique, and therefore these could not be included either. Although, since the aim of the material profile is to define the shape, the exact number of articles is not needed, it is just an indication. The total stocked number of articles in the factory was 2475 in March 2024. An assumption is made that the total number of articles in the medium product types is bigger than the number of semi-finished goods, i.e. the number of modules. The assumption is made considering order unique material being a large part of the ETO orders, and the number of stocked articles. Figure 5.3 illustrates the material profile of the medium assembly group, based on the number of product types, modules, and articles.

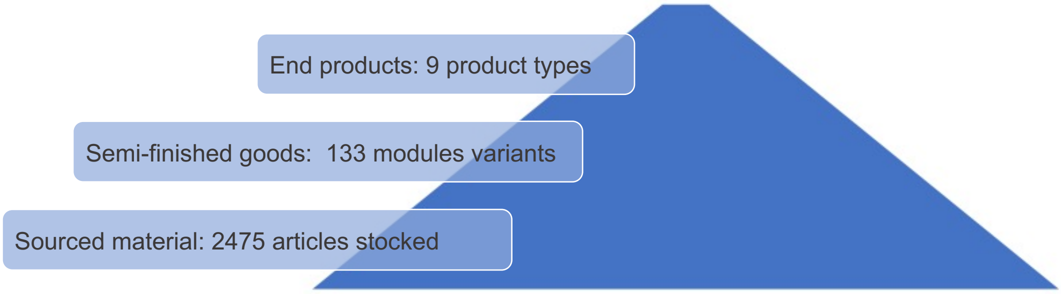

Figure 5.3. The approximate material profile for the medium assembly group.

Figure 5.3 illustrates a material profile shaped like an A-profile. Despite uncertainties, the shape distinctly represents a converging flow. It is evident that the waist of the profile is situated at the endpoint for the medium assembly group. According to theory, this should be the object of focus in all planning stages, including forecasting, i.e. product types. It is worth noting that the A-profile is common in MTS contexts. The reason for why the profile is A-shaped even though the production is an MTO may be a result of the end-products being defined as the product types and not the number of different products produced. Since Alfa Laval offers endless of possibilities for customizations, the possible number of end-products could be seen as endless as well. But if this were the definition, the number of modules and articles would be endless as well, making it impossible to create a material profile. Therefore, this shape is considered by the authors to be the best represented view of the current situation at Alfa Laval.

Additionally, it is essential to comprehend the characteristics and distribution of products within the assembly flow. When analyzing Figure 4.3, it is evident that in the medium assembly group, certain product types are dominant. Specifically, the T15 and TL10 alone account for approximately 66% of the product types produced in the medium flow. Despite the significant customization potential of these product types, their dominance remains clear. Additionally, interviews indicate that within these product types, a primary obstacle in planning is related to the number of plates, suggesting a specific module within these product types is worth further investigation. However, together with Figure 4.4, it becomes apparent that various product types are associated with different production flows. From a CTO perspective, variants T15 and TL10 are still dominate, while for the ETO flow, T20 and T21 emerge as the majority.

In summary, there are a few product types produced that account for a large share in the flows. Despite that the product types can have endless configurations, it should enable focuses on certain product types for further investigation. However, the materials causing the most difficulties for the CTO flow are the number plates which further highlight the plate modules as extra interesting in further work.

5.2.2 Production process

During the empirical study, the production process was described as a flow. Throughout the observation it was clear that the physical factory layout is adapted based on the production process, which is in line with a flow shop process. This is further supported by the that that in contrast to a job shop, the observed production process does not allow for routing in multiple direction. However, there were some differences in production processes observed between the ETO flow and the CTO production flow in terms of rate. The CTO flow is described as rate-based flow where each production step has an allocated time, and the ETO flow was described to not have a rate-based flow. A rate-based flow indicates a flow shop. Additionally, company representatives describe the production process as a flow shop. Therefore, the production process has the most common traits with a flow shop configuration.

Furthermore, upon analyzing the flows in relation to the products produced in the flows, as depicted in Table 4.1, it becomes apparent that there is a difference between the intended products for the flows and the actual products that are processed within them. This observation is significant as it deviates from an optimal production perspective that could have significant negative economic implications. The discrepancy is described to be a result of significant transferring of orders between departments. This will further be discussed in 5.3.5 Medium-term capacity adjustments and 5.5.3 Short-term capacity adjustment

5.2.3 Product-process matrix

The product-process matrix is typically employed to determine the optimal production process. However, in this case, the authors of this thesis have utilized it as a means to illustrate the current state of the company's production processes. After the previous analysis, it is clear that there are differences in both production processes and products between the CTO and ETO flows. This necessitates separating the flows in the product-process matrix, which has been duly noted. Hence, the differences will be explained more thoroughly, which in turn will provide a further explanation.

The flow shop configurations of both assembly flows indicated a middle position on the y-axis of the product process matrix. However, the flows have somewhat different focus, where CTO flows is argued to be more of a continuous flow due to the rate-based process, whereas the ETO flow does not have this. Based on the planning object, one can draw conclusions that only a few product types are manufactured in the medium flows. Nonetheless, when it comes to overall placement in the matrix with regards to the products, the authors argue that one should consider all products produced. This results in still having a small number of product types, but due to module customization, the volume of products becomes low. This indicates that both flows are positioned towards the left in the product-process matrix. Furthermore, it can be argued that there is a difference in standardization between the flows. The ETO flow tends to be more one-of-a-kind, while the CTO flow's products can be characterized as multiple products with low volume. Therefore, there is a distinction between the two flows.

In summary, there are differences between the flows that indicate a need for differentiation in the product-process matrix, and this has consequently been carried out, see Figure 5.4. The position of the respective flows signifies a general position of the entire line, highlighted with the M in the figure.

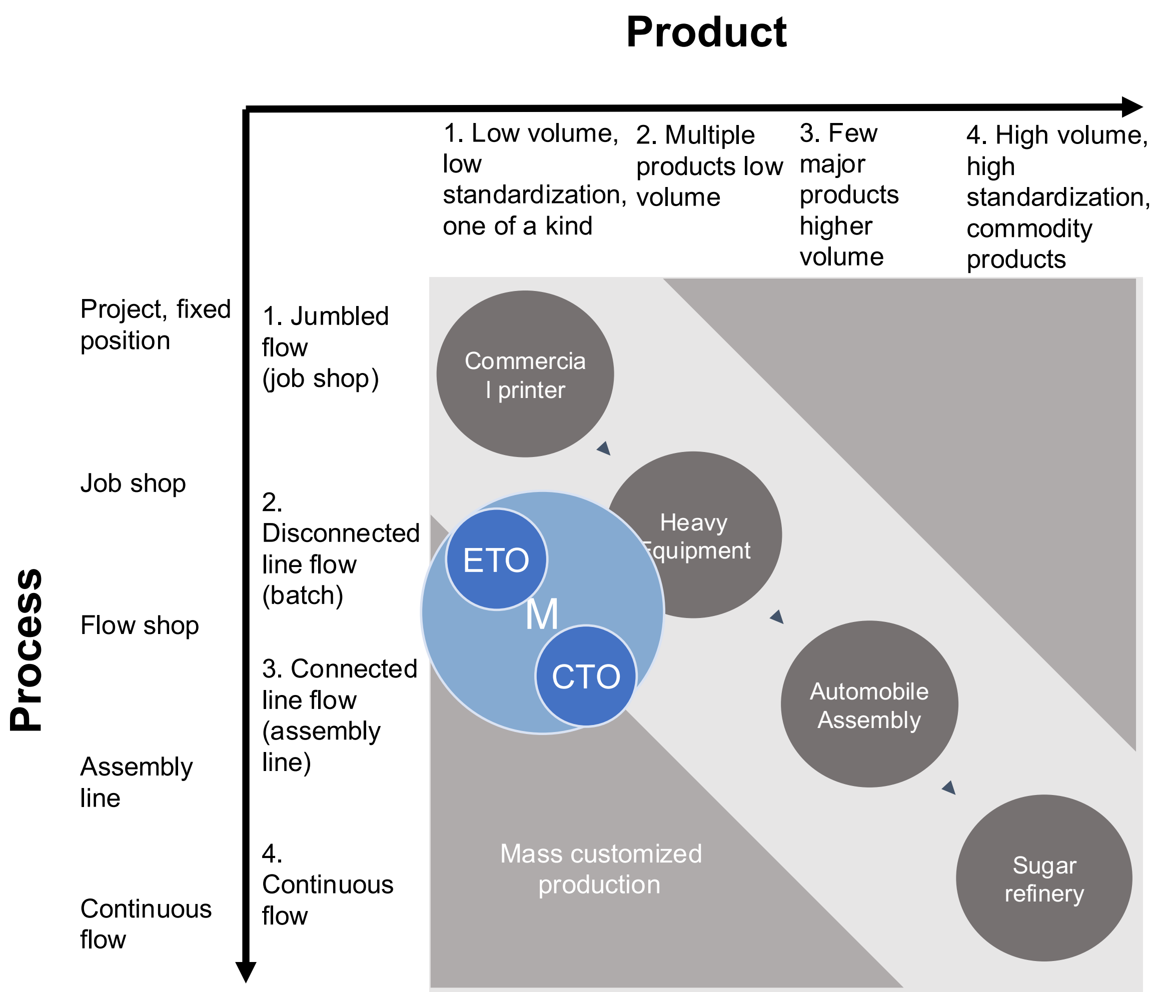

Figure 5.4. Product-process matrix for the medium assembly group and respectively ETO and CTO flow.

Based on the preceding analysis, it is evident that significant disparities exist in both the production processes and the products between the two assembly flows. As a result, it becomes imperative to segregate these flows within the product-process matrix, as done in the matrix. This segregation will facilitate a deeper exploration of the disparities, thereby offering a more comprehensive understanding. As seen in the figure, the medium assembly group is characterized by a flow-oriented process with low volume products. Significantly the analysis highlights key difference in between the flows. In turn, this could suggest that there would be beneficial to plan the flows differently. Further mapping of other flows and assembly groups could further highlight differences and similarities that effect production planning.

Additionally, significant similarities with mass customized production can be made. Based on Figure 5.4, it is evident that both flows are right on the brink of this strategy. Further, it entails a fundamentally different perspective on production operations. It can be argued that significant gains can be made by adopting this strategy, but it also has profound implications for the production process and specifically the planning process. However, this strategy and its implications are deemed outside the scope of this thesis.

5.2.4 Material issues relation to the planning process

During the empirical studies, numerous material issues were identified within the two assembly flows. These will therefore be discussed to assess the planning process' potential to impact them.

The material problems described during the empirical study mostly regard the ETO assembly flow and the main issues can be related to wrong quality, wrong specifications, many locations of storing, and that the material is not ready in time. Wrong quality is described as a large problem. It could be a result of wrong information to the supplier, damaged material, not upholding standards, and insufficient drawings, thus not directly influenced by planning. However, the root causes could be several but are unknown to the authors. Wrong specifications are described to be a recurring problem assumed to be caused by incorrect customer specifications in drawings, faulty drawings, and inadequate following of drawings. This is also not considered directly influenced by planning since the process is done in customer contact with sales companies. Further, material whereabouts are becoming an increasing issue, as described by interviewees. Materials are stored in several warehouses both onsite and offsite. This is described to causing an additional delay before deliveries to the production units but not considered in the original plans. In addition, the material issues are worsened by the fact that materials are often ordered uniquely causing longer lead times to fix the issues. These issues relate to the departments such as operations purchasing but are not directly affected by planning. Therefore, these issues originated not from the material plan but from other reasons. Thus, these issues might not be directly solved with a material plan, but it is assumed to increase the control and knowledge of materials. However, the authors contend that the delay in materials readiness may be attributed to inadequate planning, indicating a deficiency in material planning. It is argued that a part of the issues concerning delays stems from insufficient follow-up and material procurement, which in turn are governed by material planning. These issues could potentially be alleviated through the establishment of a more robust material plan.

The material issues outlined for the CTO flow are primarily described to be a result of incorrect quantities of materials. Interviewees suggest that this can be easily addressed through effective communication with the warehousing department and internal suppliers. In combination with the fact that CTO material is often stocked makes these issues relatively easily resolved. Therefore, the problems are deemed to be relatively minor compared to the ETO flow. Further, this could imply that either the forecasts for articles are largely accurate or that there are substantial safety stock levels, ensuring that materials rarely have shortages.

In summary, the expressed material issues addressed are to a large extent argued not to be directly affected by the planning process. Although, some issues can indirectly be affected by the planning process.

5.3 Master Schedule

The concept of master scheduling, as described in theory, is to some extent implemented at Alfa Laval. The main focus at the company regarding this level is on forecasting material and capacity. The main reasons that these activities are argued to belong in this section is due to the time horizon, the activities are carried out by the master scheduler, and the activity being forecasting. First the implication of an MTO strategy will be discussed, followed by capacity planning method, before discussing the forecasting steps and methods conducted compared to theory. Lastly, the horizon, medium-term capacity adjustments and object level will be evaluated.

5.3.1 MTO implications

Theory describes that in cases where final product assemblies involve significant customizations, it is recommended to assemble the product based on actual customer orders rather than relying on forecasts. This is due to the difficulty in accurately forecasting customization needs in an MTO context. Empirical data and analysis of the company's product range shows a high level of flexibility and customization options. This presents challenges in predicting which versions of the products will be produced, as the possibilities are endless. When combined with the MTO strategy, the forecasts conducted at the company will always include a level of uncertainty. Ultimately, with the company's high level of customization and the MTO strategy, there is a need to use actual customer orders in the master scheduling planning process to ensure accurate and efficient production or accept the inaccuracy.

5.3.2 Capacity planning method

There is no explicit capacity planning method at Alfa Laval, even though much time and resources are used to address and adjust capacity. In order to identify which theoretical method the company uses for this purpose, Table 3.1 and the independent variables were used in combination with empirical finding to map the current situation. The primary planning object capacity planning is the production plan from the S&OP process, thus excluding capacity requirement planning as the method employed. The object scope is based on the product type, i.e. individual article. Additionally, the primary planning level is the master scheduling level since it is at this level the forecast is conducted. Further, there is no consideration of inventory or lead time. This excludes capacity requirement profile as method. Moreover, it is described that the capacity planning is done both for the entire factory as well as for each assembly group, i.e. department. When mapping the capacity planning method done at the company, it is shown that they either use production units, capacity planning factors, or load profiles, see Table 5.1.

Table 5.1. The mapping of capacity planning method at Alfa Laval. Those marked in blue represents methods that corresponds with the situation at Alfa Laval.

Methods according to literature

Independent variable

	At Alfa Laval	Production units	Capacity planning factors	Load profile	Capacity requirement profiles	Capacity requirements planning
Primary planning objects	Production plan	**Production plan**	**Production plan**	**Production plan** Customer order	**Production plan** Customer order	Manufacturing order
Object scope	Individual article	**Individual article** Article group Article structure	**Individual article** Article group Article structure	**Individual article** Article group Article structure	**Individual article** Article structure	**Individual article**
Regards inventory	No	**No**	**No**	**No**	**No**	Yes
Regards lead time	No	**No**	**No**	**No**	Both lead time offset and distribution	Both lead time offset and distribution
Primary planning level	Master Schedule	S&OP **Master Schedule**	S&OP **Master Schedule**	S&OP **Master Schedule**	S&OP **Master Schedule**	Material planning Production activity control
Capacity grouping	Entire company and department	**Entire company**	**Department** Foreman	**Department** Foreman	**Entire company** Individual production group/machine	Individual production group/machine

As viewed in this analysis, the method conducted at the company is inconclusive. This will further be evaluated in the coming section.

5.3.3 Process steps

To analyze the process in which the Master Schedule is created the process was compared to theory. Hence the Master Schedule process conducted at the company was compared to the process steps described in theory found in 3.2.1 Process and steps. The first step is *Forecast future demand based on S&OP* and will be analyzed in it is entirety. The second step *Create a preliminary delivery plan using the forecast and backlog data* and the third step *Develop a preliminary production plan using the preliminary delivery plan and considering current and desired inventory levels and order sizes* will be discussed jointly. Step four *Reconciliation of the developed plans* and the last step *Finalize the developed plan*s will also be discussed jointly.

Step 1

The following analysis was supported both by the sections 3.2.1 Process and steps, as well as 3.1.1 MTO context and implications. There are two main forecasts created with different methods at the company, one for capacity and one for materials.

As for the capacity forecast, the object is man-hours which is based on product types. One of the inputs variables in the forecasting process is the reference hours for specific product types. These are average values and therefore the dimensioning is argued to be on a mean demand dimensioning. Given the complexity of the products manufactured, the accuracy of reference hours is limited. An additional complicating factor is the reporting issues. Moreover, the foundation of reference hours, and consequently the capacity forecast, is anchored in mean values. One empirical finding was that the capacity forecast is used to predict the capacity requirements for upcoming month to adjust the capacity, resulting in maximized capacity utilization. This aim to maximize capacity utilization in combination with the averaged values used as foundation of the forecast results in a natural disparity between actual and forecasted capacity requirements. This disparity is a key point emphasized by the authors of this thesis, as it is not currently addressed. The forecast is being utilized incorrect as it is suited to forecast further away. Additionally, the MTO implications make it impractical to expect a high degree of accuracy.

The forecast of materials is not based on the S&OP data but rather on the historical usage of materials. To make the material forecast based on historical data instead of the forecast created at the S&OP level indicates that the latter is considered uncertain. The material forecasting object level is articles and is solely done on stocked articles. There is a difference between the forecasting method used and those described in literature. At the company, an Excel file is utilized for material forecasting at the company, and different articles are forecasted with methods as moving average, exponential smoothing, or a method Alfa Laval call the *Ö-vägen method*. Although, there is little information available about how the decision of which methods to use for which articles. Company representatives aim to change this file and apply the same forecasting method to all articles. They view the moving average method as trend-sensitive and therefore applicable to all articles. However, the authors of this thesis argue against this based on the literature review. The findings indicate that the method is not trend-sensitive, but rather it mitigates the impacts of trends. In addition, the method is considered poor for the short and medium term. Further, all articles might not be suited to have the same demand model due to different demands, suggesting different forecasting methods for different articles. Additionally, the method *Ö-vägen method* needs to be questioned and examined carefully. Ultimately, the main forecasting tool used needs to be further analyzed as well as adequate methods used in order to find the optimal solution. The authors argue that the way forward is not to use own method but to use various well-known methods. To enable this process, a great way to start would be to understand the different demand models and find a decomposition model that is suited to the company, either a multiplicative model or an additive model. The understating of the five fundamental components is essential to understand the complexity of demand patterns at the company. There was no mention of this currently being done.

When comparing the forecasts of material and capacity it become apparent that they use different approaches to forecasting. The material forecast is based on historical use and the capacity one uses the S&OP forecast as basis. The authors argue that this difference creates a disparity in the materials sourced compared to the capacity. Despite a possible increase in the accuracy of both forecasts, the disparity will remain. Therefore, the authors consider it inevitable not to adjust one of the approaches resulting in the foundations being the same for both forecasts. Given the circumstances of the factory within the network of production facilities Alfa Laval operates, the authors argues that the S&OP process is viewed as a significant strategic ongoing initiative across the network. Therefore, the possibility of changing the foundation of the materials forecast is greater, compared to the capacity forecast. To enable this, the transition from product types to materials needs must be clarified, which is not possible today due to the lack of a material plan. This forms the cornerstone of material and capacity planning, highlighting the need for its implementation.

Step 2 and 3

Number two and three of the process steps include the delivery schedule and production plan. Based on the empirical study, no explicit mentioning of a production plan or delivery schedule in line with theory was made. Therefore, it was concluded that these processes as theory describes it, is not conducted at the company. That results in no consideration of the backlog of customer order is taken at the Master Schedule level. The delivery schedule and production plan would have impact if a material and capacity plan existed. For example, in cases where the production plan, and material and capacity plan exist, materials would be able to be sourced based on forecasts considering customer orders, not historical use. However, this is not the case at the company today. Since the capacity and material plan is does not exist, this improvement of the process is currently difficult.

The method for the third step, which is creating a production plan, describe one important factor to be capacity planning due to the uncertainty an MTO strategy result in. As mentioned in the previous section 5.3.2 Capacity planning method, the mapping was inconclusive. However, the three possible methods the company utilizes were production units, capacity planning factors, or load profiles. The literature describing the third step argues that the appropriate methods to use as capacity planning method in an MTO context are capacity requirement profile or load profiles. Therefore, it would benefit the company to use a load profile since they already use important parameters in agreement with the method and it suits their strategy. Although, further investigations are required to fully support the suitability. An appropriate method for planning capacity will facilitate the decisions and planning of capacity. Additionally, it is an important factor during the development of the production plan at the master scheduling level. Conducting this plan as well as a delivery schedule, the authors believe will facilitate the overall planning process and be a good option to divide the workload more evenly between the planning phases. However, to ensure the appropriate capacity planning method will be chosen, there will need to be further investigations.

As foundation for delivery schedule and production plan, the initial planning of orders done by the order handlers could be utilize since it is done at the correct horizon. Due to the delivery schedule and production plan should be on an aggravated level, it means that the change between orders day to day would not have a great impact of the plans. The fixed lead time might also improve the accuracy of these plans as it will confirm orders earlier than currently done.

Step 4 and 5
As for the reconciliation and finalizing of the developed forecasts, it is done at the monthly meetings called local supply review meeting. At these meetings the handoff is done as well as follow ups and discussion of the new forecasts. It was described that the accuracy of the forecast should be within a 20 % limit. This margin was not based on any specific rationale. Additionally, the follow up of the forecasts is done by comparing them to the actual outcome. Currently, the actual values are examined, and it is investigated if they align with the forecast. In line with the theoretical framework, which examines models for errors and control of forecasts, a method should be employed to assess the accuracy of actual values. It should also compare them to forecasted outcomes, especially when using automated forecasting techniques. This process would be suitable to conduct in Excel. Further, this method should automatically analyze the difference between the forecast and actual values and determine if it falls within acceptable margins. Contrary to findings, theory describe how acceptable margins should be based on the desired confidence interval and factors. These factors may vary depending on the importance of different groups of articles and products. If the actual values fall within the acceptable range, they should be included in the forecast calculations. If they do not meet the criteria, the values should be excluded from the calculations. This approach enhances the accuracy of forecasts as more data is collected and parameters are refined. Although this process is not currently utilized at Alfa Laval, it can be effectively applied to monitor the capacity and

material forecasts. As mentioned previously in this report, a significant part of the capacity forecast is conducted by other departments such as S&OP and Finance, making it challenging to impact these forecasts solely through the master scheduling level. The material forecast on the other hand, where forecast calculations are made and historical data is gathered at this level, it is a suitable fit to apply this method. Therefore, integrating these calculations into the process for control of errors and determining the appropriate confidence intervals and factors is crucial for improving forecast accuracy. An additional recommendation for enhancing the forecast is to prioritize improving the forecast accuracy for the product types that have the greatest impact. Analysis of the produced products, see section 5.2 Products produced, reveals that two product types produced in the medium flow correspond to 66 % of all product types produced which suggest that these would have significant impact of the forecast if they were to be improved. This improvement can be applied to both material and capacity forecasts.

The utilization of the forecasts differs. The material forecast is used by the purchasing department to be able to purchases material while the capacity forecast is used to plan the available capacity. The expectation of the capacity forecast is for it to be as accurate as possible to be able to utilize the available capacity during the manufacturing process. Ultimately, due to the nature of forecasts, it will never be completely accurate.

5.3.4 Planning horizon

Theory describes how various products necessitate distinct planning horizons. Complex products may require longer horizons spanning several months, whereas those with shorter lead times may need just a few weeks. However, at the company there were several different horizons found. Interviews reveal a horizon ranging from three to 15 months, but occasionally documented as three to 12 months. Furthermore, empirical evidence indicates that forecasts are employed to adjust capacity needs within a timeframe of less than one month. This was evident is the use of for example Figure 4.6. Ultimately, it can be argued that the actual horizon is unclear, but all identified horizons extend beyond the typical range of six months to a year, as theory suggest. Furthermore, theory suggests extending the Master Schedule scope to cover six to 15 months, necessitating a revision of the lower time limit of the horizon that the company currently utilizes. Although, the authors argue that the issue might not lies in the scope itself, but in the utilization of forecasts. Forecasts inherently involves predicting the future and should not be the sole basis for decisions. Considering arguments from the implications of the MTO strategy, considering actual customer orders at the Master Schedule level is deemed necessary. Consequently, aligning with the lower limit of the time horizon would naturally reverse the scope. Therefore, while the horizons may seem to be the core issue of the Master Schedule, the authors argue that the utilization of forecasts is the primary concern.

In contrast to theory there is no evidence of a period during which production is considered fixed at the company today; there is no demand time limit. However, there is an ongoing project to include a fixed lead time to customer. This project is assumed to influence and indirect create a demand time limit according to how the project is described. A part of the project onset is that this fixed lead time is subsequently connected to the customer order point, which is in accordance with theory. Further, in cases such as Alfa Laval, theory describes that it is important to align the fixed planning period with the final assembly timeframe. Ultimately, the fixed lead time project is in line with theory and deemed to positively influence the establishment of a demand time limit.

5.3.5 Medium-term capacity adjustments

Medium-term capacity management, which encompasses rough-cut capacity planning, is closely tied to the Master Schedule. In Table 3.2, different actions that can be done to adjust capacity at medium- and short-term horizons are listed. When comparing collected data from interviews, actions done by Alfa Laval at the medium-tern horizon were compared to this table and is illustrated in Table 5.2. The actions found at this horizon were new employment and changing the number of shifts. However, new employment is not done systematically, and it is noteworthy that while it is theoretically considered a medium-term action option, it is conducted at a short-term horizon at the company. As revealed during interviews, personnel hiring is done sometimes weekly. Changing the number of shifts at the company is done in periods of weeks at the company and is described to be utilized due to the lack of physical space in production, in line with theory.

Table 5.2. An overview of actions altering capacity at the master scheduling planning horizon. Those highlighted and bolded represents actions that corresponds with the situation at Alfa Laval.

Horizon

Type of alternative	At Alfa Laval	Medium term
Increase/decrease capacity	New employment Number of shifts Sub-contracting	**New employment/ Temporary layoff** New machines **Number of shifts/short-term week** **Sub-contracting**
Increase/decrease capacity requirements		Change production plans Increase/decrease inventory
Reallocate capacity		Transfer between departments
Adapt capacity		
Reallocate capacity requirements		Seasonal storage Change delivery cycle

Since no other actions are done at the medium term to adjust capacity, it could be a reason for why the company is experiences issues during planning and why it is time-consuming, especially in the process of reallocating personnel. Therefore, an analysis of the presented action alternatives is hence carried out.

Not all actions mentioned in Table 5.2 are suitable for Alfa Laval. For example, new machines would not improve capacity since the factory is not process-driven and is described to not have bottlenecks in production related to machines. Additionally, adjusting capacity requirements by changing production plans or adjusting inventory would not be suitable alternatives. Production plans at the master scheduling level is currently not something that Alfa Laval conducts but even if they did, changing them at this level would not have significant impact due to the production being controlled and planned based on confirmed orders. If production plans were to be change at this level, it would therefore not have an impact. Adjusting inventory levels is not suitable for the company due to no pre-manufacturing being able to be done as a result of the MTO strategy. For the same reason, seasonal storage is not required to reallocate capacity requirements. Another implication of MTO is that delivery cycles is agreed with the customer. Therefore, this cannot be changed either.

Focusing on the actions possible for the company to implement are the actions new employment, increasing or decreasing the number of shifts or utilize short term weeks, as well as transferring capacity between departments. The new employment is according to theory a medium-term capacity adjustment, even though Alfa Laval uses it on a short-term horizon. There would be both benefits and disadvantages to hiring new personnel in the medium term as well. Doing so could provide more time to assess and recruit qualified personnel, as well as train and educate them. Additionally, it could facilitate planning by offering greater visibility of available personnel at an earlier stage. Addressing capacity in an additional time horizon compared to the current situation could streamline the time-consuming meetings currently taking place. However, potential risks are evident if the gap that the new hire is intended for is not fulfilled. This could result in having excess capacity. Similarly, the same arguments apply to adjusting capacity to meet lower demand. If the forecast predicts a lower demand than the actual outcome, it could result in the available capacity not being enough, causing issues for the production.

During the empirical study, there was some evidence of sub-contracting activities. Assumingly, due to the complexity of the assembly process, the main activity sub-contracted was gasketing. Moving forward, sub-contracting in the medium term can be seen as beneficial since it could offer more focus of the main activity of assembling. However, this is disputed by reports that disclose that gasketing done by sub-contractors does not have the same quality standards, thus generating extra work. In addition, it is viewed as difficult to predict for example gasketing hours, as previously discussed, on a medium-term horizon to the extent that it can be sub-contracted. This practice is considered less risky when dealing with actual orders. To further decide whether to use sub-contracting, the authors of this paper suggest that an economic analysis of sub-contracting should be conducted. It is considered relevant to compare costs and control between the alternatives of increasing in-house personnel with temporary workers and extra equipment versus sub-contracting.

Another possible action for Alfa Laval could be transferring capacity between departments. Several benefits but also disadvantages can be seen with this action. On one hand, transferring between departments could be beneficial for the factory. With the foundation that the current forecast of the S&OP level is described as good with a higher accuracy on a factory level, it suggests that if the factory as a whole follows the forecasted capacity. Therefore, it can be argued that the factory could manage by only balancing between departments is the. However, there is a great divergence described where reference hours are used to transfer the S&OP forecast from units to hours. This implies that given the current situation, transferring capacity between departments in the medium horizon is a potential risk. If this process were carried out in the medium term, some of the balancing actions could take place earlier rather than later. Anticipated higher demands in one production group could be shifted to a production group with a lower predicted demand at an earlier stage. This could serve as a means to balance between departments in advance. However, the numbers used in the forecasts are predictions, not confirmed orders. Therefore, there is a risk that the actual customer orders might be divided differently among the assembly groups, and thereby the capacity requirement. The authors argue that the action should be employed in cases where there is greater certainty in actual customer orders or where the accuracy of forecasts is high. The medium assembly group falls somewhere in between. Therefore, the authors argue that it is a strategic decision that needs to be addressed.

In summary, as Table 5.2 illustrates, there are limited actions to proactively adjust capacity at the medium horizon by the company today. This is believed by the authors to be a contributing factor to the issues experienced regarding planning. The capacity being primarily addressed at a later stage, close to the start of production, is time-consuming and resource intensive. To address this issue, it is recommended to initiate capacity planning at the Master Schedule horizon. Hiring new personnel is typically a medium-term action, and the analysis emphasizes the advantages of addressing it at this stage. Balancing capacity across departments could be a viable approach to reallocate resources, but the uncertain forecast makes it challenging to assess the accuracy of the outcomes. Therefore, further investigation is advised. Additionally, sub-contracting shows promising potential benefits, but the company should conduct more in-depth analysis.

5.3.6 Object level

According to theory, the object level of forecasting can vary from product type to raw material in an MTO production. Another theory state that product type is the main planning object on this time horizon. At Alfa Laval, different planning objects are used in various forecasts, such as raw materials and articles for the material forecast and product types for the capacity forecast. The analysis in the section 5.2 Factors influencing planning the material profile indicates that the planning object for the medium assembly group should be product types, not individual articles. However, there is an expressed wish within the company to further forecast production processes, especially gasketing, related to product types. As a result of this wish, the capacity forecast is translated into a forecast of gasketing hours. Throughout the literature, no support for this translation of the forecast into production processes related to product types were found. Additionally, the authors of this thesis foresee significant accuracy issues when breaking down the forecast into such small pieces. This would be a result of the forecasts related to capacity is based on forecasts and assumptions are done during the breakdowns. To be able to breakdown the S&OP forecast to gasketing, numerous assumptions will need to be made, more than for capacity required as is done today, which would result in larger inaccuracy. To facilitate this translation, there would need to be improvements in reporting and feedback, as well as an upgrade in reference hours accuracy. Although it can be made, Alfa Laval needs to consider if it is necessary even if it is inaccurate. Based on these arguments the authors argue that there will need to be consensus of what the object level should be for the forecasts and what they will be used for. Considering the different objects used today and the analyses, the object level is suggested to solely be on product types. The object level of operations such as gasketing is not recommended with this argument.

5.4 Material and capacity plan

There are currently no material or capacity plans at the factory, according to interviewees, as mentioned in the deepened problem formulation. However, it is worth noting that there exists a bill of materials for all orders in the ERP system, where manufacturing orders, modules, and articles can be accessed. This information could potentially serve as a basis for material planning, such as using MRP. Nonetheless, the specifics of how the ERP system handles material and capacity planning remain unknown to the interviewees. The ERP system is described as being used for sharing information between departments, rather than for material planning. Furthermore, there is no systematic view of how material should be planned or how it affects the other planning processes. Additionally, no one is specifically tasked with material planning responsibilities. Examples of information that remain unknown are if the system uses gross or net requirements, or if cyclic patterns are considered. The closest thing to a material plan at the company is the material forecast. However, this is not based on customer order which makes unsuitable to use as a material plan. The forecast, as described previously, is used by the operational purchasers. They get an indication from the ERP system when to purchase stocked material based on inventory and safety stock levels, which are based on the material forecast. How order unique material are purchased is unknown to the authors of this thesis.

Moreover, there is currently a lack of alignment between material and capacity, a connection that theory suggests should exist. Either capacity should be planned based on the material plan, or vice versa. Currently, the company lacks a capacity plan; instead, there is only a capacity forecast followed by discussions on personnel allocation for the upcoming week. Additionally, the primary focus of production planning at the company revolves around capacity in terms of man-hours. The forecast is done in terms of hours in production, and the weekly Thursday meetings, as well as the monthly local supply review meetings, discusses how capacity should be allocated and the follow up of the utilization of the available capacity. It is the authors understanding that capacity planning is more important in a process industry were machines and production processes are bottlenecks which therefore needs to be planned for to optimized production efficiency. At Alfa Laval, the capacity is measured in man-hours which is not a bottleneck since it can be adjusted. Therefore, the authors question why only man-hours are used as performance measurement since it is a misleading capacity performance measurement for the company.

The issues the company experiences regarding material could be symptoms of lacking a material plan. Implementing a material plan would bridge the gap between master scheduling and PAC, thus enhancing the overall planning process, which the authors believe would facilitate planning and reduce the number and size of the problems experienced. In the chapter 3.3 Material and capacity plan, three alternatives for material and capacity planning methods are described. In the coming sub-chapter, these will be analyzed and the features that are needed for implementation will be analyzed based on the characteristics of the production of Alfa Laval.

5.4.1 Comparison of methods

This thesis describes the planning methods MRP, cyclic production, and OPT as possible material and capacity planning methods. There are multiple methods, and these are just a few alternatives that could be considered.

The methods chosen to investigate address different characteristics which are summarized and compared in Table 3.4. Important characteristics that the methods differ on is if they regard bill of materials, if the demand is rate-based or discrete, and if the order quantity and time between orders is fixed or variable. Moreover, there is a difference between starting with either a material plan, which is then utilized to create a capacity plan, or vice versa. It is therefore crucial to address these differences and establish a consensus understanding of these characteristics before determining the preferred method to follow.

MRP and OPT can be utilized at the company due to the existence of bill of materials. Although, it does not exclude cyclic production. The demand of product types produced in the medium assembly group has not been described as either rate-based or discrete. Therefore, further investigation is needed to determine if the demand is rate-based or not. Based on empirical findings, the order quantity does not need to be fixed which makes all three methods possible.

In addition, the time between orders in the ETO flow is variable, while the CTO flow follows the rate of 70 minutes to the best of their ability. As describe by the interviewees, the CTO flow is sometimes disturbed by ETO orders that has been moved. The difference in rate highlights the complexity of finding an optimal planning method to suit both flows. If a rate-based planning method were to be implemented for the CTO flow, there cannot be any continuous disturbances of the flow. Moreover, the authors of this thesis argue that this suggests the necessity for two distinct planning methods, as the ETO flow is not rate-based. This could potentially be time-consuming and impose different demands on the planning processes. However, one potential solution could be to introduce a period-based rate for the ETO flow. This would involve producing a certain number of products within a specified timeframe, with this cycle repeated consistently. Nevertheless, further investigation is required before implementing a cyclic production planning system. Currently, a planning method with variable time between orders appears to be more suitable.

In Table 3.5, a comparison between MRP and TOC, which is the foundation of OPT, is done that addresses other characteristics than the previous. The comparison highlights that MRP has more scheduling flexibility than OPT and that it is more suitable when the production lead time is very long. Alfa Laval can have long lead time on some orders but with the implementation of fixed lead time might result in the lead time being shorter. Additionally, the inventory levels at the company are large and the setup times are average with the use of reference hours. The main difference between these two methods is the object for resource efficiency. MRP focuses on labor and OPT on bottlenecks in production. The bottlenecks in production would be the capacity constraints integrated in the material plan as mentioned in the previous section. Alfa Laval does not describe any bottlenecks in terms of machinery in their production which suggest MRP would be better suited from this standpoint.

5.4.2 Conclusion of suitable method

An implementation of a material and capacity planning method would enable control of material, more optimal and correct handling of material and capacity, as well as enable the change from capacity focus to material. It will also establish a clear link between material and capacity. An implementation would enable the actions to adjust capacity on medium term, that was discussed in the previous chapter 5.3.5 Medium-term capacity adjustments, could be based on a capacity plan, instead of a capacity forecast which would make the basis of the decisions more accurate.

The previous analysis indicated that the most suited material and capacity planning method would be an MRP used together with a CRP. This would allow material and capacity to be planned together. However, further investigation is needed to determine this. As a basis for the decision, the characteristics of production would need to be analyzed. Given its implications for multiple stakeholders and significant investment of time and money, the authors recommend that management of the factory or higher-level authorities make the decision.

Regardless of chosen method, it is important that a material and capacity plan is implemented since there right now is a gap in the planning process. It can be argued that this is a significant root cause contributing to the planning problem at the company. Addressing this issue will be a substantial undertaking. However, the authors believe that moving forward without tackling this issue is not an option. Additionally, prior to implementation, the authors argue that it is crucial for the company to verify the presence of appropriate knowledge and information among its personnel and master data. Knowledge that is currently only known by individuals through their experience, rather than being documented, might need to be transferred into the ERP system for better accessibility.

5.5 Production activity control

As outlined in theory, the PAC process at the company marks the transition from planning to execution. This sub-chapter begins by examining the implications of the production process and points of information sharing. It then proceeds to discuss short-term capacity adjustments. Finally, the analysis of the PAC planning stages is conducted.

5.5.1 Production process implications

After the analysis of the production in the medium assembly group, it is considered a flow shop. Subsequently, according to theory, planning and ongoing work allocation take place within the group. This would mean expanded tasks and greater independence for group members. However, this is currently not the case at Alfa Laval. After the empirical study it was clear that the ongoing work allocation take place within groups, but a part of the planning is linked to other roles. The determination of the work allocation will be further be discussed during the PAC process steps evaluation.

5.5.2 Information sharing: reporting and print of shop packet

The main information-sharing system observed at the company was the ERP system. It was used as a platform to relay both statuses and reporting of operations between departments. However, the reporting in the systems has several flaws when operations are change in some way. For example, produced in a different flow or assembly group. This has been described previously as having an important impact on the reference hours. Another information sharing system is the shop packet.

Shop packet

The print of shop packet was an automatic process observed at the company. The shop packet follows an order and consists of all parts described in theory.

Reporting of orders

Order reporting was observed at various points during the empirical study which were compared to theory summarized in Figure 3.17. The shop packet conveyed information similar to what is described as order reporting in theory. The status change of orders upon material readiness aligns with material withdrawal order reporting, reflecting the longer cycle times characteristic of the company. Additionally, due date order reporting was observed, consistent with theoretical expectations. However, reporting points related to delivery and closure were beyond the scope of the thesis and therefore not considered. In summary, the order reporting processes are implemented at the company.

Reporting of operations

As further analyses show, the level of reporting and especially reporting of operations facilitates the methods that can be employed for shop planning. Some reporting of operations was done at the company, mainly the operations of gasketing and assembly in terms of hours completed. The reporting has some operations that hence will be described. Since it has an impact and facilitates the methods employed the reporting of operations will continuously be discussed.

5.5.3 Short-term capacity adjustment

Short-term capacity adjustment is closely tied to the PAC horizon, according to theory. In Table 3.2, different actions that can be done to adjust capacity at medium- and short-term horizons are listed. A comparison of the data gathered from interviews was conducted with the actions undertaken by Alfa Laval at the short-term horizon, and the results are presented in Table 5.3. All actions except extra shift and change of order quantity were found to be done in the short-term horizon.

Table 5.3. Actions done at the short-term horizon to adjust capacity. Those highlighted and bolded corresponds with the situation at Alfa Laval.

Type of alternative	Horizon: At Alfa Laval	Horizon: Short term
Increase/decrease capacity	Sub-contracting	**Sub-contracting** Extra shift
Increase/decrease capacity requirements		
Reallocate capacity	Transfer between departments	**Transfer between departments**
Adapt capacity	Overtime Put off maintenance	**Overtime** **Put off maintenance**
Reallocate capacity requirements	Advance/postpone order Alternative production groups Lap phasing/order splitting	**Advance/postpone order** Change order quantity **Alternative production groups** **Lap phasing/order splitting**

Most of the actions available in the short-term horizon were found at the company and it can be argued that simultaneously adjusting the capacity with all actions can be time-consuming. Further it can be argued that it indicates a lack of planning or adjustment of capacity in the other horizons. An analysis of the actions is hence carried out.

As disclosed in the chapter of the medium-term horizon capacity adjustments, there was some evidence of sub-contracting activities during the empirical study. The main operation found that was sub-contracted was gasketing. This action is done similar as to as theory explains it. However, there is no evidence of a structured approach to the sub-contracting activity, when it should be done and which products or product types to choose for this. A suggestion would be to develop guidelines when sub-contracting should be done.

According to theory, adding extra shifts means adding an extra shift outside the regular man hours by for example hiring new personnel. With this definition, there were no extra shifts conducted at the company. According to theory, extra shift would in Alfa Laval's situation be to change from one shift to two shifts with new employees or personnel from other production groups. With the current load of orders, there is no need for extra shifts to be implemented.

Transferring between departments are, according to theory, a suitable short-term action for reallocating capacity. There was significant empirical evidence supporting that this action was done at the company. The main outcome of the weekly planning meetings was to determine which production groups should exchange capacity in terms of employees. Theory further describes how this is only possible if the workforce is trained or for operations where the learning curve is short. The authors argue that both of these factors are present at the company today. However, the empirical findings indicate that this process is time-consuming. Therefore, the suggestion is to improve the process in which the action of transferring of personnel between departments is discussed. This could be achieved through rules or policies to streamline this process. However, that would necessitate a different perspective on capacity. Capacity would then need to be viewed as a fluctuating and changeable resource, which contradicts the current perspective. Ultimately, transferring between departments is viewed by literature as a way to increase adaptiveness. However, the consequences that transferring between departments has in an MTO contexts needs to be considered more. Ultimately, this action needs to continue within the company. Therefore, one suggestion to streamline the process is to establish clear rules and policies outlining how it should be carried out.

According to theory, overtime is a short-term action to solve the issue of the gap between capacity demand and the available capacity. With this definition in mind, it is argued that both the action mentioned as extra shifts during the evenings, as well as the extra hours that were described as a reoccurring situation in 2023, are overtime actions aimed at adapting capacity. Ultimately, this action is described to be utilized in the company. This indicates that there is an extensive gap between the capacity demand and the capacity available. Further, this argument highlights the need to adapt the capacity at an earlier stage.

Putting of maintenance is also viewed, according to theory, as a short-term action to adapt capacity. There was some evidence that this action was carried out during a meeting but not a recurring theme. The consequences were also discussed. Ultimately, this action is done to the extent that the authors of this thesis find appropriate.

In line with theory, adjusting and postponing orders are among the primary activities carried out at the company, as indicated by the interviews. Theory suggests that this is achieved by modifying start and due dates, a practice that is conducted at the company. The advancing and postposing orders between departments were discussed in the weekly meeting in similarities with the practices described in theory and visually illustrated in Figure 4.8. Further, interviewees revealed that there exists a distinct separation between the due date and the delivery due date at the company, with a safety margin between these dates. Upon analysis, the authors argue that this distinction is a prerequisite for executing this action to the extent seen at Alfa Laval today. Theory emphasizes the importance of ensuring material availability, even if the original material plans scheduled it for a later time. This is a complexity that is hard to consider today due to the lack of material and capacity planning. Consequently, the authors argue that the is an associated risk of material shortages when this action is done. To mitigate this risk, the extra buffer time between due date and delivery date is deemed reasonable by the authors. However, the empirical findings did not find any evidence of regarding any financial or economic factors in relation to the additional tied-up capital resulting from such actions, contrary to theory. Addressing this gap could serve as a potential area for improvement, enabling a more informed decision-making process regarding the advanced and postponement of orders. However, ultimately this action needs to be more carefully addressed and the risks of it taken into consideration further.

Changing of order quantity is an action linked to adjusting the relocate capacity adjustment in the short-term horizon according to theory. However, there were no indications of this practice in the empirical study. Given that it entails altering the order quantities themselves, the authors argue that this practice is not suitable for the company due to orders often only consists of one product. The change of the quantity of orders therefore falls outside the factory's scope to modify.

The practice of alternative production groups was evident both from interviews and quantitative data. Based on these findings, it appears to be one of the primary actions taken as a significant portion of products change production group and are being manufactured in other than originally planned, as Table 4.1 shows. For example, in the medium assembly group, many products originally belonging to the large assembly groups are being manufactured. Theory suggests that this action is suboptimal from a production economic perspective, as production resources may not be utilized for their intended purpose. Additionally, the authors found that the use of reference hours is linked to the reported data of product flows, but the reporting system does not consider alternative production groups, thereby greatly influencing reference hours negatively. While this action is necessary for production efficiency, several mitigating actions can be taken to help ease the negative influence it has on reference hours which is important for the forecasts. One approach is to gain a comprehensive understanding of products and provide further characterization of complex modules, beginning with those most frequently produced in the flow. Additionally, standard practices for allocating products to assembly groups need alignment with the actual flows in which they are produced, since there is currently a gap between these.

Lap phasing and order splitting are actions that were challenging to map due to the nature of operational tasks at the company. An example of lap phasing in the company's context would be when operations are carried out simultaneously, as for when gasketing of plates occurs simultaneously as assembly. Gasketed plates then directly is installed of into the raised product. A practice that could be defined as order splitting is when operations are split between assembly groups. This would be when gasketing of plates is divided between two assembly groups in order to even the load. Both of these actions are viewed as emergency measures, to be employed only when absolutely necessary. Order splitting and lap phasing align well with theory but are carefully considered and applied with caution.

To summarize, the company uses a variation of actions to adjust capacity in a short time horizon which indicated that they are responsive and flexible at this level of the planning phase. In comparison with the actions done in the medium term, shown in Table 5.2, there is a difference in terms of actions done to adjust capacity. It might be a result of the lack of capacity planning, resulting in the need for a variety of actions to be done at the short-term horizon. However, the authors consider responsiveness as a strength for the company. Although, it is important for the company to understand the consequences of the actions to decide when to use which action.

5.5.4 Dispatching

At Alfa Laval, no explicit method for dispatching was mentioned during the interviews. To analyze the current process and understand the method employed, a mapping of the situation was conducted using the theoretical framework outlined in Table 3.6. The current characteristic of dispatching is summarized in Table 5.4. The various variables pertaining to dispatching were assessed. While mapping out the dispatching process, the essence of dispatching was evaluated based on the timing of order initiation for production, in line with theoretical principles. Regarding capacity, it is evident from the interviews that available capacity is one of the most crucial factors considered before dispatching and therefore is regarded. The type of dispatching was described as sequence dispatching. The report dependency is done in line with theory but executed by the same person. There is a need to know how many orders are being manufactured in production to know if a new one can be dispatched. Therefore, the authors argue that the dispatching is reporting-based but done by one person. The material requirements are taken into consideration at the company by dispatching the order once the material receives a status representing material readiness. Although, this is not done with consideration to a material plan, but the authors argue that it is done to the best of the company's ability with the resources and systems available.

Table 5.4. The mapping of dispatching methods at the company. Methods marked in blue corresponds with the situation at Alfa Laval.

Methods according to literature

Variable	At Alfa Laval	Dispatching based on planned start dates	Regulated order dispatching	Capacity controlled dispatching
Regard to capacity	Regard to available capacity	No regard to available capacity	**Regard to available capacity**	**Regard to available capacity**
Type of dispatching	Sequence dispatching	**Sequence dispatching**	**Sequence dispatching**	Period dispatching
Reporting dependency	Reporting-based dispatching	No reporting-based dispatching	**Reporting-based dispatching**	**Reporting-based dispatching**
Regard to material requirement	Regard material requirement	**Regard material requirement**	**Regard material requirement**	No regard to material requirements

According to the mapping in Table 5.4, there is a method employed today at the company, regulated order dispatching. However, the description of the method is that it has a comprehensive system support which the authors partly agree exists at Alfa Laval. No analysis of rescheduling can be done with the system which suggests that the company uses a simpler version of regulated order dispatching. This argument is further supported by the fact that the process described also has a great resemblance with regulated order dispatching, shown in Figure 3.14. This similarity is evident mainly in that the dispatching process is described as a consequence of first generating manufacturing orders by the planner, followed by considering the planning capacity which is in line with the process chart. This is further supported by the fact that, in capacity-controlled dispatching, the type of sequencing is periodic, which the company did not follow according to empirical findings. Dispatching based on planned start dates, on the other hand, necessitates an even demand, something the authors found no indication of in the empirical findings. Therefore, despite the flaws of regulated order dispatching, it is considered the best choice of method according to the authors of this thesis. Additionally, the empirical findings highlight space limitations in production, emphasizing the importance of considering capacity aspect in dispatching. Moreover, the material profile and use of order-specific materials underscore the necessity of a method that accounts for material requirements. Ultimately, the analysis indicates that the company currently employs regulated order dispatching, which is considered a sound choice.

5.5.5 Staging

There was no specific staging method explicitly mentioned during the empirical study, even though an established process does exist. Therefore, Table 3.7 was used to examine the present process and map the similarities and differences of the methods for staging. Based on the interviews, the material included on a product receives a status in the ERP system based on readiness. The ERP system controls the balance based on inventory on hand, not what is available. The use of the ERP system implies that the availability control is done with administrative inventory. Thereafter the warehouse personnel collect the materials from all around the warehouses before dropping it off at the requested area, without any time delay. It is described that it can take a few hours, but it is not done days in advance and is therefore considered not to be done with any displacement. Additionally, no regards towards schedule receipt are taken during this process. These actions describe an administrative control towards balance, as illustrated in Table 5.5.

Table 5.5. The mapping of staging methods at the company. Methods marked in blue corresponds with the situation at Alfa Laval.

Variable		Methods according to literature			
		At Alfa Laval	Physical reservation	Administrative control towards balance	Administrative control towards available balance
	Type of balance	Inventory on hand	**Inventory on hand**	**Inventory on hand**	Available inventory on hand
	Physical or administrative control	Availability check of administrative inventory	Availability checks of on-hand balance	**Availability check of administrative inventory**	**Availability check of administrative inventory**
	Time displacement	Appropriate for staging without time delay	**Appropriate for staging without time delay**	**Appropriate for staging without time delay**	Appropriate for material staging beforehand
	Scheduled receipt	No regard	**No regard**	**No regard**	Can regard scheduled receipt

The authors consider this an advisable method for the company as it suits the characteristics of their production. Using inventory on hand instead of available inventory on hand results in easier to do the sequencing of orders more flexible since materials are not fixed to an order. For the same reason, it would not be appropriate to conduct staging beforehand, especially with the space constraint. Physical controls of balance would be time-consuming due to the number and locations of Alfa Laval's warehouses. Ultimately, no direct issues are identified related to this stage.

5.5.6 Shop planning

Similar to the other steps of PAC, there is no specific method mentioned for shop planning but when mapping processes using Table 3.8, a pattern was found. The mapping of the method can be seen Table 5.6. Based on the empirical findings the authors argue that the process regards capacity when conducting the shop planning for the medium assembly group. This is described as necessary for several reasons. The lack of space in production requires consideration of the capacity in terms of physical space. Additionally, during gasketing, it was described as important to consider available capacity due to the requirement of an even number of employees for this phase as well as it being a time-consuming operation. Lastly, some of the requirements of orders require employees to have specific expertise which means that during the sequencing phase, it is necessary to regard what knowledge the available capacity retains. Therefore, it is argued that particular attention is given to capacity, especially within their own production group at the company today. Furthermore, the responsibility for sequencing and product mix can be analyzed. In empirical findings, a perceived difference between the two emerges, where product mix refers to a broader term on a weekly or daily basis, ensuring that the mix is producible. Sequencing, on the other hand, follows this, and determines the actual production order on the shop floor, although sometimes within the same timeframe. According to empirical findings, sequencing at the company is managed by the production team leader, while the scheduler is responsible for determining the product mix, including the manufacturing timeframe and due date. However, the team leader only considers the due date and bases the sequencing on that, even though it is not the only factor considered during the process. The sequencing is done to accommodate complex and time-consuming orders with simpler orders. For gasketing, this means that the number of plates is an important factor due to the linear connection between time and number of plates. If a product has many plates, it needs to be started manufactured early for it to be ready for the assembly operation. For the assembly operation, the level of complexity and customizations of an order are important for the sequencing as these affect the time it will take to manufacture the orders. For the CTO flow, the orders do not experience same variety between orders as the ETO flow. Although, in this flow it is important to balance the orders in order to withhold the rate of the flow. Ultimately, it is therefore argued that the sequencing, in line with theory, is done by the team leader at the shop floor. Since it is the team leader that does the shop planning, no formal reporting once an operation is done. As to the authors understanding, reporting would have been necessary if there was not the same person doing the sequencing and the reporting but since this currently is not the case, there is no need for it. Although, reporting of hours is done after an operation is finished in the ERP system which then visualize it QlikView. This is then used for following up on how they follow the plan as well as the basis for the calculations of reference hours. Additionally, before starting an order, the material situation is considered which is shown during the staging phase where the material receives a status based on if it is ready or not. Although, this is used for the dispatching and staging only, not the shop planning itself. There is no material plan, which result in the lack of a connection to it during shop planning.

Table 5.6. The mapping of shop planning methods at the company. Methods marked in blue corresponds with the situation at Alfa Laval.

			Methods according to literature				
		At Alfa Laval	**Foreman overseen shop planning**	**General prioritization rules**	**Planning-based prioritization rules**	**Prioritization-based shop planning**	**Rate-based shop planning**
Variable	**Regard to capacity**	In own production group	**In own production group**	No	No	No	In own or multiple production groups
	Sequencing of operations	No effect of planning function	**No effect of planning function**	Indirect effect of planning function	Indirect effect of planning function	Direct effect of planning function	Direct effect of planning function
	Timed sequence	Sequencing not defined by start/due dates	**Sequencing not defined by start/due dates**	**Sequencing not defined by start/due dates**	Start/due dates define sequencing	Start/due dates define sequencing	Start/due dates define sequencing
	Material planning connection	Regards the material situation	**No regard**	**No regard**	Regards the material situation	Regards the material situation	Regards the material situation
	Reporting dependency	No	**No**	**No**	**No**	Finish reporting needed	Time and finish reporting needed

According to the mapping, there is indications that foreman overseen shop planning is employed as a method. This is partially supported by the empirical findings which describe that previously the shop planning was conducted by the team leaders but there has been a desire to have more control over the shop floor. Therefore, the planning department was created. However, the planning department does not cover the process of shop planning, but function as a bridge between order handlers and team leaders by rescheduling the orders placed by the order handlers and handing over a production mix to team leaders. The authors believe that the aim of the planning department was to change the shop planning method and give the planning department indirect or direct effect of the sequencing. Although, there are no general prioritization rules, policies or similar to accommodate the process of either schedulers or the sequencing done by team leaders. Instead, the company rely on extensive expertise of the employees which can be consider a liability. This is in line with theory that when manual systems are used, priority control is typically managed by foremen. If an employee with no experience of production at Alfa Laval where to do either of these processes, it would be difficult to understand how customizations affect the production in terms of time and resources, which could affect the production, and thereby the company, negatively. Ultimately, there is currently not an option to change shop planning method due to the lack of prioritization rules and similar.

If there is a desire to change shop planning method, there would need to be a decision regarding how involved the planning department should be. If there is a wish for them to have direct effect of the sequencing, the sequencing will need to be based on start or due dates, as Table 5.6 shows. Additionally, consideration to the material plan is required which mean that it needs to be created, and reporting would have to be done with increased accuracy. If indirect effect is wanted, it will result in no consideration to be taken to capacity, meaning that no matter what, the sequencing will need to be followed. The view of capacity as it is today will have to be change and looked at as something that is more flexible and would not need to be 100 % utilized constantly, which is something the authors understands as important for the company.

Which method is most suitable is difficult to determine. Foremen overseen shop planning has the advantage of using the knowledge and expertise of the team leaders since they conduct the sequencing. Although, it is described that it is appropriate for small shops, which contradict the suitability of the method. The configuration of the layout does not affect the decision since all methods are suitable for flow shops. The current reporting system does not support the accuracy needed for prioritization-based shop planning. Consequently, achieving the required level of accuracy is not feasible with the existing setup. As for rate-based shop planning, it is described that a comprehensive system support is needed which suggest an implementation of such system is required.

To summarize, the current shop planning process aligns with the foreman overseen shop Planning method. Any desire from the company to shift to a different method will necessitate changes to this process. First, if the planning department will have an effect of the sequencing, rules and policies of prioritization will need to be established. The authors believe it will be difficult to accommodate all options of customization since there are endless of possibilities. However, some sort of rules and policies will be necessary to put in print. The view of capacity might be required to change to utilize another planning method. Additionally, the choice of method will also impact the sequencing being determined by start or due dates or not, the need of a material plan, as well as reporting ability. The foundation of the decision should include the configuration of the medium assembly group, in terms of layout and strategy. The final decision will affect where the control of production will be placed which makes it an important choice to take. The result might be that two different methods will be used for the CTO and ETO flow due to the differences these have.

5.6 Summary of analyses

In this sub-section discussed issues are presented in a joint table, see Table 5.7. It includes all issues identified from the planning levels master scheduling, material and capacity planning, as well as PAC. The issues are divided between the levels and into sub-areas. Additionally, a short explanation of the issues is provided.

Table 5.7. Summary of issues identified during analyses.

Identified, categorized, and explained issues

Planning horizon

Level	Sub-area	Issue	Reason
Master schedule	MTO implications	Different perception of accuracy of forecasts	Creates different expectations of the forecasts resulting in inappropriate usage
	Capacity planning	No capacity planning method	Lack of mythology on how to make decisions and planning of capacity
	Forecasting	Uses forecast to predict demand in immediate horizon	The forecast is used in a shorter horizon than it is suited for
		Not in control of material forecasting method	Does not know how method for articles is chosen
		Plans on using one method for all articles in the material forecast	Would imply that no consideration of different demand pattern of articles are made
		The basis of the forecasts are on different horizons	Creates large inherent differences between material sourced and capacity acquired
		Does not include customer orders in forecasts	MTO context underlines the limitations of forecast thus indicating the need for this
		No structured method to define accuracy requirements of forecasts	Inaccuracies in forecasts remains since no continuous improvements are conducted
	Process steps	Delivery schedule and production plan not conducted	Does not follow the process step that enables material and capacity being sourced on orders
	Medium-term capacity adjustments	Few actions conducted to adjust capacity	Few structured and methodical ways to adjust capacity resulting in the need for more actions to be done at a later stage
	Object level	Capacity forecast is translated into an inappropriate object level	MTO inaccuracy does not enable translation into gasketing operation
Material and capacity plan	Method	No material and capacity plan found	Creates a gap between master scheduling and PAC. Ultimately limiting the control and disconnects material and capacity
PAC	Reporting	Inadequate system for reporting	Causing faulty data which is the basis for reference hours
	Shop planning	No alignment regarding whether to consider capacity within each production group or not at all	Creates different goals between actors
		No alignment about how much affect the planning function should have on sequencing	Causes confusion in the allocation of responsibilities
		Difference between described and actual method	No alignment between actors
	Short-term capacity adjustment	Time-consuming action of alternative production group	Complex workload for personnel conducting this
		Time-consuming action of transferring between departments	Time-consuming meeting in which this action is discussed

As illustrated, most of the issues regards the master scheduling level. Although, these issues are not as extensive to address compared to the issue regarding the material and capacity planning level. There are numerous issues related to the PAC level as well. Suggested improvements of all issues will be addressed in the next chapter, as well as an estimation of the benefits and efforts to implement these.

6. RECOMMENDATIONS

This chapter aims to connect and evaluate the issues and suggested improvements addressed in this thesis. The suggested improvements have been discussed throughout Chapter 5. Analysis. In this chapter, the suggested improvements will be summarized, and the implementation effects evaluated. The evaluation will be based on the benefits for the company and effort to implement them, consequently assessed in a benefit-effort matrix. First, the improvements for master scheduling will be presented, followed by material and capacity planning. Thereafter, improvements on the PAC level will be discussed. Lastly, the recommendations that the authors find most urgent are presented in a final recommendation to the company. The structure of this chapter can be seen in Figure 6.1.

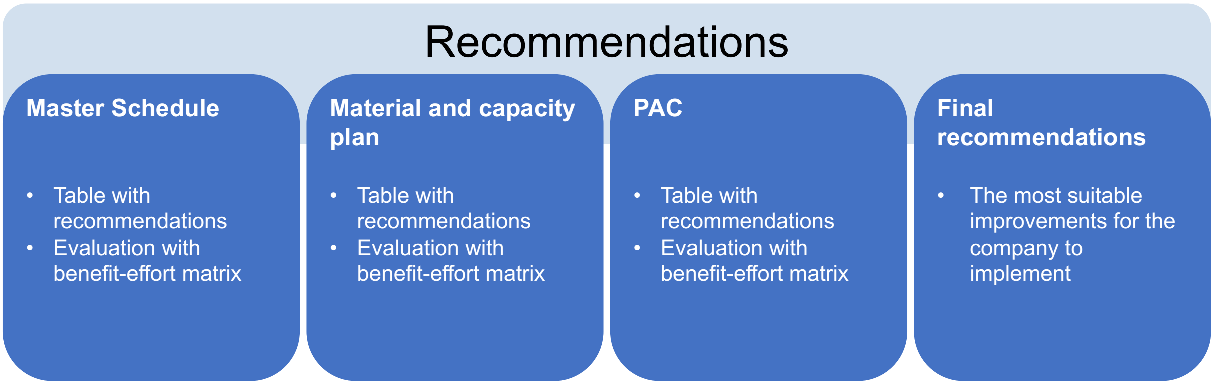

Figure 6.1. The structure of this chapter 6. Recommendations.

The evaluation of the benefit-effort matrix, as first presented in Figure 2.7, was conducted based on an understanding of the current company landscape. The placement in the matrices were based on discussions between the authors after conducting the analyses, focusing on two key parameters: effort and benefit. The effort assessment for suggested improvements primarily considers the number of stakeholders involved and potential changes to processes and systems. The benefit evaluation involves a relative comparison of all improvements, prioritizing those with highest potential to address causes. However, in some cases, the risk associated with implementing an improvement may negatively impact its perceived benefit. Evaluation of the parameters and placement in effort matrix was conducted jointly for all suggested improvements across planning horizons to ensure consistency. Subsequently, the benefit-effort matrices are presented separately, before being discussed jointly to finalize recommendations in the subsequent chapters.

6.1 Master Schedule

This sub-chapter addresses the improvements associated with the issues identified at the Master Schedule horizon. It begins with the presentation of a consolidated table summarizing the analyses from previous chapter 5. Analysis. Thereafter, the effort and benefits of the improvement suggestions are discussed, and subsequently, the improvements are placed in the matrix accordingly.

Throughout the analyses, several issues and improvement suggestions were discussed. The issues were summarized in Table 5.7, and the improvement suggestion of each issue that have been analyzed is presented in Table 6.1 below. The suggested improvements have each been assigned a number, not in any prioritization order, but simply to facilitate their later placement in the benefit-effort matrix.

Table 6.1. Identified and categorized issues with suggested improvements, and motivations at the level of master scheduling.

Identified, categorized, and explained issues

Planning horizon		Sub-area	Issue	Improvement	Motivation	Number of improvement
	Master Schedule	MTO implications	Different perception of accuracy of forecasts	Unanimous expectation of accuracy	Creates limitations of the forecasts. Indirect effect of usage of forecast on correct horizon.	1
		Capacity planning	No capacity planning method	Create a capacity planning method	Unanimous understanding and possible to control capacity	2
		Forecasting	Uses forecast to predict demand in immediate horizon	Use the forecast on a horizon of three months and further	Usage of forecast in the horizon creates accuracies of plans and aligns usage with the company´s current conditions	3
			Not in control of material forecasting method	Evaluate the method of the material forecast	To know how it does the calculations	4
			Plans on using one method for all articles in the material forecast		Chose suitable methods and to allocate the right methods.	
			The basis of the forecasts are on different horizons	Same basis of the forecasts	Limits the differences between material source and capacity acquired	5
			Does not include customer orders in forecasts	Incorporate customer orders into the forecasts utilizing the output generated by the order handlers	Important in an MTO context due to extensive customizations	6
			No structured method to define accuracy requirements of forecasts	Implement a process for accuracy calculation of forecasts	Enable continuous improvement of forecasts	7
				Change accuracy margin based on desired confidence interval	Create a reasonable expectation of the accuracy of forecasts	8
		Process steps	Delivery schedule and production plan not conducted	Implement a delivery schedule and a production plan	Bridge the gap in the master scheduling process. Enable future implementation of a material and capacity plan	9
		Medium-term capacity adjustments	Few actions conducted to adjust capacity	Systematic employment of personnel	Suitable actions to adjust capacity	10
				Evaluate the number of shifts for both flows		11
				Evaluate sub-contracting as alternative for capacity adjustment		12
				Transfer capacity between department at an earlier stage		13
		Object level	Capacity forecast is translated into an inappropriate object level	Product types as object level	According to the analysis, the object level should be product types, not gasketing	14

As seen in the table, there are some issues which have several improvements. To analyze the benefit and improvement of the suggested improvements the benefit-effort matrix was used. Figure 6.2 illustrates the placement of all 14 suggested improvements in the matrix. The improvements fall into all quadrants. The rationale behind their positioning will further be explained.

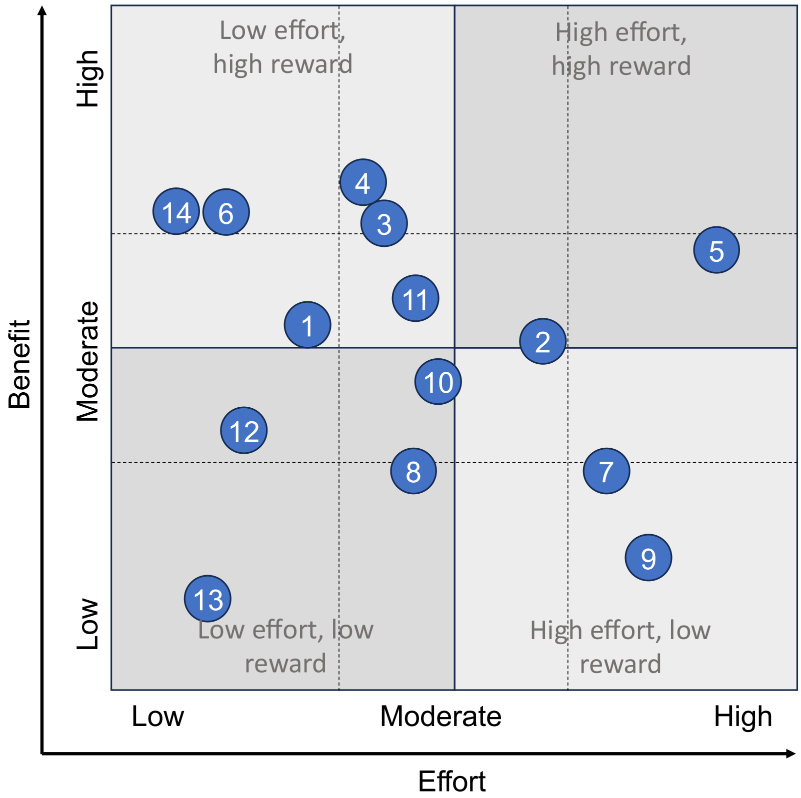

Figure 6.2. The benefit-effort matrix for suggested improvements at the Master Schedule planning level.

The placement of the improvement suggestion with number 1, *different perception of accuracy of forecasts,* in the benefit-effort matrix is motivated by several factors. Effort is considered low due to the involvement of only a few actors and the nature of the task primarily involves discussing expectations rather than implementing process changes. However, the benefit is regarded as relatively low as it impacts the accuracy of forecasts, which although significant, may have less pronounced effects in a MTO context.

The positioning of improvement number 2, *create a capacity planning method*, is influenced by multiple factors. Establishing a consensus is deemed beneficial given the company's current emphasis on capacity management. However, it is suggested that this focus should be somewhat reduced considering the MTO context, resulting in a moderate level of benefit. Implementing this improvement would necessitate the involvement of various stakeholders and adjustments to decision-making processes, thus warranting a moderate to high level of effort.

When considering the third improvement suggestion, *use forecasts on a horizon of three months and beyond*, the implementation comes under light. While the effort to make the decision might be minimal, gaining agreement from multiple stakeholders and ensuring ongoing adherence to established boundaries can pose implementation challenges. Considering both perspectives, the effort is considered moderate. Nonetheless, the benefits are deemed significant as it requires no process changes, yet it enhances perceived accuracy, thereby offering substantial value.

When evaluating the effort required for improvement suggestion number 4, *evaluate the method of the material forecast*, it is relatively low compared to previous suggestions, as one person oversees both input and output variables of the forecast and thus have more control. However, the effort remains substantial for that person. The benefits are regarded as high since it exerts significant control over various aspects. Therefore, it can also be argued that the implementation carries inherent risks, as any flaws could have widespread effects. Therefore, the authors contend that the perceived risks increase the effort involved and the potential benefits as moderate.

Implementing improvement suggestion number 5, *same basis of the forecasts*, would place significant demands on data accuracy, the ERP system, and particularly on translating between material requirements and product type forecasts. As a result, the effort required is considered high. The benefits, however, is argued to outweigh the effort, as a closer alignment between the materials sourced and the capacity acquired would be obtained. This in turn would result in better control over material and capacity gaps, thereby enhancing overall efficiency and resource utilization.

The effort required for implementing suggested improvement number 6, *incorporate customer orders into the forecasts utilizing the output generated by the order handlers*, needs to be assessed in light of the current availability of customer order information at the company. However, incorporating this information into the forecasts would necessitate the development of new calculation methods. Ultimately, it is argued that the effort is relatively low considering both perspectives. The perceived benefits are high, as it would significantly improve accuracy on a large scale, according to theory.

Aligned with the previous suggestion, the seventh implementation, *implement a process for accuracy calculation of forecasts*, would also necessitate the development of new calculation methods. These would particularly involving statistical evaluation of the forecast, which would require comprehensive knowledge. Additionally, a new system for supporting the calculations needs to be constructed. Further, the company does not conduct follow-ups on the forecasts accuracy in the way theory describes. Consequently, the effort required is considerably higher compared to implementation suggestion 6. The benefit is considered positive, however relatively low, as the improvements are projected to have limited impact due to the MTO context, which prioritizes the use of actual customer orders over forecasts.

The placement of suggestion number 8, *change accuracy margin based on desired confidence interval*, follows a similar rationale to the previously suggested implementation. The benefit of this improvement is regarded similarly to suggestion 7, as it addresses the same issue. However, the effort required is deemed to be less, as it does not entail the same level of extensive calculations and alignment with other processes for reporting.

The placement of improvement suggestion number 9, *implement a delivery schedule and a production plan*, is significantly influenced by the absence of a material and capacity plan. Without such plans in place, the delivery schedule and production plan would lack the control outlined in theory. Moreover, the MTO context adds further uncertainty to these plans. Ultimately the benefits are therefore considered low. Effort is also considered high due to the absence of existing plans at the company that align with theoretical frameworks. The process and system in which the construction of the plans would need to be created.

Improvement suggestion number 10, *systematic employment of personnel*, is deemed to be a resource-intensive action since it today is described to be hard to execute. However, the level of difficulty varies depending on the personnel required. Overall, the effort is considered moderate. The benefits are also assessed as moderate since it would facilitate the use of less capacity adjustments at a later stage. Based on this rationale, the improvement suggestion is arguably challenging to position in both dimensions and is therefore suited to be placed in the center-right of the matrix.

Improvement action number 11, *evaluate the number of shifts for both flows*, entails several factors to consider. The effort required is deemed slightly less than the previous suggestion since this process is already observed at the company, which implies that there are existing processes in place. The benefits are considered moderate and higher than the previous improvement. One reason for this is that the action can alleviate and assist in working around the described limited space in the production flows.

The effort required for the twelfth improvement suggestion, *evaluate sub-contracting as an alternative for capacity adjustment*, is considered low. This is because the action is already implemented at the company today. The action requires more trust in the capacity forecast than other improvements, which elevates the risk and makes it less beneficial. However, easing the workload and adjusting capacity at an earlier stage are advantageous, ultimately deeming the benefit moderate.

The benefit of improvement suggestion number 13, *transfer capacity between departments at an earlier stage*, is deemed the lowest of all improvements. This is because the MTO context emphasizes uncertainty in forecasts, which this action must solely rely on. Additionally, the capacity forecast is based on S&OP forecasts, which are considered more accurate at a factory level. Thus, it supports only keeping the overall capacity aligned without mixing it with individual capacity groups at this horizon. The effort is also considered low at this horizon since it is just preliminary decision and no processes, systems, or people are affected at this point.

The final improvement suggestion, number 14, *product types as object level*, is deemed to have a high benefit as it contributes to the correct utilization of forecasts. Effort is regarded as lower since it simply involves ceasing the process of translating to the gasketing.

6.2 Material and capacity plan

In previous analyses, it has been noted that the company does not have any material or capacity plan in place. This presents a significant issue as it results in a gap between various planning levels, a lack of control over material and capacity, and creates an uncertainty of the impact these two factors have on each other. It is important to address this problem to enhance the planning process. The suggested improvement is therefore to implement a material and capacity planning method to bridge this gap, see
Table 6.2.

Table 6.2. Identified and categorized issues with suggested improvements and motivation at the level of material and capacity plan.

Issues and improvements

Planning horizon		Sub-area	Issue	Improvement	Motivation	Number of improvement
	Material and capacity plan	Method	No material and capacity plan found	Implement a material and capacity planning method	Connect and control material and capacity	1

The authors consider that addressing this issue is crucial in resolving the experienced production planning issues, stating that there is no way to avoid it. Figure 6.3 illustrates an estimation of this suggested improvement in terms of effort and benefits.

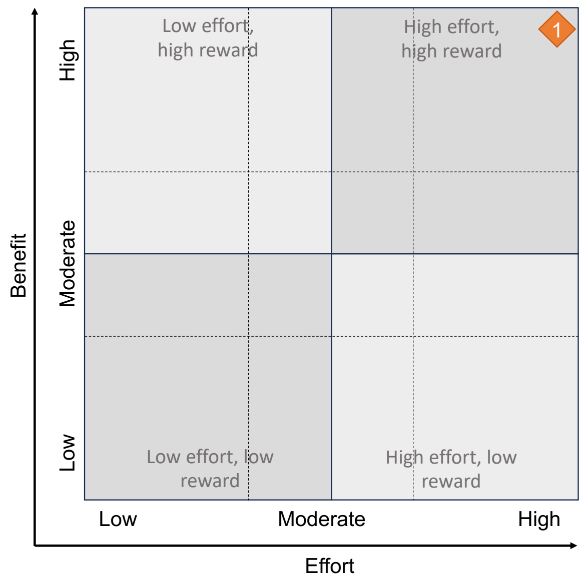

Figure 6.3. The benefit-effort matrix with the recommendations regarding material and capacity planning.

In terms of effort, the implementation of a material and capacity plan will be a major and long-term project, as it includes multiple actors and might extend beyond the factory itself. This is due to material and capacity planning methods might put requirements on the ERP system which could affect other factories within the network. Despite the anticipated high level of effort required for implementation, the benefits are deemed high. It will enhance material control, and align it with capacity, which is predicted to improve the overall planning process. Additionally, it will connect the other planning levels, which will make the planning process one entity.

6.3 Production activity control

This sub-chapter focuses on addressing the improvements related to the challenges identified within the PAC horizon. The sub-chapter starts with the presentation of a consolidated table summarizing the improvements that addresses the issues found in the analysis from previous chapter 5. Analysis. Subsequently, the effort and benefits of the proposed improvements are evaluated, followed by their placement in the matrix as appropriate. The issues and improvements connected to PAC are summarized in Table 6.3. Each suggested improvement has been assigned a number for easy reference, without any prioritization, to aid in their later placement in the benefit-effort matrix.

Table 6.3. Identified and categorized issues with suggested improvements and motivation at the level of PAC.

Issues and improvement

Planning horizon		Sub-area	Issue	Improvement suggestion	Motivation	Number of improvement
PAC		Reporting	Inadequate system for reporting	Improve reporting possibilities within systems	Increase the accuracy of reference hours	1
				Improve reporting of product types with large share, TL10 and T15 specifically	Limits the scope of a project but keeps impact high	2
		Shop planning	No alignment regarding whether to consider capacity within each production group or not at all	Selection of a method for shop planning	Needs to be done in accordance with method chosen	3
			No alignment about how much affect the planning function should have on sequencing			
			Difference between described and actual method		Unanimous understanding of process and responsibilities	
		Short-term capacity adjustment	Time-consuming action of alternative production group	Investigate which modules are main contributor to complications of the production and planning process	Understand how product complexity affect to facilitate relocation more easily. The number of plates has been identified as such a module	4
				Determine which product types should belong to which flow	To further optimize production flow and the planning process	5
			Time-consuming action of transferring between departments	Define rules and policies outlining how transferring capacity between departments can be accomplished	Would ease the decision process and align views of prioritization	6

The suggested improvements are evaluated based on benefits and efforts using the matrix found in Figure 2.7 using the improvement suggestions number found in Table 6.3. The placement was based on the authors' joint analyses.

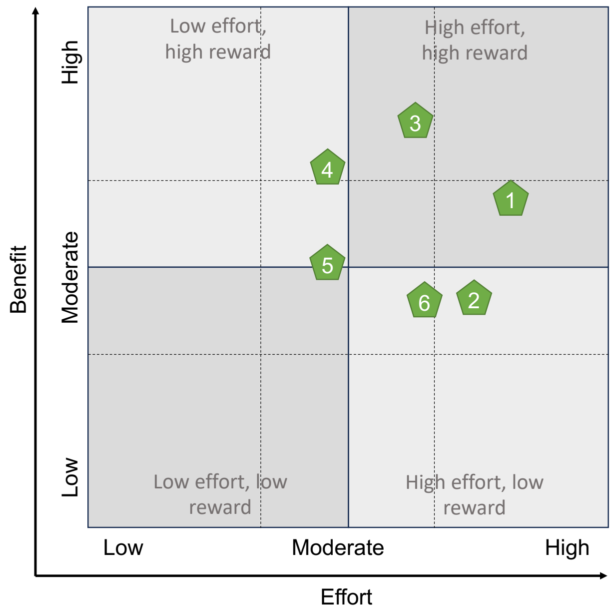

Figure 6.4. Suggested improvements evaluated with a benefit-effort matrix.

The improvement with number 1, *improve reporting possibilities within systems*, is considered requiring high effort due to need for changing or updating the system used for reporting. Additionally, it involves multiple stakeholders at the company, from system support to team leaders. The benefits of conduction the change is deemed relatively high since it will improve the foundation of reference hours which dictated the forecasts.

For the second improvement suggestion, *improve reporting of product types with large share, TL10 and T15 specifically,* the effort is considered less than number 1, but still high. This is due to the extent of the reporting needed. The benefit is deemed moderate since it requires using the system with the current functionality, thus not addressing the core reporting problem.

Improvement number 3, *selection of a method for shop planning*, will require several actors to have a joint view of how shop planning should be conducted. This will need to be evaluated and is therefore argued to be a strategic decision, making it moderate effort. The benefits of this implementation are considered to be high since it would allow the shop planning to be streamlined and responsibilities will be divided between actors. It is beneficial since it will give mandate to act and take decisions.

The improvement *investigate which modules are main contributor to complications of the production and planning process*, referred to as number 4 in the matrix, is more difficult to evaluate in terms of the required effort. To get a general overview, it could be enough to discuss this with experienced personnel, making it a moderate effort. If more accurate information is desired, the information should be based on data which then needs to be analysed. Therefore, it would increase the effort. In this matrix, the authors assumed a general overview would be enough for the company. The benefits of this implementation are believed to be high since it will facilitate the reduction of product complexity from a planning perspective.

Determine which product types and constituent modules should belong to which flow is the implementation referred to as number 5. The implementation is similar to number 4 but on a higher aggregation level. It is considered less beneficial due to the previous suggested improvement having a higher impact on capacity adjustment options. The effort is deemed the same as number 4 since it requires similar information.

As for the last improvement, *define rules and policies outlining how transferring capacity between departments can be accomplished*, the effort is predicted to be high. Policies regarding transferring capacity between department requires consensus on a factory level in which orders to prioritize, and thereby which assembly groups to prioritize. The benefits on the other hand, is considered lower compared to the other suggestions on this level. This is due to the variability in day-to-day personnel availability, often caused by illness, means that the available capacity can never be fully controlled.

6.4 Final recommendations to company

To ultimately decide what improvements to recommend, a joint benefit-effort matrix was evaluated, seen in Figure 6.5. The joint matrix has been complemented with zones where the improvements are shown to have their emphasis. The implications of the different zones positioning as well as a reasoning for finding the final most relevant suggested improvements will hence be discussed. Since there is considerable effort related to most actions at this level, it is argued that not all improvement suggestions can start right away. There is therefore a need to prioritize which actions to start with.

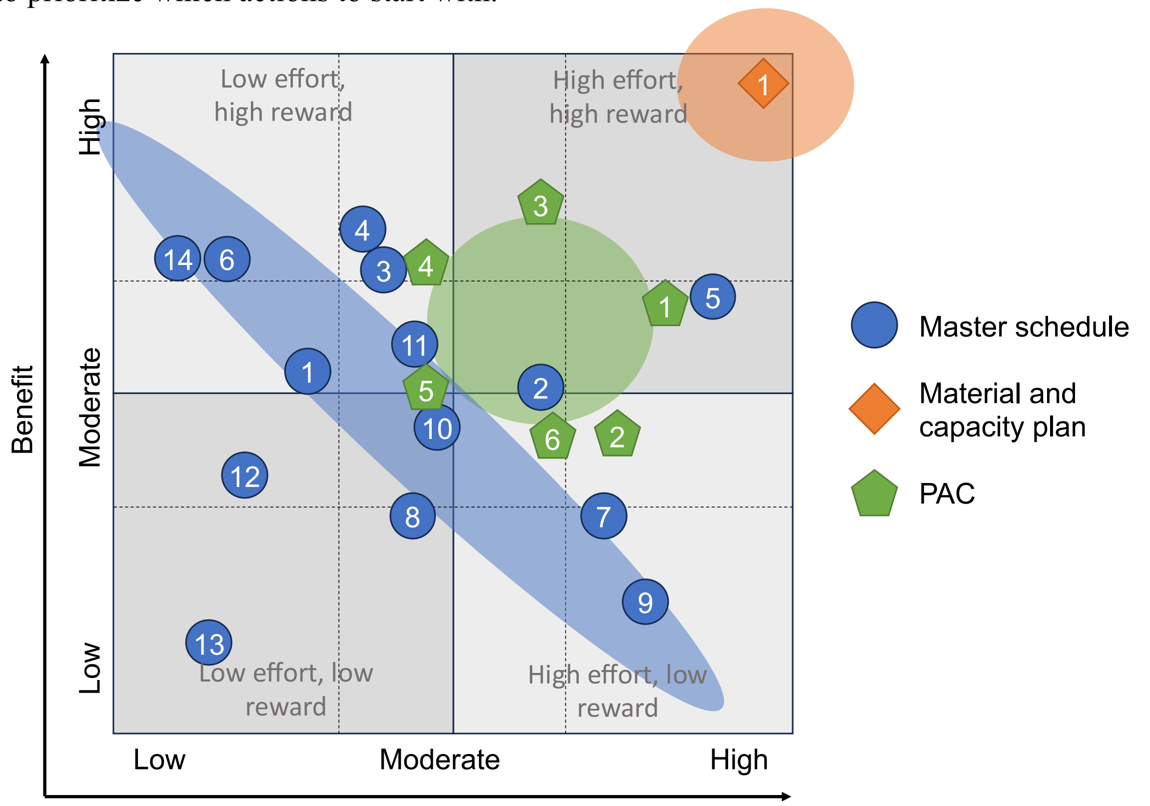

Figure 6.5. A joint benefit-effort matrix. Zones highlight the centrum for the planning level´s improvement suggestions.

In the analysis of the matrix in Figure 6.5, an intriguing correlation emerges, only the material and capacity plan implementation suggestion are considered high in benefit and effort. This is further underlining the fact that this can be viewed as a root cause to other problems.

Furthermore, improvement suggestions at the Master Schedule level are many but they are also spread out more evenly across the matrix. However, excluding outliers such as numbers 5 and 13, it can be argued that most improvements are positioned along a diagonal line, highlighted as a blue zone in Figure 6.5. Thus, the improvements span in both benefits and effort, but compared to the other planning levels have a zone that is lower in importance. The authors further argue that suggested improvements linked to issues at this horizon needs to be carefully evaluated to avoid investing effort into actions with low benefit. Additionally, there are visibly six improvement suggestions found in the low effort, high reward quadrant. This highlights that there might be many issues at this level, but the improvements addressing them can in some instances be considered quick fixes.

Further, when looking at the PAC level improvement suggestions, they primarily cluster around a point, highlighted with a green zone in Figure 6.5, in the lower left corner of the quadrant with high effort and high reward improvements. The authors argue that this highlight that some of the problems identified at this level are actions that require several actors to have the same view.

To identify what recommended improvement to start with, a methodical exclusion of improvements was made based on their positioning in Figure 6.5. First, the improvements with low benefits are argued to be excluded as alternatives to implement as these will not have a greater impact on the planning process. This means the improvements on master scheduling level with the numbers 7, 8, 9, and 13 is argued not to be implemented at the company. Additionally, suggested improvements with high effort and moderate benefits are also argued to be excluded since the efforts are too big when comparing with the outcome and therefore cannot be motivated. With this reasoning, the improvements on master scheduling level with the numbers 2 and 5, as well as the improvements on the level of PAC with the numbers 1, 2, and 6 also considered not urgent to implement.

When the excluding of some suggested improvements is done, there is a need for further analysis of the remaining improvement suggestions. Further analysis of the matrix shows improvements with low effort and high benefit which are argued to be quick fixes, i.e. number 6 and 14 on the level of master scheduling. Additionally, the only improvement on the material and capacity planning level, is place in the matrix with high effort and high benefits. As previously discussed, the authors argue that it is inevitable to not implement this improvement. Furthermore, there are a few suggested improvements that is deemed high reward and moderate effort. These are numbers 3 and 4 on the master scheduling level, as well as numbers 3 and 4 on the level of PAC. Since the benefits are considered high, the authors argue that these should be addressed as well. Although, since they require moderate effort, the size of these projects can vary, requiring various time. The other improvements are not considered critical at the moment, and it is therefore recommended to address these in the future.

The final recommendations and their prioritization are summarized in Table 6.4 below, based on the motivations in this section. The ranking is based on the improvement suggestions deemed benefits. The table is structured based on planning horizons, followed by an internal ranking within each horizon. This reflects the organizational structure of processes and personnel within the company today, which are aligned with these horizons. Consequently, it is presumed that multiple projects can start concurrently if they pertain to different horizons. As discussed earlier, there is no individual specifically assigned to material and capacity planning, resulting in an indirect lack of accountability for this aspect.

Table 6.4. Final recommendations and prioritizations.

	Prioritization within respective horizon	Number of improvement	Improvement	Time perspective for implementation
Master Schedule	1	4	Evaluate method for material forecast	Medium term
	2	14	Product types as object level	Short term
	3	6	Incorporate customer orders into the forecast utilizing the output generated by the order handlers	Short term
	4	3	Use the forecast on a horizon of three months and beyond	Medium term
Material and capacity plan	1	1	Implement a material and capacity planning method	Long term
PAC	1	3	Decision of a method for shop planning	Medium term
	2	4	Investigate which modules are main contributor to complications for the production process and planning process	Medium term

7. CONCLUSION

This final chapter aims to conclude and summarize this thesis. It will cover how the purpose is achieved, research questions will be answered, discussion of future work, as well as contributions. Figure 7.1 illustrates the structure of this chapter.

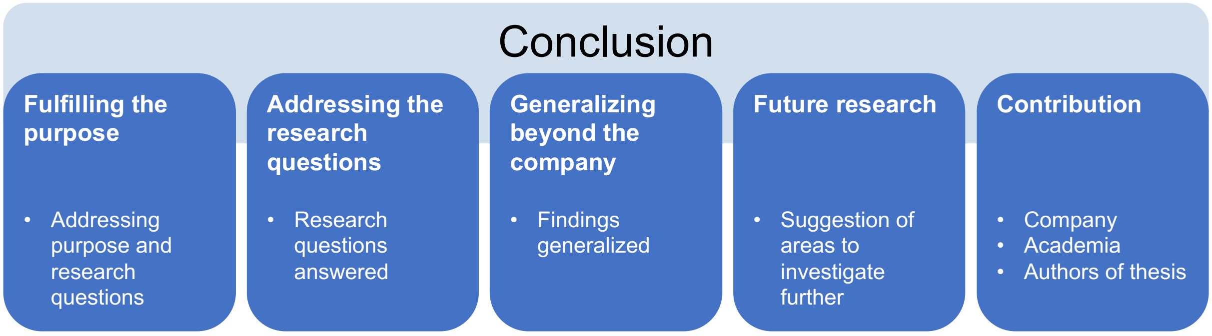

Figure 7.1. The structure of chapter 7 CONCLUSION.

7.1 Fulfilling the purpose

The purpose of this thesis is to find improvement areas of the planning processes by identifying root causes affecting the issues related to production planning at Alfa Laval. To accomplish the purpose, a literature review was conducted to understand what methods and strategies that could be used by a company with the characteristics of Alfa Laval in regard to production planning. Thereafter, interviews, observations, and information gathered from the ERP system and internal documents were used to map the current situation at the company, including existing methods and processes. This was then followed by an analysis where the findings of the literature review and the empirical findings was compared and mapped. Differences and similarities were discussed as well as possible improvements. Lastly, recommendations to the company were presented. Ultimately, the thesis has navigated in the challenges experienced related to the planning process at Alfa Laval. The final recommendations for the company will help enhance efficiency in the production planning.

7.2 Addressing the research questions

The research questions served as the cornerstones guiding the entire thesis. The first research question *how are methods and principles used to conduct production planning processes in a manufacturing industry with a wide product range and MTO production?,* was the foundation for the theoretical framework presented in this thesis. Furthermore, the formulation of an exploration of theories predominantly linked to industries with an extensive product range and MTO context facilitated the refinement of the gathered theoretical perspectives. However, it was imperative to explore the implications of such a manufacturing concept, thus necessitating its thorough exploration within the theoretical framework.

The second research question, RQ2, *what deficiencies or gaps are present in the production planning processes within the assembly factory at Alfa Laval?*, steered the empirical inquiry towards identifying and examining the current planning practices at the company. Moreover, the RQ2 guided the authors to compare the empirical data with described theoretical frameworks to identify gaps within the processes. During this phase, the absence of a material and capacity plan became apparent. Additionally, some issues identified at other planning levels were greatly influenced and affected by the lack of a material and capacity plan. Further, some issues that were not affected by the material and capacity plan and related to the other planning levels were identified.

The last research question was *what strategies can be implemented to improve the production planning process and address the identified root causes affecting production planning challenges in manufacturing industries with wide product ranges and MTO production?*. This research question was thoroughly explored and discussed in the chapter 5. Analysis, where the issues were discussed. Thereafter, subsequent conclusions and supported recommendations were provided in section 6. Recommendations. This ties back to the research question and linked the issues with improvements supported by theory. Furthermore, the feasibility and required efforts to address these issues were outlined in the final recommendations. Ultimately, the identified issues were summarized in the main suggestions presented in Table 6.4. Final recommendations

7.3 Generalizing beyond the company

Several critical issues are raised that extend beyond the scope of the company. The lack of a material plan is a central challenge, which can hinder effective planning for any company. The issue should be carefully assessed in a company with a wide production range and in an MTO context. It shed light on how different planning horizons were affected and necessitated adaptation to still be functional.

Furthermore, unity and alignment of perspectives emerged as a recurring theme when addressing identified issues. This stresses the importance of collective agreement, a lesson worth noting when generalizing the findings. Moreover, this thesis highlights the significance of having models and methods that aligns with products produced and existing processes, serving as critical components for successful production planning. While methods may not always be explicitly named, their implementation in practice streamlines the chain of command and decision-making processes. Additionally, the thesis stresses the importance of the intricate interplay between the produced product, applied production processes, and their implications for planning in an MTO context. The interconnected relationship between these dimensions is deemed crucial for achieving efficacy, a focal point highlighted throughout this thesis.

The investigation in this thesis demonstrates the importance of collaboration ability. The company can, despite identified gaps, keep the production running due to the collaborative effort and invaluable internal knowledge. The company exhibits a great ability to solve complex systematic problems that arise in the planning process thought the horizons through collaboration both within the company and externally. Furthermore, internal knowledge strengthens processes and, in some cases, mitigates issues that arise. In conclusion, this case company illustrates how significant problems can have reduced impact if the collaboration ability is great.

7.4 Future research

Time limitations made it impossible to investigate all angles of the planning process. Therefore, further research withing the area can be advised. In addition to determining which recommendations to implement, it is essential to examine other areas that impact the planning process. This includes for example purchasing and warehousing, both of which were delimitations in this thesis. An additional factor not investigated in this thesis was the impact of order unique material. By both evaluating this and the purchasing function new issues and improvements can be identified. These areas indirect affect and are affected by the planning process, making it necessary to investigate how the recommendations impact them and vice versa.

Another area to look in to further is mass customization, as briefly mentioned during the analysis of the products produced. In the product-process matrix, the medium products were positioned at the brink of mass-customized production. Although, it was considered outside the scope for this thesis. Further investigation into the implications of mass customization could provide valuable insights for future research.

Additionally, Alfa Laval should consider investigating the potential impacts and possibilities of the new ERP system on the planning processes. For example, the new system might have different support functions that could enable the change from a manual process to a more automatic system-supported one.

7.5 Contribution

This report has contributed by mapping the planning process, its gaps, and suggested areas for improvement at the company. The final recommended implementations have a varying spread between the planning horizons but with a large emphasis on the importance of bridging the gap caused by the lack of material and capacity planning. Moreover, the authors of this thesis have deepened their knowledge of production planning, including both theoretical frameworks and practical approaches. Furthermore, the report has contributed academically by methodically comparing literature with real processes, thus consequently verifying existing theories. Furthermore, it has underlined the great implications MTO context, and a broad product range can have on a planning process. This thesis suggests that exploring suitable methods for material and capacity planning is a future undertaking, maybe even an excellent subject for a new master's thesis at Alfa Laval.

In summary, this master's thesis extensively navigated the challenges of production planning. Through the recommendations, the report aims to enhance efficiency in production planning, not only for the case company but also to provide valuable insights for manufacturing firms with a wide product range.

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Appendix

Appendix A – Interview guides

Questions asked all interviewees
Date:
Interviewer:
Co-Interviewer:
Location:
Time:

Context: Description of the purpose of the thesis, the research questions, as well as the focus area.

Introduction
- What is your current job role?
- How long have you been in this position?
- Who do you interact with as part of your role?

Work Process
- What specific tasks or responsibilities do you oversee?
- What is the timeframe for your and you team's work?
- What differences do you see between the different assembly groups in terms of planning?
- Could you walk us through your typical work process?
- How do different departments or teams coordinate during the planning process?
- What KPIs are you and your team measured on?
- What are the main challenges you face in your daily tasks?
- What do you consider the key strengths of your planning process?

Decision-making and Resource Allocation
- What types of decisions do you make regarding resource allocation?
- What specific calculations do you perform in the resource allocation process?
- Could you walk us through your decision-making process when it comes to resource allocation?
- What are the key factors that influence your decisions in various scenarios?
- How does the production process you interact with differentiate between rate and time?
- Are there any constraints or limitations in terms of space within the production facility?
- What unique challenges do you encounter when planning for medium assemblies?
- How do you effectively manage resource allocation to meet the needs of production?
- How do you balance factors such as demand, resource availability, and time constraints in your planning process?
- Do you have to make any trade-offs or compromises in your resource allocation decisions?

Conclusion

- Is there anything you want to add?

Questions asked schedulers, team leaders, team managers, and master scheduler

Work process

- What tools and methods do you use for planning?
- Are there any specific systems you rely on?
- How do these systems integrate with other production or business systems at the factory?
- What type of information do you receive and analyze, including variables, capacity, materials, forecasts, and capacity plans?
- How do you communicate this information onwards?
- Who do you hand over information to?

Questions asked schedulers, and master scheduler

Material and Capacity Planning

- Do you have a material planning system in place?
- Are product structures taken into consideration during the planning process?
- Is capacity considered when planning production?
- Is the production rate determined by a fixed rate or based on discrete demand?
- How are orders initiated within the production process?
- Is the order quantity typically fixed or does it vary?
- Is the time between orders consistent or does it vary?
- How flexible is the scheduling process?
- What is the typical production lead time?
- Is the focus of resource efficiency on labor or on identifying and alleviating bottlenecks?
- How are the inventory levels?
- Are setup times in production averaged or adjusted based on specific circumstances?
- What is the typical production batch size?

Questions asked schedulers, team leaders, and team managers

PAC

Dispatching

- Who does the dispatching of orders on the products you are planning?
- When dispatching orders, is available capacity taken into consideration?
- What type of dispatching method do you typically use - sequence-based or period-based?
- Is the dispatching process dependent on real-time reporting?
- Are the materials required for production taken into consideration before dispatching orders?

Staging

- Who does the staging of the products you are planning?

- What type of balance is used during staging – inventory on hand or available inventory on hand?
- Is physical control or administrative control typically used for staging purposes?
- Is material staging conducted in advance or without any time delay?
- Are scheduled deliveries taken into account during the staging process?

Shop planning

- Who does the shop planning of the products you are planning?
- Is capacity considered in shop planning?
- Does the sequence of operations impact the planning process?
- Are operation sequences based on start and due dates in shop planning?
- Is material availability taken into account during shop planning?
- Is there any reliance on reporting in the shop planning process?