School of Engineering Science
Industrial Engineering and Management
Master's Thesis

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Evaluating the opportunities for improvement in the engineer-to-order manufacturing process

Examiner: Associate Professor, D.Sc. (Tech.) Petri Niemi

ABSTRACT

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The objective for this study is to find ways for improving the engineer-to-order manufacturing process in a precast concrete element company. The literature review focuses on manufacturing process theories and production management. The research was conducted as a case study, where the production data from the selected time period were collected from the company's database and then analyzed during all the manufacturing stages. Observations from the data analysis were then discussed with the company's experts through interviews.

As a result of this research, the case company's manufacturing process in one factory is analyzed during all its stages, and improvement opportunities are located and identified. Minor improvement opportunities were found for all manufacturing stages, but two can be categorized as major opportunities. The first was the opportunity for 30% time reduction in drawing publishing requirements when the design work is performed by the company's internal design office. The second significant finding was the suggestion for new production planning guidelines for avoiding too-early manufacturing.

This thesis provides a deep review of the case company's internal process and highlights matters that should be considered in the decision-making process and the long-term strategic planning process. This thesis concludes that with slightly minor changes, the case company could improve the manufacturing process and benefit from having an internal design office.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
School of Engineering Science
Tuotantotalouden koulutusohjelma

Joonas Leinonen

Asiakasohjautuvan tuotesuunnittelun ja valmistusprosessin tehostamismahdollisuuksien arviointi

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Tämän työn tavoitteena oli löytää keinoja ETO-tuotannon tehostamiseen ja nopeuttamiseen betonielementtejä valmistavassa yrityksessä. Diplomityön teoriaosuus keskittyy tuotantostrategioita käsittelevään kirjallisuuteen, sekä tuotannonohjaukseen. Varsinainen tutkimus toteutettiin case-tutkimuksena, jossa kohdeyrityksen tietokannasta poimittiin valitun ajanjakson tuotantodata, jota analysoitiin kaikissa valmistukseen liittyvissä vaiheissa. Havaintoja tuotantodatan analysoinnista arvioitiin ja kommentoitiin yhteistyössä yrityksen asiantuntijoiden kanssa haastattelujen avulla.

Tämän tutkimuksen tuloksena kohdeyrityksen yhden tehtaan valmistusprosessia analysoitiin kaikissa vaiheissa ja tehostamismahdollisuudet paikallistettiin sekä tunnistettiin. Pienempiä mahdollisuuksia löytyi kaikista vaiheista, mutta kahta havaintoa voidaan pitää merkittävänä. Ensimmäinen oli mahdollisuus pienentää valmistuspiirustusten valmistumisaikavaatimusta 30% kun elementtien suunnittelutyö tehdään yrityksen omassa suunnittelutoimistossa. Toisena merkittävänä havaintona oli ehdotus tuotannonohjauksen periaatteiden uudelleenmäärittelystä, jotta vältyttäisiin liian aikaiselta valmistukselta.

Tämä diplomityö antaa kattavan katsauksen kohdeyrityksen sisäiseen prosessiin ja korostaa niitä asioita, jotka pitäisi ottaa huomioon yleisessä päätöksenteossa ja pitkäntähtäimen strategisessa suunnittelussa. Työn lopputuloksena voidaan todeta, että varsin pienten muutosten avulla kohdeyritys voisi parantaa tuotantoprosessia ja aidosti hyötyä enemmän omasta suunnittelutoimistosta.

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With completing this master's thesis, it is time to finish my studies at LUT. During my studies, I have learned a lot and had the opportunity to meet so many great people. This thesis was made for a company where I have worked for a couple of years. I would like to thank the case company for overall flexibility, and for giving me the opportunity to conduct this research.

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Last but not least, I would like to thank my family and friends for supporting me during this journey. With special thanks to my girlfriend Annika, who has endured me and all my worrying during this project. Now it is time to end the journey as a student and take the next step to working life. I am excited to see what kind of adventures the future holds.

Kotka, 2.4.2020

Joonas Leinonen

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LIST OF ABBREVIATIONS

APP	Aggregate production planning
ATO	Assemble-to-order
BOM	Bill of materials
CODP	Customer order decoupling point
DDA	Due date assignment
ERP	Enterprise resource planning
ETO	Engineer-to-order
HPP	Hierarchical production planning
JIT	Just-in-time
MPC	Manufacturing planning and control
MPS	Master production schedule
MRP	Materials requirement plan
MTO	Make-to-order
MTS	Make-to-stock
OPP	Order penetration point
PPC	Production planning and control
RPA	Robotic process automation
SFC	Shop floor control
SFS	Shop floor scheduling
TCT	Total cycle time

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1 INTRODUCTION

This first chapter introduces the main topics of this thesis. Chapter 1 firstly introduces the background for this thesis and provides an overall overview of the business environment, and it also introduces research objectives and the main research questions. This chapter lastly presents the research methods and structure of the report. These topics are mandatory to internalize before proceeding through the research and acquire a general overview.

1.1 Background

This thesis is created for a Finnish precast concrete element company which is operating nationally in the market of Finland. This company is part of a larger corporate group which is operating globally, and they might exploit other global units in national business. The case company has multiple factories in Finland, and their product portfolio covers different types of concrete elements for residential and non-residential buildings. The manufacturing process varies between different element types, and this thesis concentrates on the manufacturing process of partition wall elements.

The case company has its own design department, which is spread across several factories in southern Finland. These design offices primarily design several different types of concrete elements: partition wall elements, lift shaft elements and slab elements. These elements are usually considered to be a warm framework of an apartment building, and contractors typically order all the warm framework elements from the same supplier. Other types of elements, such as façades, are usually designed by structural engineer consulting services due to their complexity and then ordered from one of the many suppliers in Finland. The case company has a strategy to design all the produced elements themselves in the future. Several pilot projects with all element types designed have been created, and the results have been positive for the manufacturer and the customers have been pleased.

The supplier having their own design services is considered as a positive thing among the contractors. Value for the customer is created due to a more cost-efficient alternative and reasonable use of available stock accessories. The solutions and use of different accessories vary on a large scale between structural engineers, which reduces the benefits of standardization. As a result, this thesis is focused on the possibilities for improving the engineer-to-order (ETO) production based on the case company's objective of having all produced elements designed by themselves.

The construction industry is highly sensitive to the cyclical fluctuations of the economy, and the demand for concrete elements strongly follows this trend. Especially during high demand, concrete element factories face situations where they must refuse to accept additional orders. Such situations create a strong desire to obtain opportunities for quickening production lead time and the whole project lead-through. At the time of this thesis, the volume of orders in construction industry is decreasing. During August to October 2019, the number of granted building permits decreased 10.8% from the previous year (OSF 2019). This creates the perfect opportunity to examine and analyze the company's performance during peak demand and to improve operation methods for upcoming cyclical recovery.

1.2 Research objectives and scope

The objective of this research is to evaluate different opportunities and the cost-saving potential of improved ETO-production and how it could be implemented. There are multiple steps in the manufacturing process and some necessary delays between these production steps, which are due to, for example, material ordering or production preparations. The aim of this thesis is to generate documentation for the company's executives so that they can acquire a conception of what kind of improvements would be possible to achieve and how. This thesis also includes an assessment of potential implementation problems and risk analysis on a few different variable factors. This thesis provides a comprehensive analysis on what could be done and what should be considered in decision-making and will not make exact changes in procedures.

This thesis is limited to the company's internal process, beginning with the confirmation of an order and ending when the delivery truck leaves the stockyard. Especially at the end of the supply chain, practices vary somewhat due to, for example, the storage capacity at the construction site. These variables are ignored in this thesis which focuses on the manufacturing process itself, which includes the engineering process.

This thesis focuses on practices at the company's one factory in southern Finland which manufactures partition wall elements. There is also a design office located in the factory area, which means the collaboration between production and the design office will be more visible. The limitation to partition wall elements is justified by having a simple product that is designed by the company's own designers. This research is based on a retrospective manufacturing simulation and data analysis for a certain production time period, where lead time will be quickened, and delays decreased in the simulation model. Observations from the data analysis will be analyzed and discussed with the company's employees and experts in specific areas through interviews.

1.3 Research questions and methods

The main purpose of this thesis is to provide insight into improving opportunities in ETO production. The case company has an objective to have all produced elements designed by their own design office, and they thus want to take advantage of having internal designers by improving the manufacturing process as ETO production. There is currently no difference in production practices whether manufacturing drawings are created by external or internal designers. In order to achieve the greatest benefits from the internal design office in the manufacturing process, the main research question is:

"How could the case company improve the current manufacturing process?"

In order to achieve a deeper understanding of the research scope and to answer the main research question, it is essential to divide the latter into the following supportive research questions:

"How could the case company shorten the delays between manufacturing stages (if the design work is done by the internal design office)?"

"What kind of cost effects might result from improvements?"

"What kind of risks or challenges could occur if ETO production lead time were quickened?"

This thesis follows the structure of a typical case study with the help of retrospective simulation research and data analysis on a selected time period. Simons (2009, p. 21) defines a case study as follows: "Case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a 'real life' context. It is research-based, inclusive of different methods and is evidence-led." Later on the same topic, Simons (2009, p. 21) also mentions that "the primary purpose is to generate in-depth understanding of a specific topic." In a case study, information can be focused accurately from selected parts that affect each other in different ways. There are also multiple methods of gathering data for a case study, including interviews, observations and examination of databases (Hirsjärvi et al. 2007, p. 130).

Like most case studies, both qualitative and quantitative methods are used in this research. Thomas (2003, p. 33) describes that qualitative research “refers to collecting and interpreting information about some phenomenon without concern for quantities” and that it “uses numbers and statistical methods. It tends to be based on numerical measurements of specific aspects of phenomena” (Thomas 2003, p. 2). As stated earlier, both methods are used in most research and that makes specification between methods difficult and sometimes unnecessary (Hirsjärvi et al. 2007, p. 133).

The theoretical part of this thesis is based on a literature review of the manufacturing process as well as production management. The theoretical foundation consists of using published books, scientific publications and articles on the selected area, which helps to achieve a better understanding of the manufacturing context. The other objective of the literature review is to adopt good practices in the area of production management.

The theoretical part of this thesis is followed by the data analysis and retrospective simulation research, which is executed by utilizing quantitative data that have been collected from the case company’s database. The simulation model is performed with the use of real production data from the selected time period, and more detailed information about the simulation process and used data is presented later in this thesis. The final part of this research is to analyze the results at every stage of manufacturing. Combining the findings and suggested improvements in different manufacturing stages enables answering the supportive and main research questions and presenting opportunities for improvement.

1.4 Research structure

This thesis is divided into two parts: first the theoretical part which is followed by the actual research. In total, this thesis consists of seven main chapters, each of which has input and output data, which are presented in Figure 1. After the introduction, this thesis continues with a literature review about a manufacturing process and production management process.

The fourth chapter introduces the methodology of retrospective simulation research and how the data have been collected and analyzed. After the simulation process, the results and observations are presented regarding the different stages of the manufacturing process in the results chapter. After the fifth chapter, comes a discussion chapter where improvement findings are described, and research questions are answered. The final chapter concludes with managerial recommendations and suggests further research topics or areas.

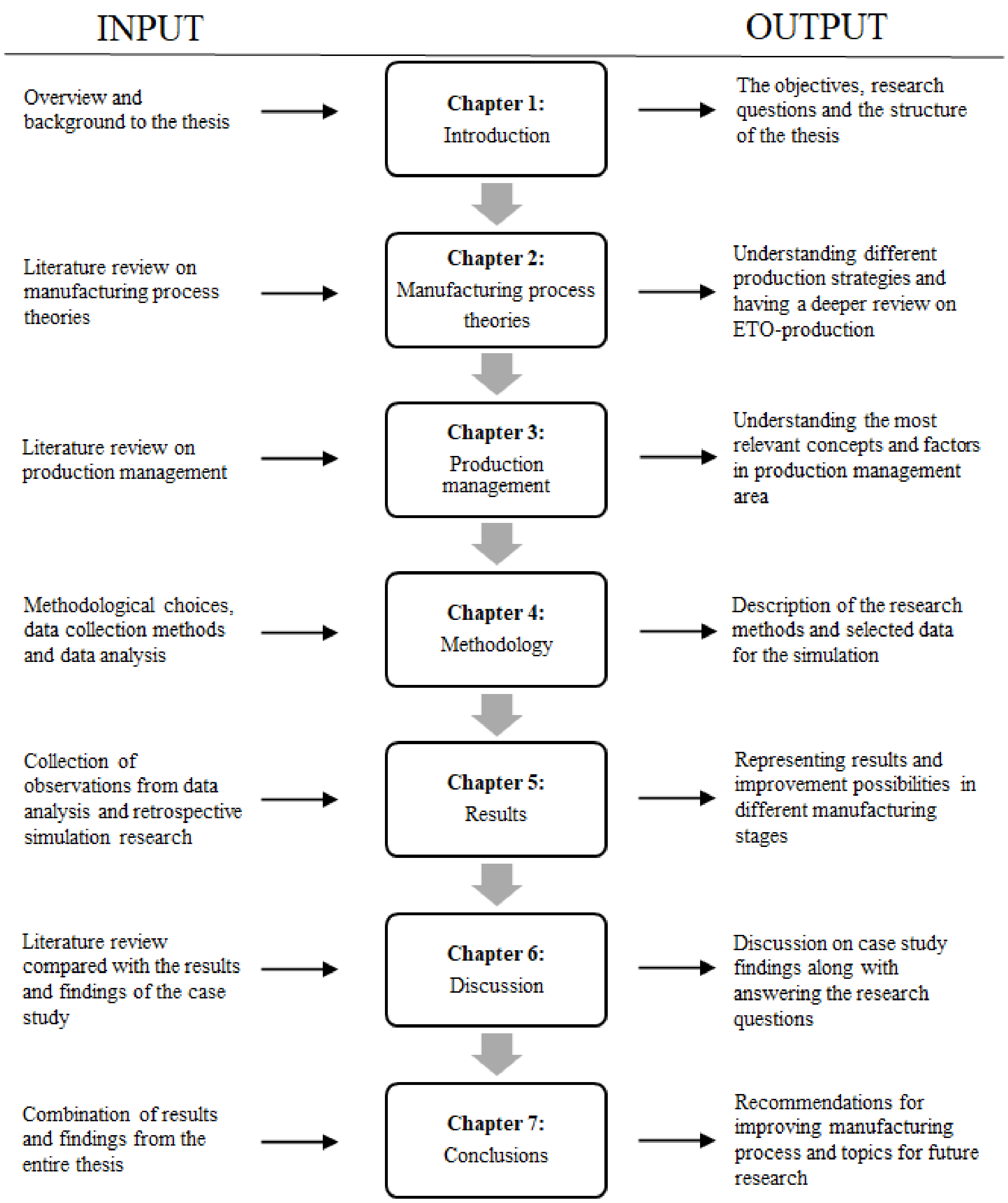

Figure 1. *The structure of the thesis.*

2 MANUFACTURING PROCESS THEORIES

This second chapter presents the literature review of manufacturing process theories and provides an overview of different types of manufacturing environments. A manufacturing process regards how the company controls production activities to satisfy customer demand over a specific time horizon (Graves 1999, p. 1). Its main objective is to develop a plan that meets the demand at minimum cost or fills the demand that maximizes profit. The plan may vary due to differences in manufacturing and market context (Graves 1999, p. 1).

2.1 Major manufacturing environments

Based on Olhager (2003, p. 320), the most common manufacturing environments or strategies are make-to-stock (MTS), make-to-order (MTO), assemble-to-order (ATO) and engineer-to-order (ETO). Each of these four types of environments are different and have specific characteristics.

Make-to-stock (MTS) is a production strategy where products are usually standardized functional products with predictable demand and a longer life span. This strategy is based upon the forecasts of product demands, and production is accomplished without considering the specifications of customer orders (Rafiei & Rabbani 2011, p. 550). Sharda & Akiya (2012, p. 161) depict the MTS production strategy as: “it can streamline production, reduce customer lead time, and reduce product transitions costs, but it can lead to higher inventory and product expiration costs.”

Make-to-order (MTO) is an opposite production strategy of MTS. In MTO, the manufacturing process begins only after a customer’s order is received. It is also possible to combine these two strategies, which is called a hybrid of MTS and MTO. In this type of strategy, semi-finished products are stocked in intermediate storage and finished after a customer order is received (Sharda & Akiya 2012, p. 161). In another article, Ioannou & Dimitriou (2012, p. 551) describe the MTO manufacturing environments as being typically "characterized by unique requirements, such as: highly sophisticated product types with high customization levels and customer involvement in product design and, thus, long lead times."

Assemble-to-order (ATO) regards an environment like MTO, however the products are usually assembled from components to fulfill the customer's specific needs. This usually means that there are multiple end products which comprise complex subassemblies (Atan et al. 2017, p. 866), and therefore the most important factor in ATO production is inventory management. Managing an ATO inventory system involves two control policies: the replenishment policy, which determines the ordering of components, and the allocation policy, which distributes components to serve different demands (Reiman et al. 2016, p. 436). Assemble-to-order systems are difficult to analyze and manage since they can be viewed as a combination of an assembly system and a distribution system (Atan et al. 2017, p. 867).

The different manufacturing situations presented above and ETO, which is presented later in a more in-depth overview, relate to different positions of the customer order decoupling point (CODP). The CODP separates the manufacturing stages that are forecast driven (upstream) from those that are customer order driven (downstream) (Olhager 2003, p. 320).

2.2 A customer order decoupling point

A customer order decoupling point (CODP), or which some researchers call an order penetration point (OPP), regards a point where forecast-driven activities change into real customer orders (Van Donk & Van Doorne 2016, p. 2580). As Figure 2 presents, different product delivery strategies relate to different OPPs. The dotted lines depict the production activities that are forecast driven, whereas the straight lines depict customer-order-driven activities (Olhager 2003, p. 320).

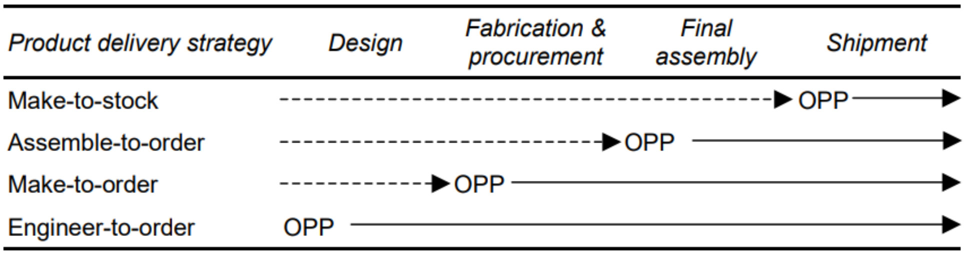

Figure 2. *The position of OPP (=CODP) in different manufacturing environments (Olhager 2003, p. 320).*

Andreev & Panayotova (2013, p. 245) describe the meaning of CODP in a project environment as: “The philosophy of CODP therefore is founded on the opportunity given to the customers to determine the final appearance of their end product/service, by means of their choice among a number of alternatives offered at CODP.”

2.3 Engineer-to-order supply chain

Olhager (2003, pp. 320-321) simplifies the classification between different production environments regarding the location of the CODP. As shown in Figure 2, in ETO production the decoupling point is located at the design stage and means that the manufacturing process begins with a customer’s order. This type of production is typically used in project-specific environments, where products are highly customized and customer specific (Gosling & Naim 2009, p. 744).

In ETO production, every product is the ultimate result of a project (Yang 2013, p. 109), and project-specific industries are typically highly schedule orientated and deliveries must be on time. Just-in-time (JIT) production is a philosophy that aims to achieve excellence through continuous improvements in productivity and the elimination of waste (Ríos-Mercado & Ríos-Solís 2012, p. 5). According to Yang (2013, p. 111), operation improvement practices that involve a JIT management philosophy, such as the elimination of waste, employee involvement, supplier participation and total quality control, may help a company to achieve manufacturing goals in the ETO environment. The JIT management philosophy is presented more deeply later in this thesis.

The poor coordination of project activities concerns a repetitive issue that occurs across multiple companies that work in ETO environments. Based on Mello et al. (2015, p. 1023), poor coordination represents a major reason for delays that increase the overall lead time. Mello et al. (2015, p. 1027) also state that "in ETO companies, both engineering and production are fundamental processes to fulfil a customer order." This means that cooperation between engineering and production must function flawlessly.

In the ETO environment, the engineering process regards the largest controllable consumer of lead time by requiring up to one half of the total lead time (Little et al. 2000, p. 546). The engineering process is usually considered to be a bottleneck resource although it is a core process and is never supposed to be outsourced (Gosling & Naim 2009, pp. 741-742). The engineering process is distinct from traditional shop floor processes since its inputs and outputs are intellectual rather than physical in nature (Grabenstetter & Usher 2015, p. 204). The engineering office often needs to release design documentation and report to the factory in order to meet the deliveries of special parts and manage the bill of materials (BOM) (Cutler 2009, pp. 36-37).

According to Cutler (2009, p. 36), although nearly every order begins with engineering, this process often requires far too much time. He thinks that designers are fearful of releasing the BOM information too early due to the demands that clients' changes or factories can create for them. This leads to the result where the purchasing area receives information too late and is unable to purchase special accessories in time or at affordable prices. (Cutler 2009, p. 37)

2.4 Characteristics of ETO production

Many industrial firms can be characterized as an ETO company. These companies may differ in terms of complexity of products, degree of customer specification, complexity of the production process and the characteristics of the market area (Bertrand & Muntslag 1993, p. 4). Engineer-to-order companies produce products that are often used in large projects with tight schedules, and as a result it is not unusual for their customers to impose large cost penalties for lateness (Grabenstetter & Usher 2015, p. 202). This means that supplier companies must understand the importance of on-time deliveries.

Bertrand & Muntslag (1993, pp. 5-6) state that an ETO production situation can be described using three aspects: dynamics, uncertainty and complexity. A production situation can be called dynamic if, for example, sales volumes can be predictable but are difficult to anticipate. Uncertainty is defined as a difference between the amount of information required to perform a certain task and the amount already available in the organization. The complexity of the production situation originates from three main factors: the structure of the goods flow, multi-project character of the situation and the assembly structure of the product (Bertrand & Muntslag 1993, pp. 6-7).

Hicks et al. (2000, p. 179) think that the characteristics of ETO companies are described in terms of their markets, products and the internal processes of their organization. Based on Gosling & Naim (2009, p. 750) the ETO supply chain can also be characterized as one of several supply chain structures which has a high degree of customization compared with others.

According to Grabenstetter & Usher (2015, p. 204), little information exists about the ETO process and how engineering due dates are calculated. The challenges of complex ETO environments have forced multiple firms to adopt similar process steps, which are presented below in Figure 3 (Grabenstetter & Usher 2015, pp. 204-205):

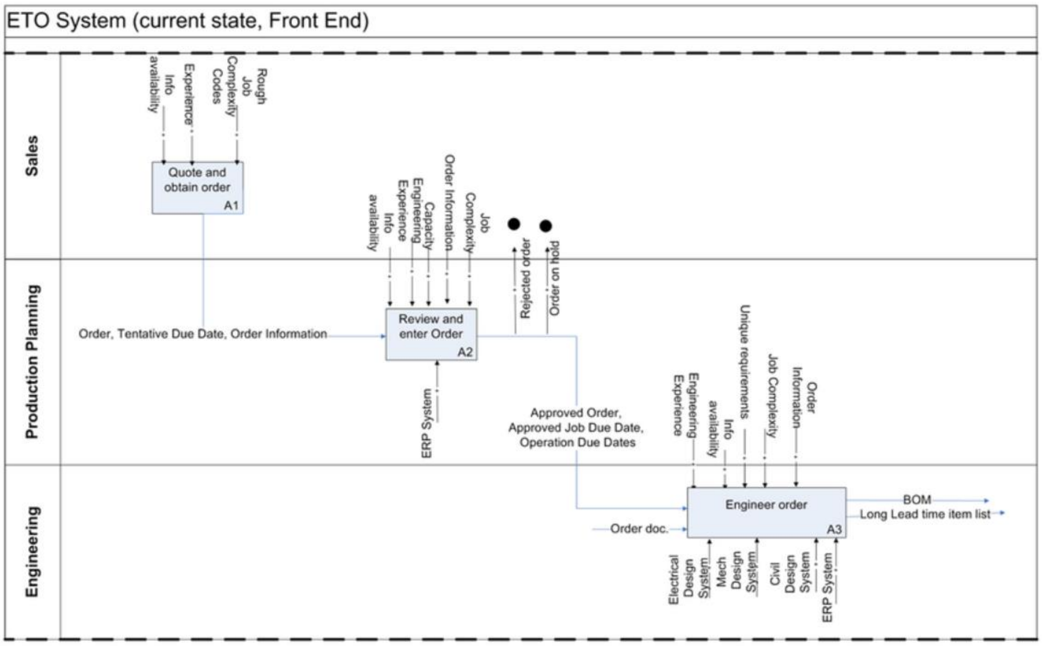

Figure 3. *ETO engineering flow of front-end process (Grabenstetter & Usher 2015, p. 205).*

2.5 Competitive factors in ETO production

Hicks et al. (2000, p. 183) simplify competition between ETO companies by stating that, “A key competitive factor in ETO markets is delivery performance.” Improving the overall performance regards two key components: reducing lead-time and increasing the reliability of lead-time estimates (Hicks et al. 2000, p. 183). Modular configurations and standard items can reduce costs and lead times, however this kind of modularity moves construction away from the ETO and towards the ATO structure (Gosling & Naim 2009, p. 745).

In many cases, the competitive advantage has historically been sought through customization capabilities (Hendry 2010, p. 22). Although the ability to customize is not always a source of competitive advantage, it may merely qualify an organization to operate in in pure customization markets like ETO (Gosling & Naim 2009, p. 745). Because competitors have become increasingly able to offer customization too, other factors such as the price, reputation and customer relationships have also become important (Hendry 2010, p. 22).

According to Cutler (2006, p. 64), some of the best opportunities for improving competitiveness in the ETO environment can be found in the business process and office systems rather than solely the shop floor. Eliminating non-value-added activities in the engineering process, estimating, customer quotations, purchasing, shop-floor reporting and accounting functionality offers opportunities for dramatic improvement. Regarding the most key sources of competitive advantage, Hicks et al. (2000, p. 189) have stated that “effective sharing of knowledge and information requires the use of common databases that support tendering, design, procurement and project management.” This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information (Hicks et al. 2000, p. 189). These kinds of databases are usually called enterprise resource planning (ERP) systems, which are later presented in further detail.

According to Gosling & Naim (2009, p. 747), a total cycle time (TCT) is also an opportunity to gain a competitive advantage. Some research has examined time compression to improve the ETO supply chain. Towhill’s (2003, p. 586) research on TCT concludes that a 40% reduction in project time can lead up to a 25% reduction in total work undertaken and costs. Procurement, competitive bidding and the design stage have been highlighted as time-consuming bottlenecks for ETO supply chains (Gosling & Naim 2009, p. 747).

3 PRODUCTION MANAGEMENT

This third chapter presents the literature review of production management. In the literature, there are multiple terms for production management, however those used in thesis are manufacturing planning and control (MPC) and production planning and control (PPC). Production management concerns the planning and control of different functions that relate to a company's products and services (Martinsuo et al. 2016, p. 139).

Manufacturing planning and control aims to define what, how much and when to produce, buy and deliver (de Oliveira Neto & Lucato 2016, p. 148). Vollman et al. (2005, p. 7) define MPC as follows: "The essential task of the MPC system is to manage efficiently the flow of material, to manage the utilization of people and equipment and to respond to customer requirements by utilizing the capacity of our suppliers."

3.1 Evolution of production management

Manufacturing firms have always attempted to find better ways to improve their performance and competitiveness. Research conducted in the production management field has advanced multiple firms in a wide range of production environments, especially in investment planning, solution techniques, software and inventory management (Buzacott 2013, p. 6766). Many things have changed in the area of operations management over the past 50 years. Today, firms need to be competitive in many areas, such as quality, delivery, cost efficiency and flexibility (Olhager 2013, p. 6836).

Olhager (2013, p. 6836) also determined that the planning and control task has become more complex than before. In today's production, the lead times are shorter, product life cycles are shorter, bottlenecks must be utilized more efficiently etc.

Environments change and the focal point in MPC has shifted over decades. The evolution of focused areas on the planning level is presented below in Figure 4:

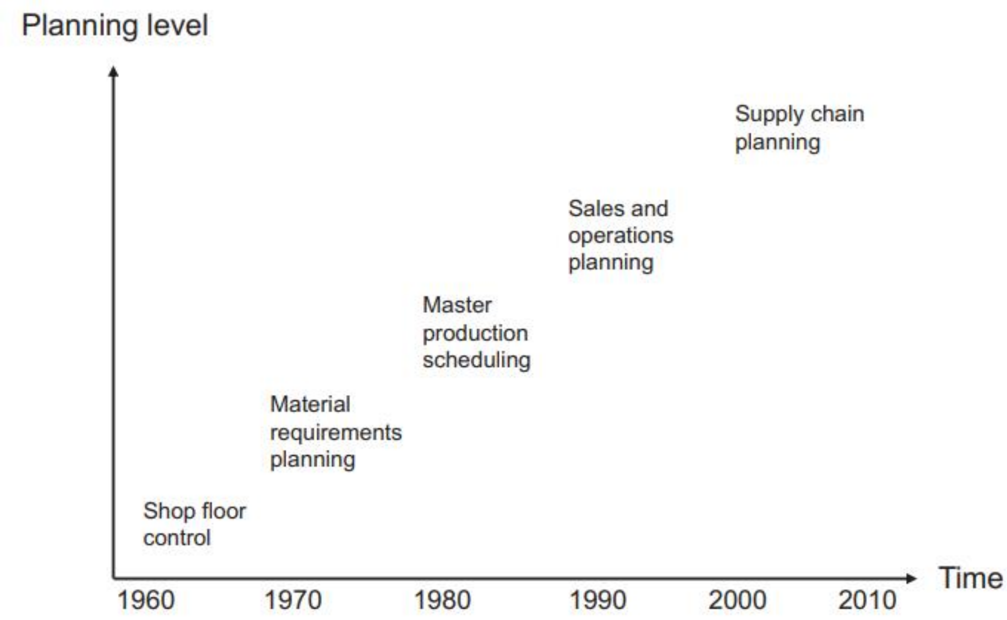

Figure 4. *The evolution of planning level focus shifting (Olhager 2013, p. 6837).*

Concerning the development of production over the past 50 years, Buzacott (2013, p. 6761) states: “Terms like supply chains have come into widespread use. Techniques like Kanban and Just in Time have been developed.” The main thing that Olhager (2013, p. 6841) has noticed is that the focus on operations planning and control has changed over a 50-year period from individual machines to larger plants in the area of supply chain.

Figure 5 shows the shifting of the evolution of improvement focus over 50 years. The first shift occurred around 1980, when companies began to realize that basic characteristics could be improved. The second shift occurred around the turn of the century, when companies observed the need for extending the planning and control system to include suppliers and customers (Olhager 2013, p. 6841).

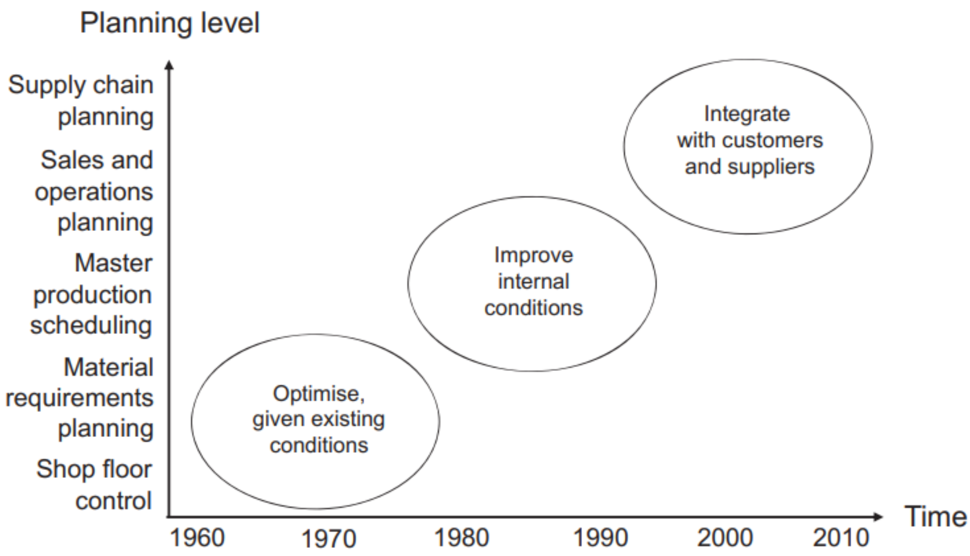

Figure 5. *The evolution of improvement focus shifting (Olhager 2013, p. 6840).*

3.2 Objectives of production management

The purpose of production planning is to schedule, sequence and launch the production orders into the activities in the factory with respect to the firm's strategies and the actual conditions of the production shop floor (Hassan Zadeh et al. 2014, p. 842). Both process planning and production planning focus on minimizing costs and times within the limits of the constraints while meeting all necessary requirements (Hassan Zadeh et al. 2014, p. 842).

Martinsuo et al. (2016, p. 139) define the main objectives of production management as a realization of customer value, cost efficiency, ability to deliver, quality and flexibility. Haverila et al. (2009, p. 401) think that the main objectives are capacity utilization rate, optimization of working capital, delivery reliability and an efficient production lead time. All these aspects lie at the core of the production management area. In summary, the main purpose of production management is to control and organize the company's use of resources in the most appropriate ways

(Haverila et al. 2009, p. 402). The formation of production management objectives is presented below in Figure 6:

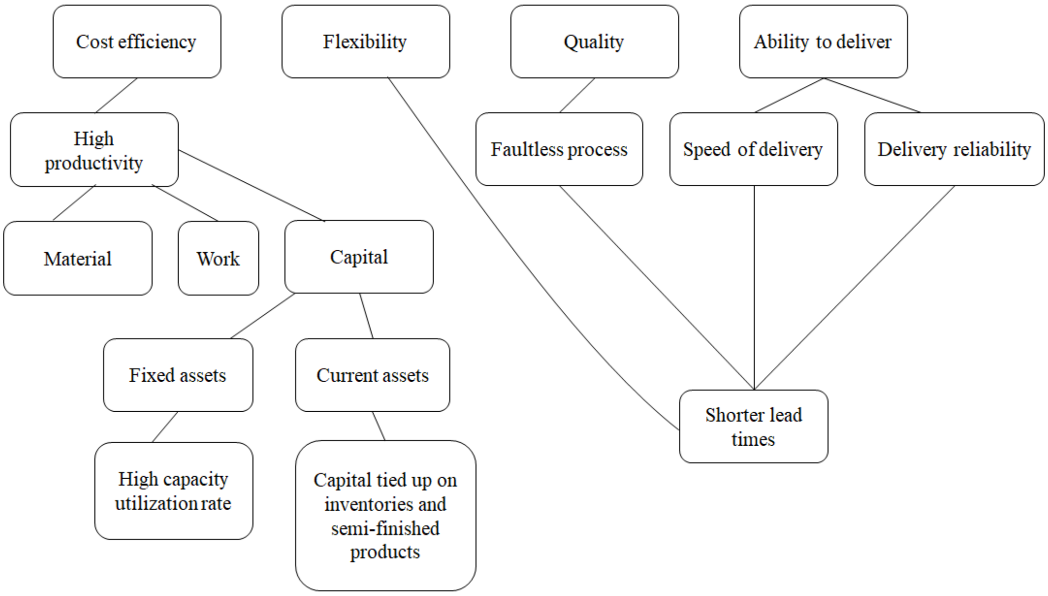

Figure 6. *The formation of production management objectives (Based on Haverila et al. 2009, p. 403).*

A high capacity utilization rate means that the capital productivity is strongly correlated to the volume of production. In addition, production batches should be organized so that all central resources are used in the most efficient manner. The minimization of current assets refers to the minimization of tied-up capital in raw materials, semi-finished products and in end-product store (Haverila et al. 2009, p. 402).

The ability to deliver regards a company's customer service function. Companies must ensure that they can deliver their products on time, and they must maintain their capability to deliver products based on the customer's needs (Haverila et al. 2009, p. 402).

These three main objectives are often presented in the form of a triangle. There are multiple disharmonies between these objectives, which affects the production in different ways. For instance, high delivery capability requires high inventories, which increases the amount of current assets. If every tip of the triangle is weighted in balance, the mass center is located in the center of the triangle. Although, this is not always the optimal solution and the objectives of production should be determined to follow the company's strategy along with competitive factors (Haverila et al. 2009, pp. 403-404). Disharmonies between production objectives are presented below in Figure 7:

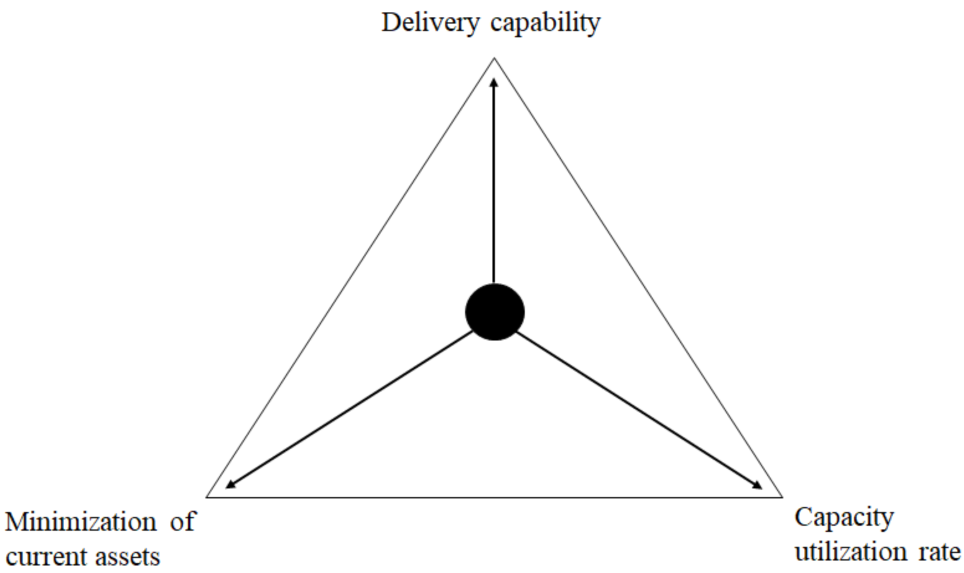

Figure 7. *Disharmonies between production objectives (Based on Haverila et al. 2009, p. 404).*

3.3 Process of production management

Production management tasks should be divided between different organizational levels and between manufacturing units. Top management should mainly focus on the company's strategy and function as a linkage between production and the strategy. Middle management and personnel who are responsible for production planning should focus on the allocation of resources, master production scheduling

(MPS) and controlling the overall schedule. At the same time, work supervisors and production personnel should focus on manufacturing planning with a weekly production program and overall control of the manufacturing process (Martinsuo et al. 2016, pp. 140-141).

The control of production planning can be either centralized in the combined planning department or decentralized to different manufacturing units. These alternatives each entail pros and cons, and the characteristics, strengths and weaknesses between centralized and decentralized production planning are presented below in Table 1 (Martinsuo et al. 2016, pp. 140-141):

Table 1. *Special characteristics between centralized and decentralized production planning (Based on Martinsuo et al. 2016, p. 141).*

	Centralized	Decentralized
Characteristics	• Centralized design personnel • Strong data processing system for data acquisition, integration and reporting • Especially suitable for high volume process production plants	• Responsibility of design in manufacturing units • Information system for combining data and reporting • Especially suitable for one-off production and serial production
Strengths	• Centralization of information • Coordination and distribution of work between manufacturing units • Uniform control of supply chain • Standardized procedures	• Responsibility for targets • Allocation of tasks directly to makers • Motivation • Easier to detect problems • Closer to customer interface, flexibility • Easier to develop
Weaknesses	• Rigidity, not flexible • Draw away from customers, manufacturing and products • Enormous scale, slowness in change • Complicated information systems • Counting on data from information system can include risks • Decision-making difficult	• Low transparency between units • Optimization challenges when demand, capacity and material availability varies • Differences in modes of operation • Not necessarily efficient in total

Production management can be viewed as a step-by-step process, whereby the company adapts the real-time and forecasted data on demand in their production planning and control process (Martinsuo et al. 2016, p. 139). The division of the production planning process into smaller, sequentially performed subprocesses is called a hierarchical production planning (HPP) (Vogel et al. 2017, p. 193). These steps are divided into different levels of an organization, and the steps and their content may vary due to different branches of industry and between different companies (Haverila et al. 2009, p. 409). Although steps vary, it is common to separate aggregate planning, master production scheduling and manufacturing planning in the process (Martinsuo et al. 2016, pp. 139-140). The traditional production management process is presented below in Figure 8:

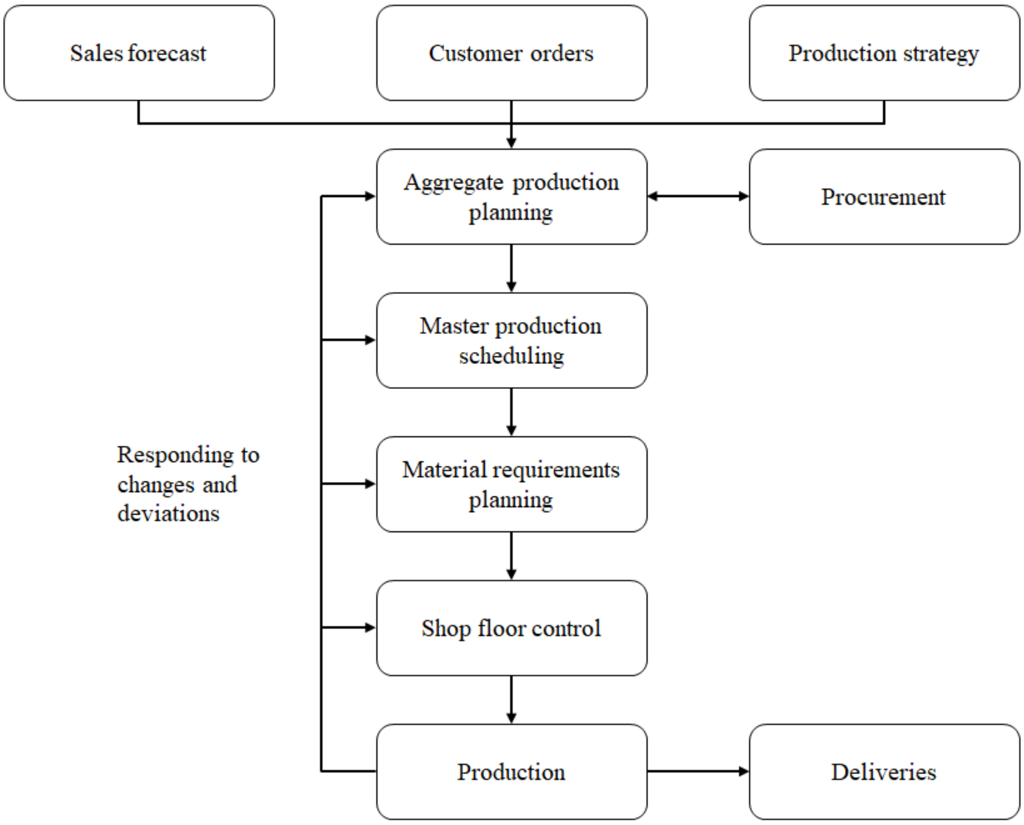

Figure 8. *The typical production management process (Based on Martinsuo et al. 2016, p. 140).*

During every stage of the production management process, deviations may appear and the plans need to be redesigned (Martinsuo et al. 2016, pp. 139-140). The amount of redesign and coordination depends on the accuracy of the production plans, as more detailed plans require a more complicated redesign process. It is unfortunately common in industrial environment for something that affects the decision making to appear at the last moment (Haverila et al. 2009, pp. 409-410).

3.3.1 Aggregate production planning

Aggregate planning is considered to be top-level planning, where the main purpose is to function as a link between top management and production. This planning focuses on the total volume of production, the need for resources, inventories and procurement (Martinsuo et al. 2016, p. 143). Aggregate production planning (APP) is meant to balance capacity requirements and production quantities for medium-term planning horizons (Gangster 2015, p. 521).

Aggregate plans aim to provide the basic input for all further planning steps (Gangster 2015, p. 521). In aggregate planning, the decision maker first estimates an aggregate cost component, including labor costs, capacity changing costs, production costs, inventory holding costs, stock-out and backlogging costs and subcontracting costs (Türkay et al. 2016, p. 4). Subjects that affect the APP process and decisions that need to be executed in APP are presented below in Figure 9:

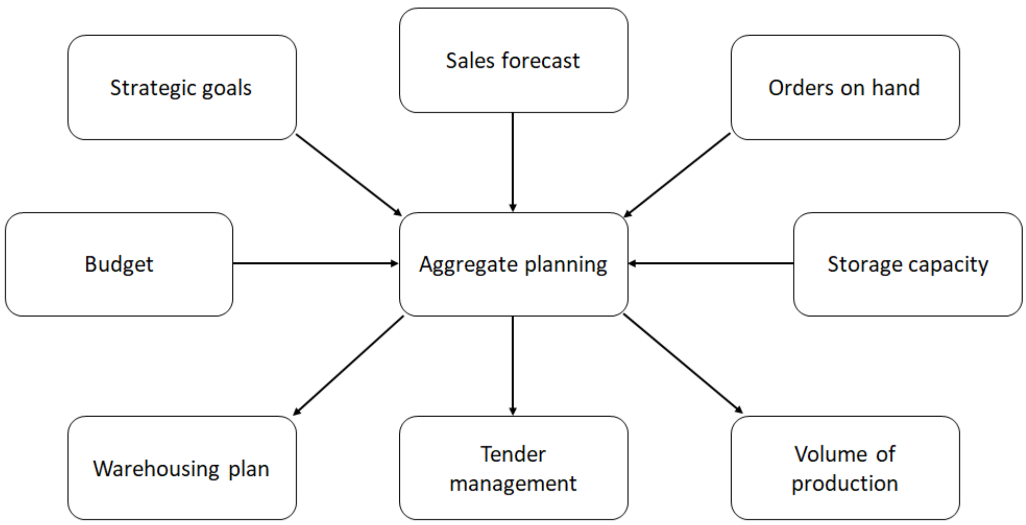

Figure 9. *Aggregate production planning (Based on Haverila et al. 2009, p. 412).*

Aggregate production planning is typically performed based on sales forecasts (Gangster 2015, p. 522) and can be done as a part of the yearly budget draft, but usually plans must be redesigned during the budget period (Haverila et al. 2009, pp. 411-412). Highly uncertain demand leads to the frequent revision of production planning from one planning period to another, which causes not only anxiety/nervousness in production environments but is also one of the major cost drivers (Demirel et al. 2018, p. 45). The need for demand flexibility in aggregate planning is driven by fluctuations in market demand, which occur for reasons such as the product lifecycle and seasonality. Therefore, the flexibility of the workforce and working time play an important role (Sillekens et al. 2010, p. 5058).

The resulting plan should then be specified to form the master production schedule (MPS) and to obtain the materials requirement plan (MRP) (Türkay et al. 2016, p. 4).

3.3.2 Master production scheduling

Master production scheduling (MPS) is a process of developing plans for identifying which quantities of products should be manufactured during a certain time period. This process therefore drives operations regarding what is assembled, manufactured and purchased (Vieira & Favaretto 2006, p. 3607). Master production scheduling is generally accomplished over a horizon of multiple weeks and is based on estimated or known demands (Englberger et al. 2016, p. 6192). This scheduling operates the strategic plans and interfaces between strategic planning and tactical planning in an integrated production planning and control system (Vieira & Favaretto 2006, p. 3608).

According to Vogel et al. (2017, p. 201), MPS makes the decisions regarding capacity and targets in terms of inventory levels. Production work loading charts are typically utilized in the MPS process. In a loading chart, it is possible to observe the backlog of orders and forecasts of a certain timeframe (Haverila et al. 2009, pp.

416-417), and the overall objective is to balance the loading. An example of a capacity loading chart is presented below in Figure 10:

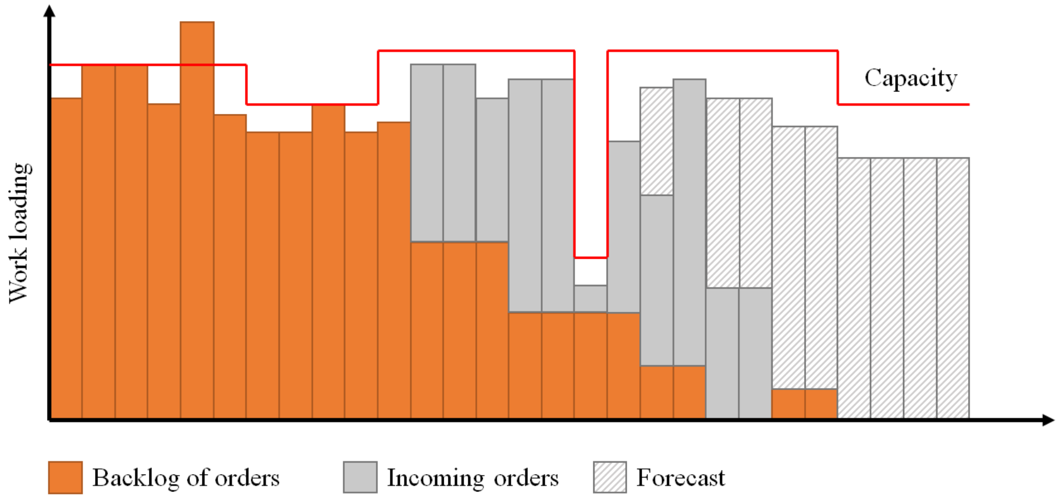

Figure 10. *An example of a work loading chart (Based on Haverila et al. 2009, p. 417; Martinsuo et al. 2016, p. 144).*

The main purpose of MPS is to plan product families, which is a group of items that share the same setup, while a product type comprises all product families with similar holding costs, productivities and seasonality (Vogel et al. 2017, p. 199). The MPS process can be simple, however it becomes a highly complex problem as the numbers of products, periods and resources (production lines, assembly lines, machines, production cells) increase.

According to Vieira & Favaretto (2006, p. 3611), there are three main aspects needed for the creation of MPS:

- A clear definition of objectives and respective performance measure indicators.
- Parameters to be used, such as initial inventories and gross requirements, which include firm customer orders and demand forecasts, standard lot sizes and minimum or safety inventory levels.

- Final adjustments must be made by the master scheduler (human). No planning (or scheduling) information system will generate a plan (or schedule) that will perfectly fit the expectation of those responsible for this task in the industry.

Table 2. *Input and output parameters of master production scheduling (Based on Vieira & Favaretto 2006, pp. 3611-3613).*

Input parameters	Output parameters
• **Planning horizon** *(usually weeks to a couple of months)* • **Resources and products** • **Gross requirements** *(mainly demand forecasts and customers orders)* • **Subcontracted** *(the quantity to be manufactured by a third-party company in a certain period)* • **Standard lot size** • **Minimum lot size** • **On-hand inventory** • **Safety (or minimum) inventory** • **Maximum inventory** • **Production rate** *(number of products that can be made per time unit)* • **Production routings** *(detailed information on how each product is to be manufactured)* • **Changeover (or setup) time** • **Backlogging** *(the maximum quantity of a product)* • **Capacity** • **Overtime** *(the maximum number of hours (or days) that can be used as overtime per time period per resource)*	• **Beginning inventory** • **Ending inventory** • **Net requirements** *(what should be manufactured)* • **MPS row** *(contains the final results, i.e., product quantities to be made.)* • **Used capacity** *(for each resource)* • **Requirements met** • **Requirements not met** • **Service level** *(a percentage representing how much of the gross requirements (demand and orders) will be met by the MPS)*

As a result, MPS transforms general information into more detailed information, which entails desegregating such plans into detailed programs that are individually defined for each product and usually written in weekly and/or monthly time periods. The input and output parameters for MPS are presented above in Table 2. An important factor is that MPS also provides information to the sales function regarding what can be promised to customers and when delivery can be made (Vieira & Favaretto 2006, p. 3609).

In a hierarchical production planning procedure, MPS is a series of planning decisions that guide the material requirements planning (Soares & Vieira 2009, p. 550).

3.3.3 Material requirements planning

Material requirements planning (MRP) aims to efficiently schedule production requirements so that the raw materials, components and subassemblies can be provided in the right amount and at the right time (Ram et al. 2006, p. 399). Material requirements planning systems operate at a part number/plant level of detail, and they divide end-item demands through the bills of materials (BOM) and supply chain to determine planned manufacturing releases and purchase orders (Milne et al. 2012, p.1566). Matters related to MRP are presented in Figure 11.

Material requirements planning is based on the idea that the company can use it to determine the application for the planned production of materials. A master program initializes and uses a BOM to convert it into a calendar of required materials, which can be further used for scheduling orders that are sent to suppliers and other internal operations (Rusanescu 2014, pp. 21-22). Material requirements planning has its strength in traditional job shops, which require flexibility in the production sequence, the quantity of production, and the timing of the production process (Plenert 1999, p. 98).

Rusanescu (2014, p. 22) defines MRP's purpose: "MRP has its principal forms from master program and using it to design a detailed timetable for ordering materials." A master program article shows the number of units made every week. The manufacturing unit requires a list of materials that are needed and a timetable for the suppliers, and the required materials are either purchased or produced internally. Based on Rusanescu (2014, p. 22), the main results of MRP are:

- Calendars showing the necessary materials
- Calendars showing when purchased materials should be ordered
- Calendars for the operations required to produce materials internally

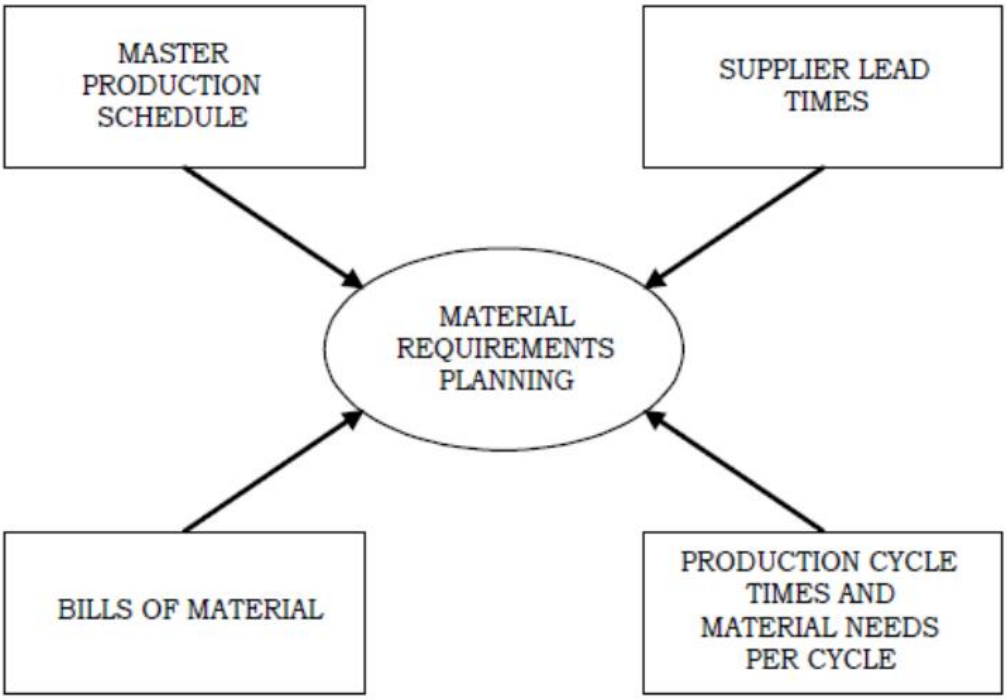

Figure 11. *MRP in a context of the production management process (Rusanescu 2014, p. 24).*

3.3.4 Shop floor scheduling and control

Shop floor scheduling (SFS) is a part of production management that ensures material flow throughout the production system by scheduling all present jobs in terms of their release date (Stock & Seliger 2015, p. 510). Shop floor scheduling requires a consideration of the dynamic, time-varying and unpredictable nature of the manufacturing environment (Tian et al. 2019, p. 1).

In a real-world shop floor environment, it is rarely the case to execute assignments exactly as planned. Wang et al. (2008, p. 2433) state that usually in industrial companies, "operation durations tend to vary, machines break down, raw materials fail to arrive on time, new customer orders appear, others get cancelled, etc." To address these issues, practical scheduling systems need to be able to effectively reorganize the shop floor production plan and repair or redo the production schedule accordingly (Wang et al. 2008, pp. 2433-2434). These aspects mentioned above highlight the importance of flexibility.

As some researchers demonstrate, due date assignment (DDA) can be considered to be the most important task in shop floor control (SFC). Assigning exact due dates and delivering goods to the customer on time will enhance the quality of customer service and simultaneously provide a competitive advantage (Hsu & Sha 2004, p. 1727). In addition, DDA has multiple cost effects; for example, if a job is finished prior to its due date, it must be held in inventory until that date, which consequently incurs an earliness cost depending on the length of time it is held in inventory (Shabtay 2016, p. 79). In some cases, a firm may consider the possibility of outsourcing some time-sensitive orders, such as when the system is highly loaded and completing all the orders in-house would lead to high cost penalties due to, for example, late deliveries or poor quality (Wang et al. 2008, p. 2451).

3.4 Just-in-time manufacturing

Just-in-time (JIT) is a production philosophy that was developed for the automotive industry in Japan, and its main goal regards the elimination of waste by optimizing the manufacturing process (Vincent 2011, p. 3191). Typical characteristics for JIT production include high productivity, low tied-up capital, high quality and short lead time (Haverila et al. 2009, p. 428).

Just-in-time production is one of the main principles for lean manufacturing and leads to associating JIT with efficiency, continuous improvement, quality and optimal flow (Ríos-Mercado & Ríos-Solís 2012, p. 5). The backbone of JIT manufacturing is a fluent production, where the flow of materials and overall production management have been organized in the most efficient manner (Haverila et al. 2009, p. 428).

According to Haverila et al. (2009, p. 429), the key principles for JIT production are:

- Efficient quality management
- Commitment of employees in development work
- Minimization or even removal of intermediate storage
- Thin and steady material flow
- Continuous development in operations
- Preventive maintenance
- Development of customer relationships
- Short lead time
- Clear flow of materials
- Small manufacturing lot size
- Levelled production
- Visual production management
- Pull production system

3.5 Digitalization of production management

Digitalization has significantly advanced in recent years, as nowadays multiple firms are using computer-based enterprise resource planning (ERP)-software to support their production management. Based on Poston & Grabski (2001, p. 275), an ERP system automates business processes and provides an electronic trail of employee responsibility, which results in the improvement of information management quality through enhancing the integration of enterprise-wide information and reducing administrative processes and operating costs. The use of ERP systems is beneficial or even essential for organizations that face dynamic market requirements (Tenhiälä & Helkiö 2015, p. 162).

According to Su & Yang (2010, p. 81), when ERP systems are fully integrated in a business organization, they can be expected to yield many benefits, such as a reduction of cycle time, faster transactions, better financial management, the laying of groundwork for e-commerce, linking the entire organization together seamlessly, providing instantaneous information and making tacit knowledge explicit. Enterprise resource planning systems significantly vary between companies and can be customized to support the customer's needs, but the market of ERP systems is dominated by a small number of vendors, including SAP, Oracle and Microsoft (Holmberg & Johansson 2017, p. 17).

3.6 Production management in the ETO environment

According to Rahim & Baksh (2003, pp. 184-185), the variability and uncertainty characterizing project based, ETO companies generate a complexity that requires specifically tailored managerial approaches to handle all the processes, from design and engineering to production and delivery. Companies working in the ETO environment usually manage a high level of uncertainty in terms of product specification, demand composition, supply and delivery lead times and duration of production processes (Adrodegari et al. 2015, p. 911). This generates challenges in production management at ETO companies.

Due to the difficulties of the ETO manufacturing strategy, carefully tailored managerial paradigms, methods and supportive tools are required for effective and efficient management (Adrodegari et al. 2013, p. 289). The main consequence of lacking specific organizational and managerial approaches for the ETO context is the incidence of re-work, with consequent time-to-finish delays and total increased costs (Adrodegari et al. 2015, p. 913).

Adrodegari et al. (2015) executed a case study comparing the types of action in 21 different industrial ETO companies. This study led them to develop an empirical, high-level production planning reference framework using typical steps. This framework is presented in Figure 12.

According to Adrodegari (2015, p. 922) the framework summarizes all the tasks supporting the primary activities related to PPC processes and is divided into two parts: (1) engineering and plan and (2) execution and control.

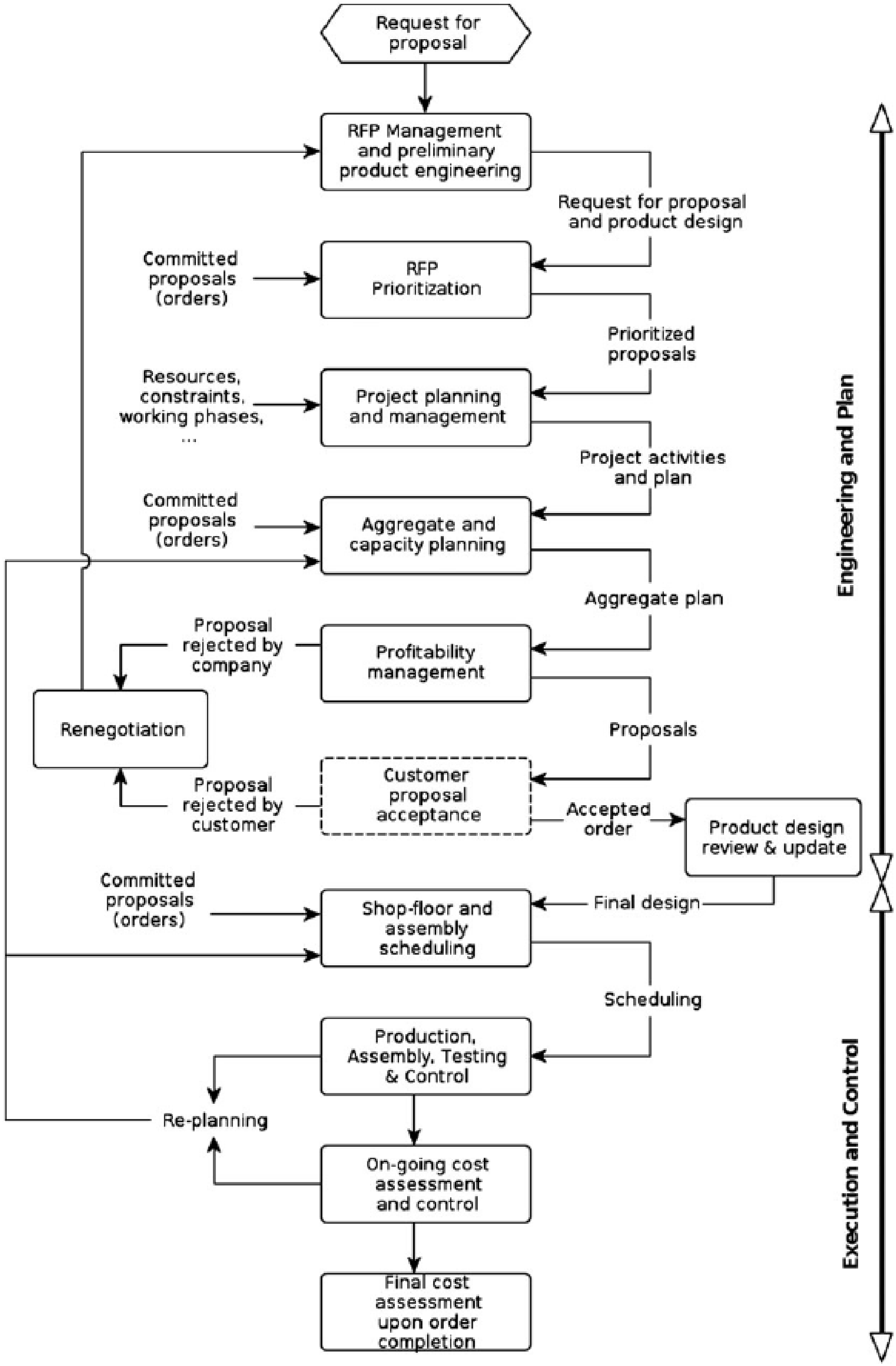

Figure 12. *The process reference framework for a typical ETO company (Adrodegari 2015, p. 921).*

4 METHODOLOGY

This fourth chapter explains the research methods used in this thesis. First comes the introduction of the case company and a small overview of the precast concrete industry. Afterwards follows the explanation on data collection methods, data analysis and reliability of the results, and then finally this chapter presents how the retrospective simulation is executed.

4.1 Case company introduction

The case company for this research is a precast concrete element manufacturer which operates in Finland. The company is a leading concrete element manufacturer in Finland, operates in 17 different locations nationally and produces all the different types of concrete elements in different factories. This research is focused on the company factory that is in southern Finland, which manufactures only partition wall and lift shaft elements.

Partition wall elements are traditional full concrete panels that form the framework of multi-storied buildings. Partition walls made from concrete are typically located between apartments. Partition walls are made in all different sizes and shapes, every wall panel has its own manufacturing drawing, and every element has a different kind of lead-through equipment and holes in specific places. As a result, the manufacturing drawings are unique for every element.

Partition walls also include electrical reservations, such as tubing and electrical socket bases, as well as reservations for water pipelines. Partition walls are reinforced in different manners due to the differing load stress of the elements. These accessories mentioned above are unique and need designing, which is usually done by a design engineer who uses architectural drawings, structural drawings, electrical drawings and heating, ventilation and air conditioning (HVAC) drawings to design an element that is properly sized and includes all the necessary equipment.

The design work represents an important phase in the manufacturing process and where many important decisions are made that affect the cost structure. The case company has its own design department for improving the quality and cost efficiency of the design solutions. Manufacturing drawings are currently created in either a company's design office or by an external structural engineer consulting service, however the case company has the goal of having all manufactured elements designed by their own design office.

The case company's factory used in this research has a design office on site, where designers design partition wall elements which are manufactured at the same factory. This illustrates the collaboration between the design office and production, which consequently provides a perfect opportunity to analyze the improvement potential of the whole ETO manufacturing process, especially regarding how the case company can benefit from having an internal design office.

4.2 Data collection and analysis

This research is based on a case-typed data analysis and simulation, whereby the real manufacturing process schedule during a three-month period is analyzed and then simulated as a retrospective study with quicker lead time. A case study typically regards an in-depth inquiry into a topic within a real-life setting (Saunders et al. 2016, p. 184). Both qualitative and quantitative methods are used in this research. Quantitative is often used as a synonym for any data collection technique or data analysis procedure that generates or uses numerical data (Saunders et al. 2016, p. 165), and quantitative methods are used in simulation research where both input and output data are numerical.

On the other hand, qualitative is often used as a synonym for any data collection technique (such as an interview) that generates or uses non-numerical data (Saunders et al. 2016, p. 165). Qualitative methods are used by interviewing the company's experts about the observations from data analysis and to analyze the enhancement opportunities and possible related risks or challenges.

The qualitative data are mainly collected via semi-structured interviews from the case company's employees who work in different stages of the manufacturing process. In a semi-structured interview, the researcher has a list of themes and possibly some key questions to be covered, however their use may vary from interview to interview (Saunders et al. 2016, p. 391). Semi-structured interviews provide an opportunity to deepen the interviewees' answers with further questions and grant the ability to build on their responses (Saunders et al. 2016, p. 394), which increases the overall flexibility of the interviews. In total, seven employees were interviewed for this research, and their roles and experiences in the company are presented below in Table 3:

Table 3. *The roles and experiences of the interviewees.*

Number	Role in the company	Experience in the company
1	Production planner	12 years
2	Transportation planner	12 years
3	Design manager	2 years
4	Designer	7 years
5	Design manager	14,5 years
6	Production supervisor	1 year
7	Production supervisor	Half a year

The interviews were conducted as three group interviews, with participant numbers one and two in the first group; three, four and five in the second group; and six and seven in the third group. The interviews were recorded to ensure a more complete analysis, and the total time of recorded interviews was 165 minutes. The numerical data for the retrospective simulation and data analysis were collected from the company's ERP system, which holds all the manufacturing information from design stage to delivery.

4.3 Reliability of the results

The reliability of the results must be examined when analyzing the research, because it is problematic to form conclusions if it is not clear how the results were formatted and regarding whether they match the purpose. Reliability refers to replication and consistency, and Saunders et al. (2016, p. 202) describe reliability as: "If a researcher is able to replicate an earlier research design and achieve the same findings, then that research would be seen as being reliable."

Reliability can be divided into internal and external reliability. Internal reliability refers to ensuring consistency during a research project, which can be achieved by using more than one researcher in the project to analyze the data (Saunders et al. 2016, p. 202). External reliability refers to the data collection techniques and analytic procedures and regards the replication of the study, where if research would be replicated by a different researcher, it would produce consistent findings (Saunders et al. 2016, p. 202).

According to Saunders et al (2016, pp. 202-203), ensuring the reliability of the research is not easy and several threats to reliability might occur. Possible threats to reliability are presented below in Table 4:

Table 4. *Threats to reliability (Based on Saunders et al. 2016, p. 203).*

Threat	Definition and explanation
• **Participant error**	Any factor which adversely alters the way in which a participant performs. For example, asking a participant to complete a questionnaire just before a lunch break may affect the way they respond compared to choosing a less sensitive time (i.e. they may not take care and hurry to complete it)
• **Participant bias**	Any factor which induces a false response. For example, conducting an interview in an open space may lead participants to provide falsely positive answers where they fear they are being overheard, rather than retaining their anonymity
• **Researcher error**	Any factor which alters the researcher's interpretation. For example, a researcher may be tired or not sufficiently prepared and misunderstand some of the more subtle meaning of his or her interviewees
• **Researcher bias**	Any factor which induces bias in the researcher's recording of responses. For example, a researcher may allow her or his own subjective view or disposition to get in the way of fairly and accurately recording and interpreting participant's responses

The data for the analysis and simulation model regard real-life production data that vary between different months due to the state of the market. This makes the exact replication of the research somewhat difficult, however the overall observations should be consistent. Interviews of the company's experts will occur in a secure meeting room, where the chances for interruptions or disturbance are minimized as much as possible. Interviews will be timed in a timeframe so that the interviewees are not in a hurry and can concentrate on questions and observations from the data analysis.

4.4 Retrospective simulation research and data analysis

The case company has their own manufacturing process in partition wall elements, which includes some delays between manufacturing steps. Some delays are necessary while others are unnecessary. The main goal of this research is to locate the hot spots or bottlenecks using a data analysis. In a simulation model, the production schedule from the selected time period will be enhanced and optimized.

These results and opportunities will then be evaluated with the help of the company's employees in different stages of a manufacturing process.

The selected time period for the data analysis is a three-month time span in the year 2019. The selected months are September, October and November. This three-month timeframe is as close to the optimal schedule as possible since there are no summer vacations left and the winter has not yet slowed the construction sites, which means that production is running at maximum aggregate capacity.

In total, there were 2835 individual partition wall elements manufactured during this time period, and 2708 elements were delivered to customers. Wall elements are typically measured as a surface area of the element and published in this parameter, and 25 840 m^2 of walls were casted. There were 65 working days in this period of time and elements were casted every day, which means that the average daily production amount was 43,62 elements or 397,54 m^2 per working day.

In total, manufactured elements during this three-month period were part of 21 individual projects (different orders). The segmentation of the production schedule is presented in Figure 13. Twelve of these projects have been designed by the company's own design office, which means that 57% of projects during this time period were designed internally. Regarding how many elements were produced in each project, 68% elements were made with the company's own designers manufacturing drawings during this three-month period.

Initial data for data analysis are listed below in bullet points:

- High demand season
- Three-month period with 65 working days (13 weeks)
- 2835 individual partition wall elements manufactured
- 21 different projects
- 68% of production is pure ETO production

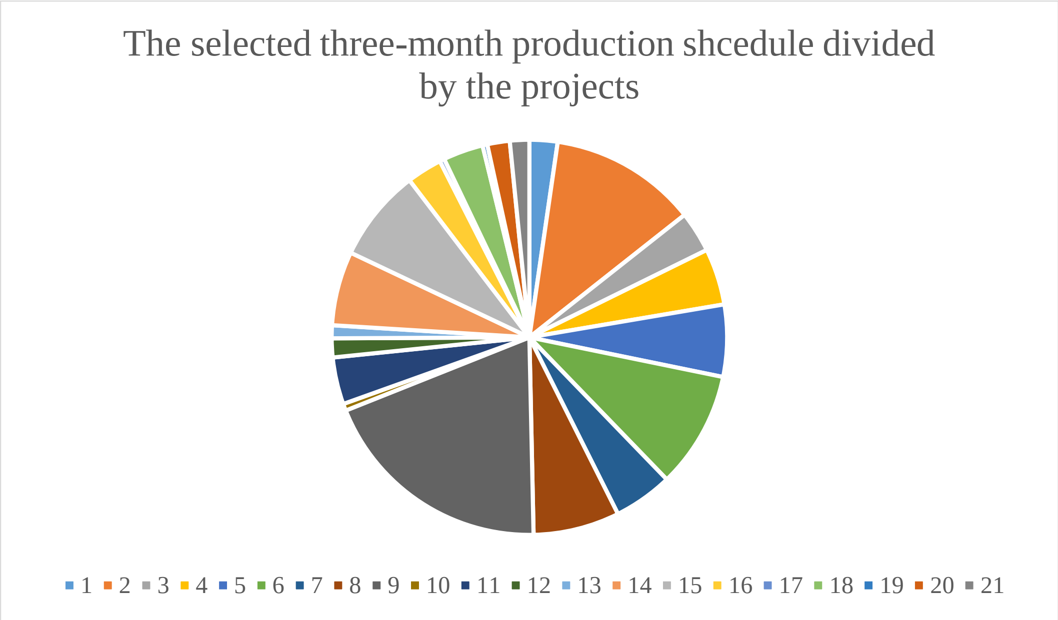

***Figure 13**. The selected three-month production schedule divided by the projects.*

5 RESULTS

This fifth chapter analyzes the results and observations from the examined data and retrospective simulation. Firstly, this chapter introduces the current-state process flow so that the reader can acquire an overall conception of the whole partition wall manufacturing process. The results and alternative improvement possibilities are then analyzed in the different stages of manufacturing. Lastly, the potential risks and challenges are examined with the help of the company's experts.

5.1 The current state process flow

This research focuses on the ETO manufacturing process with the help of the case company's plant in southern Finland. There is also a design office located on site at the same plant, which helps to analyze the whole ETO manufacturing process. This plant primarily manufactures partition wall elements but also a relatively small number of lift-shaft elements. Most of the manufactured elements are transported to the metropolitan area in Finland since most of the new buildings are being built there.

The manufacturing process begins with a customer order. However, there are certain requirements for acceptable orders: Based on the company's current rules, there must be at least 12 weeks' time before deliveries if the order includes designing, the customer is not buying the design service and the designing is performed in an external office. The manufacturing drawings must be delivered to the factory six weeks before element deliveries. If the design service is being purchased, the customer must provide the required reference data at an adequate level so that the design process can be initiated 12 weeks before deliveries. The case company has its own guides made for customers regarding what kind of starting data are needed for the design process.

In total, six weeks are reserved for design work in the internal design office, which means that the first manufacturing drawings must be ready six weeks before element delivery. In the design stage, the geometry of the building is divided into suitable pieces that are possible to manufacture and safe to assemble. The design process is further explained in the next section. After design comes production, where the element is produced, however production planning occurs before the actual production.

The casting process requires only one working day since the mold is assembled in the morning and then the element is equipped with required accessories during the day. After the element has all the equipment demanded by the manufacturing drawing and after the mold is measured to verify the dimensions, the concrete is poured into the mold during the afternoon. The concrete then hardens overnight, and the finished element can be lifted from the casting table to the storage area the next morning. In the storage area, the element is stored for a while and then loaded onto a truck that delivers the element to the construction site.

The production process is simple and old fashioned since most of the work is performed through human labor, without automation in the process. Automation currently plays a greater role in back office systems and there is consequently significant potential for the usage of robotic process automation (RPA) in other activities. The current-state production flow is presented below in Figure 14:

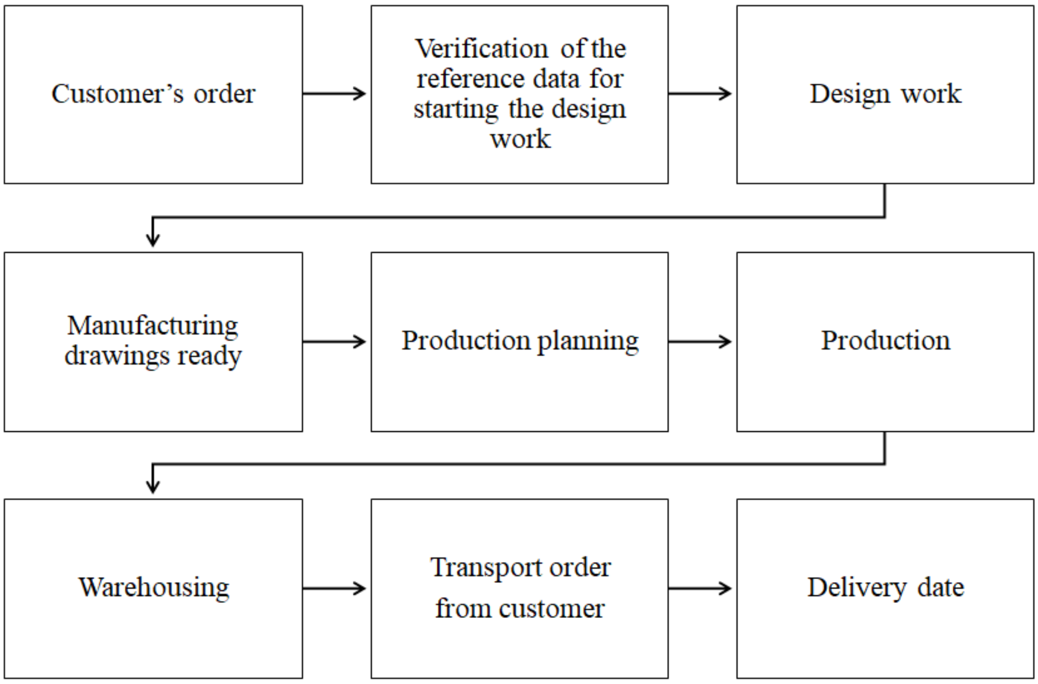

Figure 14. *The current-state production flow in case company.*

5.2 Design stage

When the customer buys designed elements, the manufacturing process begins with design work. After the customer's order has been confirmed and the timetable for initial deliveries meets the requirements, a project manager grants permission to begin the design work. The case company's requirements for the customer include reference data at a sufficient level so that design work can begin and at least 12 weeks' time before initial element deliveries.

A typical element designer is a relatively young person at the beginning of his career and whose work can be viewed as an entry-level job. An element designer usually holds a bachelor's degree in structural engineering or is an engineering student. The primary objective is to design elements that are correctly sized and contain all necessary accessories. The benefits of having an internal design office appear in the use of accessories, because an internal design office can be guided to use accessories that are already stocked in the factory, while external design offices use a wider range of accessories. In addition, elements must be safe to handle and install. Because the element designer usually divides the wall lines into elements, the designer has a great responsibility of making geometrically efficient and safe elements.

An element designer creates an element that meets the dimensions of the architect, structural demands from the structural designer, electrical accessories from the electrical designer and holes/recesses from the heating, ventilation and air conditioning (HVAC) designer. As a result, the element design process requires a continuous interaction between different designers in order to make the result as functional as possible. Some of these previously mentioned plans must usually be changed during the element design process in order for the element to meet all the demands.

5.2.1 The start of the design work

Six weeks are currently reserved for the design work, which means that the first manufacturing drawings must be ready six weeks before the delivery date. In total, this makes a 12-week time period as a theoretical manufacturing lead time. The design work begins when the design manager assigns a selected designer to design the project, and the chosen designer can have multiple projects to design, which means that the designer must balance his/her workload to meet the agreed schedule. A typical time span for element assembly is one week per floor, so to stay on the schedule, a designer must release at least one floor of drawings per week six weeks before the delivery of that floor level.

When the project manager grants permission to begin the design work, there is typically more than 12 weeks before deliveries commence, which provides the design manager an opportunity to select the designer well in advance. The lack of time is usually not a problem compared to a lack of reference data. An element design process requires the upper-level designs and plans to be almost completely ready.

Upper-level plans regard architectural, structural, electrical and HVAC plans, which are all needed for the element design process. The quality of the plans must meet the requirements set from the case company, which is often a problem. The designers in other areas are typically also in a hurry and the plans are not totally complete to begin 12 weeks before deliveries, so the element design must be initiated with preliminary plans. This usually leads to a situation where manufacturing drawings must be revised and updated in order to satisfy changes to these upper-level plans.

As mentioned earlier, it should be possible to begin an element design process 12 weeks before initial deliveries based on the case company’s standards since six weeks are reserved for the design process. For achieving deeper knowledge about a typical situation, the dates of when a project was given to the designer that are manufactured during the selected three-month period are presented in Table 5. In total, 12 of the 21 projects in this time period were designed by an internal design office and are presented in the table below:

Table 5. *The dates when the project was given to the internal designer.*

Project number	Project assigned to the designer	First deliveries	Weeks in between
1 (1)	20.3.2019	5.7.2019	15,3
2 (2)	20.3.2019	13.9.2019	25,3
3 (3)	8.11.2018	1.4.2019	20,6
4 (4)	28.2.2019	30.8.2019	26,1
5 (5)	11.2.2019	24.5.2019	14,6
8 (6)	6.5.2019	22.8.2019	15,4
9 (7)	6.5.2019	5.9.2019	17,4
14 (8)	30.4.2019	27.8.2019	17
18 (9)	6.9.2019	6.11.2019	8,7
19 (10)	12.8.2019	12.12.2019	17,4
20 (11)	12.8.2019	4.11.2019	12
21 (12)	12.8.2019	4.11.2019	12
			AVG 16,8 **STD 5,18**

As shown from the table, the time available is not the main problem since most of the projects were assigned to a designer well in advance, as only one project can be identified as an express order with 8,7 weeks' time before initial deliveries. On average, a designer can acquire the project 16,8 weeks before initial deliveries, which means that, it is 10,8 weeks' time before manufacturing drawings must be ready. If the designing is performed in an external design office, the time schedule varies and consequently the external design process is ignored in this thesis.

5.2.2 The design process

Because the project is usually assigned to the designer well in advance, the designer must explore the project's scope and possible challenges. When the details of the project are revealed, the designer can schedule his/her working time and ensure that their workload is not overloaded. At this point, the designer also verifies that the quality of the reference data is at a sufficient level so that the design process can be initiated. Some small details are usually missing that the project manager failed to notice, which leads to communication between other designers. These situations cannot be completely avoided since only the designer knows exactly what he/she needs for the design process.

The design process is straightforward and proceeds step by step. An architect defines the geometry of the building such as the positions of the doors and dimensions of the wall lines. A structural designer ensures that the building is safe to use and structurally durable, and the structural engineer may demand some special joints or accessories which must be considered during the element design process. An electrical engineer and HVAC engineer ensure that the house functions and is comfortable to use. An element designer considers the above-mentioned aspects and designs element pieces that can be combined into a full-sized building. Elements are designed to be safe to handle and as cost efficient as possible. The benefits of an in-house design office can include cheaper solutions due to the reasonable use of stock accessories.

The duration of the element design process varies according to the size of the project, however a theoretical design speed is one week per floor in one stairway as ready drawings. At the beginning, more time is typically required to produce the initial drawings, and at the end a designer can copy drawings from the lower floors, which means that the design speed increases towards the end. A designer typically publishes drawings of several floors at a time in order to avoid possible changes. Cutler (2009, p. 36) stated that the design process requires too much time when designers withhold publishing due to fear of changes, which can also be identified in the case company’s design office.

The manufacturing factory currently demands the drawings six weeks before delivery from internal and external design offices. During this time period before manufacturing, the production planning personnel become familiar with the plans and order possible special accessories. The dates when drawings were published during the three-month period are presented in Tables 6 and 7, with internally designed projects in Table 6 and externally designed projects in Table 7.

Table 6. *The times when internally designed element drawings were published.*

Project number	The number of elements	The number of publishing times (Published drawings)	On Average, the time between published drawing and a delivery of the element (weeks)
1 (1)	61	3 *(1,24,36)*	16,5
2 (2)	342	5 *(29,178,11,44,80)*	8,9
3 (3)	95	5 *(12,5,36,10,16)*	8,25
4 (4)	131	2 *(61,70)*	9,2
5 (5)	167	7 *(2,12,55,17,21,40,20)*	4,6
8 (6)	200	7 *(25,37,14,36,36,30,22)*	4,5
9 (7)	549	10 *(7,90,71,30,26,156,52,46,70,1)*	4,9
14 (8)	172	4 *(10,36,74,52)*	11,3
18 (9)	93	5 *(20,19,22,21,11)*	5,6
19 (10)	11	1 *(11)*	3,9
20 (11)	52	4 *(6,23,19,4)*	6,2
21 (12)	45	4 *(2,26,16,1)*	6,7
			AVG 7,5 **Weighted AVG 7,1** **STD 3,62**

Table 7. *The times when externally designed element drawings were published.*

Project number	The number of elements	The number of publishing times (Published drawings)	On Average, the time between published drawing and a delivery of the element (weeks)
6 (1)	271	4 *(68,87,51,65)*	5,8
7 (2)	137	7 *(1,13,32,36,16,31,8)*	8,5
10 (3)	16	2 *(3,13)*	28,1
11 (4)	109	2 *(95,14)*	13,1
12 (5)	44	2 *(27,17)*	8,8
13 (6)	30	1 *(30)*	7,1
15 (7)	215	1 *(215)*	11,9
16 (8)	82	2 *(36,46)*	9,9
17 (9)	11	1 *(11)*	4,6
			AVG 10,9 **Weighted AVG 9,4** **STD 7,0**

As shown in the tables, publishing practices vary between the internal design office and external consulting service. On average, an external design office publishes the drawings two weeks earlier than the internal design office but with much higher standard deviation. Although both internal and external design offices seem to on average fulfill the factory's demand for submitting the drawings six weeks before the delivery date.

5.2.3 Opportunities for improvement

The main reason that the manufacturing factory demands the drawings six weeks before deliveries is that they require time to respond to special occasions, which typically include:

- The ordering of special materials (e.g. extra-long bolts, special electrical equipment, specific penetration units or special reinforcements)
- The ordering or manufacturing of special casting equipment (e.g. if the elements have special shapes or if the thickness of the wall is exceptional)
- The possible ordering of reinforcements as a complete package that are made by another company

The usage of special accessories in elements cannot be completely eliminated since buildings are unique and require unique solutions. This means that the requirement of receiving drawings six weeks before delivery might be reasonable if the designing is performed in external design offices. As Table 6 shows, external design offices usually meet this requirement since the weighted average during the three-month period was 9,4 weeks between the drawing arrival and element delivery.

The benefits of having an internal design office can be especially achieved during this phase, as interviewee 1 (the production planner) said: *"A sufficient time window for internally designed partition wall elements is four weeks."*

Based on the interviews, the current requirement of having drawings ready six weeks before deliveries might be reduced to four weeks, which would lead to a reduction of 20% in theoretical lead time. However, this would require new methods during the design process. An element designer should release the BOM sufficiently early (e.g. six weeks before deliveries) for special projects, however the drawings might not be completely ready at that point. In addition, a meeting between design and production personnel before beginning the production of a certain project would be highly helpful in non-basic situations. Such special occasions would be considered between the designer and the production personnel, however such preparation meetings are currently not held before beginning production. There are few new projects during a year which are internally designed, and therefore the time consumed in such meetings would be irrelevant.

Interviewee 1 (the production planner) stated that:

> *"A sufficient time window for internally designed partition wall elements is four weeks, as then it is still possible to handle the ordering of materials while most of the solutions are typical. If the project includes special parts, a production launch meeting could be useful as it would give us more time to react.* "

5.3 The production planning

Production planning regards a stage where the element drawings are delivered, special materials are ordered, and the production schedule is created. The element drawings are not physically delivered to the production planners' desk but instead to the company's document portal. The database is constructed so that when a designer uploads element drawing documents, the production planner still needs to import the documents into the ERP system. This ensures that the production planner knows exactly which drawings are published and which are not.

5.3.1 Transferring data to ERP

When the element designer uploads the drawings into the document portal, he/she informs the production planner of which floors the drawings are from and how the design process is progressing. This provides the production planner a better conception of the overall process. Firstly, the production planner becomes familiar with the drawings and overall situation of the project, and he/she then uses special software to transfer the element information to the ERP, which includes the dimensions of the element and some material data. The case company has a database for raw material management, however the system is infrequently used due to the large difference in material nomenclature; for example, there are multiple names for same items, which complicates the inventory management database. There is great potential for facilitating inventory management if the database uses a relatively small number of basic materials and the system is simple enough to use.

While the production planner examines the element drawings, he/she observes any special accessories and also divides the elements to be produced between the production methods. Partition wall elements can be produced in vertical battery molds or on horizontal casting tables, and possible changes in element drawings (i.e. revisions) are delivered to the production planner, who ensures that the drawings are kept up to date. Changes in plans are not uncommon, and in the three-month period under examination, 622 drawings were updated, which results in a total revision rate of 22%.

Internally designed elements were revised 117 times while externally designed elements were updated 488 times. This means that 7% of internally designed element drawings and 53% of externally designed elements were updated, which means that more than half of the externally designed elements were revised. As interviewee 3 (the design manager) stated about revisions:

> *"The first reason for revisions is the high schedule pressure and a low quality of available reference data. Especially external design offices knowingly publish drawings as imperfect to meet a contractual term for timely delivery. The contract only demands that drawings are published at a certain time frame and then the drawings will be updated without additional costs."*

As interviewee 3 stated, the high amount of revisions represents a problem. Updates cannot be completely prevented, unlike the knowingly imperfect publishing, which especially relates to the culture of external design offices with a 53% revision rate. This would require changes in contractual terms and possibly a fee for processed revisions. The case company currently does not charge anything for processing revisions, and if the fee would be, for example, 50 € per updated drawing for external design offices, this would allow an additional billing of approximately 97 000 € annually. This would also provide the positive effects of increasing the quality of drawings and decreasing the total amount of revisions.

5.3.2 Ordering of special materials

While the production planner observes the special accessories in element drawings, he/she also simultaneously analyzes the manufacturing capability. The production planner is responsible for ordering special accessories and casting equipment, while the production supervisors are responsible for ordering materials that are stocked at the factory. Because multiple operators are ordering materials, the production planner must know which accessories are stocked and what is required to be ordered separately.

Accessories that are typically ordered separately are:

- Specific appropriately sized penetration units for leading pipelines from apartment to apartment for ensuring fire protection

- Special reinforcement or jointing equipment that the structural engineer requires (some common ones are stocked)
- Special electrical equipment (special socket bases or uncommon tubing)
- Special lumber for making special formwork and molds

It is important that the production planner understands the whole production process and is able to notice the items which are mentioned above. The production planner is the first one after the designer to work with the drawing six weeks before delivery. The production personnel only receive the drawing a few days before the actual casting date, and if special occasions are discovered at this point, a rush is required to solve the problem. This might lead to situations where a small number of accessories must be delivered via courier service with relatively high unit costs.

5.3.3 Method of production

In the precast industry, there are generally two ways to produce partition wall elements: either a vertical battery mold or horizontal casting table. A battery mold is a vertical casting unit where the molds are separated with steel blocks, which allows the production of 10+ partition walls per unit while the number of blocks are not basically limited. When the walls are in an upright position, the casting unit requires little floorspace. The concrete is poured between steel blocks from the top of the casting unit, and the next morning the blocks are opened one by one and complete wall elements can be lifted to the storage rack.

A horizontal casting table regards a table where wall elements are produced in a horizontal position, which allows a better capability to install accessories and reinforcements into the element. These casting tables require significant floorspace since the walls are produced as a slab. Casting tables typically have a tilting mechanism that allows turning the element upright after it has hardened.

There are certain requirements concerning which kind of elements are manufactured with each method. Simple elements with simple shapes and accessories can be produced in a battery mold since there is little space to install equipment between steel blocks. All other elements are produced in casting tables and regards heavily reinforced elements with different shapes and special accessories. Battery mold production is thus more efficient, and it is commonly desired to produce as many elements in a battery mold as possible. This strongly relates to the design phase, where some small design solutions might make the element unsuitable for battery mold production. An internal design office plays a key role here since the designers can be guided to design elements which are as productively efficient as possible. The division between the battery mold production and casting table production in the three-month period is presented below in Figure 15:

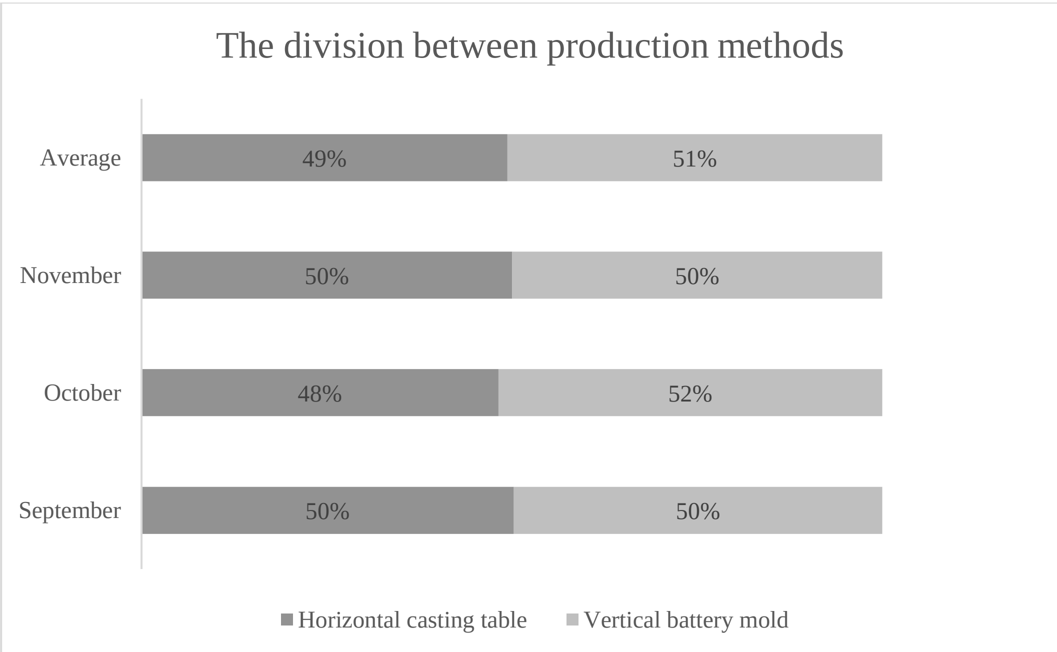

Figure 15. *The division between production methods.*

As shown in Figure 15, the production is divided quite evenly between battery mold and casting table production, and there is thus significant potential for achieving cost savings by increasing battery mold production. However, this requires more precise design guidance, which links to Cutler's (2006, p. 64) opinion that the high amount of cost effects is bound already in the design process.

Interviewee 1 (the production planner) said:

> *"I think that the designer has some opportunities for influencing the production method if he/she truly understands the production process. I also believe that we could make more elements in battery molds and that would be a benefit for both us and the customer. Also, 10 years ago, the division was 70/30, as 70% of the elements were battery production."*

On the same subject, interviewee 3 (the design manager) stated:

> *"The designer can affect the method of production significantly with design solutions, division and shape of the elements and with the equipment of elements. However, there are places and situations where there are no options, but usually there are. The time when the influencing should be happening is around six months before deliveries. At that time, the solutions aren't that final and there is a greater opportunity to change plans. Most of the things relate to basic geometrical solutions such as the locations of openings and general detailing. Commenting on those things doesn't take long and our designer should absolutely be involved at an early stage of general designing."*

5.3.4 The timing of production

Timing represents one of the most important aspects in the production planning process. In the case company, the production is scheduled differently for casting tables and battery molds. This is because with casting tables, the work is individual as the workers produce 2-3 elements per day at one table, while with battery molds, they work in teams of 2-3 and produce 8-12 elements per day. For casting tables, the production is scheduled by the production planner, while for battery molds, the schedule is done by one of the workers in the battery mold team.

The reason that battery mold teams handle their own production schedule is unknown but seems related to serial production, as usually upper-level floors repeat themselves and the mold would already be set in the correct dimensions. However, this is not the optimal solution from an economic point of view, as end products should not be produced too early since this bind’s capital to the product and negatively affects the inventory management and turnover. The case company has a target of producing the element seven days before delivery. The work supervisors provide a list of available elements for battery molds in the next couple of months and then schedule production based on their own preferences.

During the three-month period, the number of produced elements per day slightly varies, for which there can be many reasons, such as sick leave or machine failures. On average, 43,6 elements were casted per day, and the division between production methods are on average 22 elements casted at casting tables and 21,6 in battery molds per day. The number of casted elements per day are presented below in Figure 16:

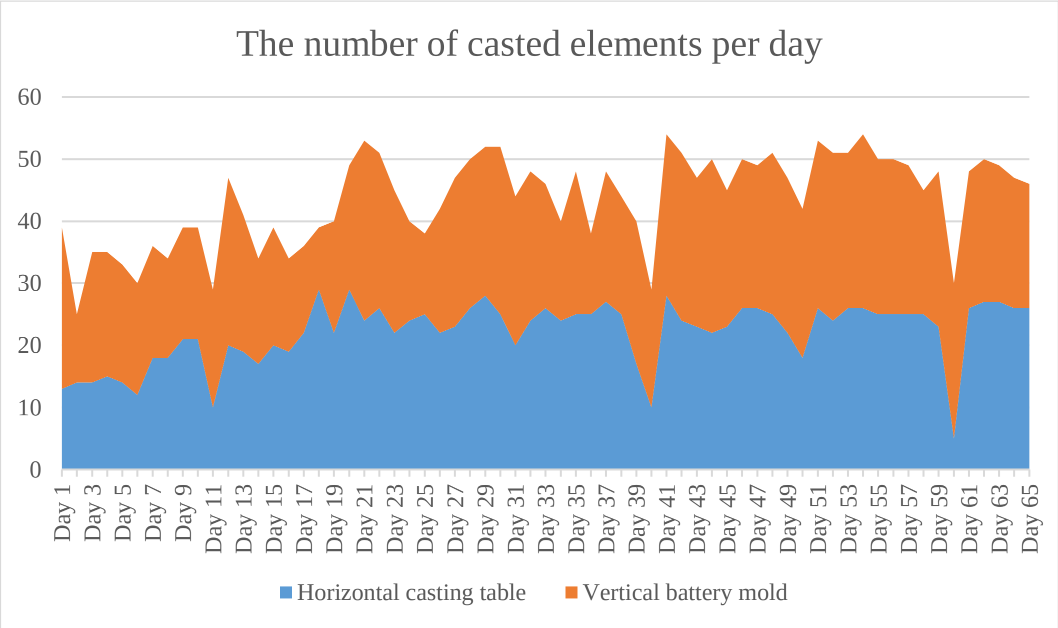

Figure 16. *The number of casted elements per day.*

As shown from Figure 16, the division between production methods splits quite evenly and they follow the same increases and decreases. When the timing of production is considered, the findings are more significant since the case company's target production timing is seven days before delivery. The casting date comparison to the delivery date is presented below in Figure 17:

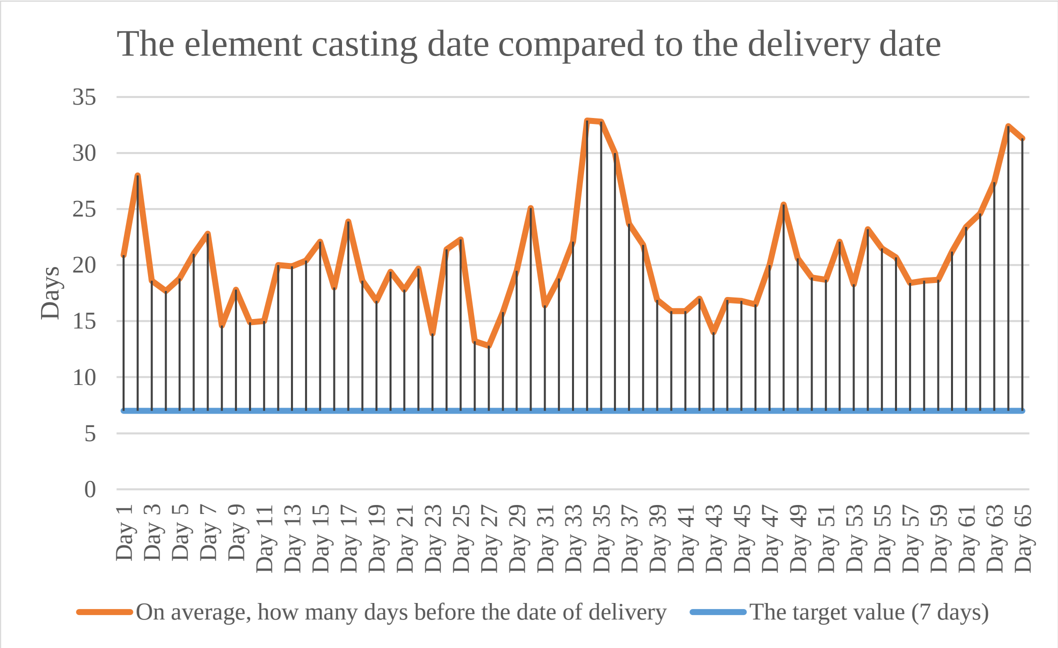

Figure 17. *The element casting date compared to the delivery date.*

As shown in Figure 17, the casting date greatly exceeds the company's goal of manufacturing the element seven days before delivery. In the three-month period, the element was casted on average 20,4 days before delivery, which means that it exceeds the target value by 191%. When the effects of production planning between production methods are considered, the findings are more obvious. The timings between different production methods and production planning procedures are presented below in Figure 18:

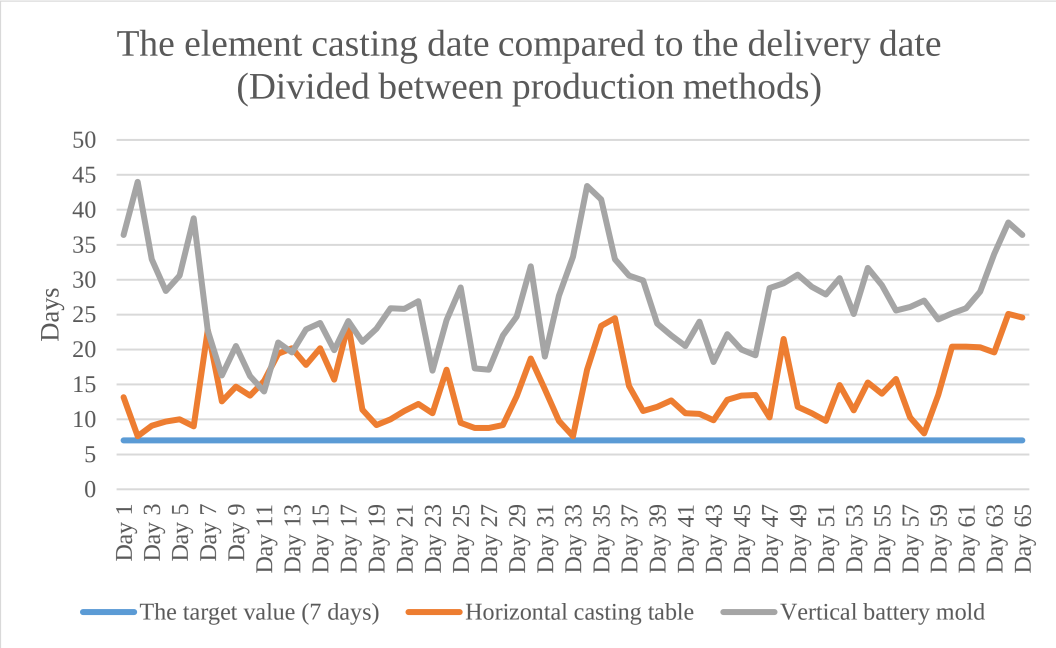

Figure 18. *The element casting date compared to the delivery date (divided between production methods).*

It is obvious that there is a difference in casting date determination between production methods. Because the production planner schedules the production for casting tables, the elements at tables were casted on average 14,2 days before the delivery date. Because the battery mold production is scheduled by the battery mold workers themselves, the elements were casted in battery molds on average 26,4 days before the delivery date.

Interviewees 1 and 2 both stated:

> *"There are two reasons for early manufacturing. Firstly, the casting platform might have a relatively low order backlog, so the elements must be produced up-front. Secondly, the construction sites don't order elements as predicted and the delivery time is therefore delayed."*

The amount of orders varies, however there is no reason for manufacturing elements over a month early, especially when the warehousing capacity is limited. There is also the issue of construction sites not ordering elements as agreed. The project manager sets an estimated delivery date for each element based on the installation schedule he/she received from the customer, and the construction site orders elements about one week before delivery and thus confirm the delivery date. This means that the production schedule is mostly based on the estimated delivery dates since the construction site might not have ordered the transportation yet.

Although the production schedule is mostly based on estimates, interviewees 1 and 2 both thought that the estimates are poorly accurate. According to them, this negatively affects the production scheduling. However, these assumptions are not correct, because although it is true that there is variance during the three-month period between the estimated and real delivery dates, the difference varies from 36 days to -25 days with a standard deviation of 6,6. The variance range is quite high, however during the three-month period, the element was delivered on average 2,74 days after the estimated delivery date. This means that the estimated delivery dates are generally quite accurate, although there are exceptions in both directions. The differences between the estimated the realized delivery dates per casting day are presented below in Figure 19:

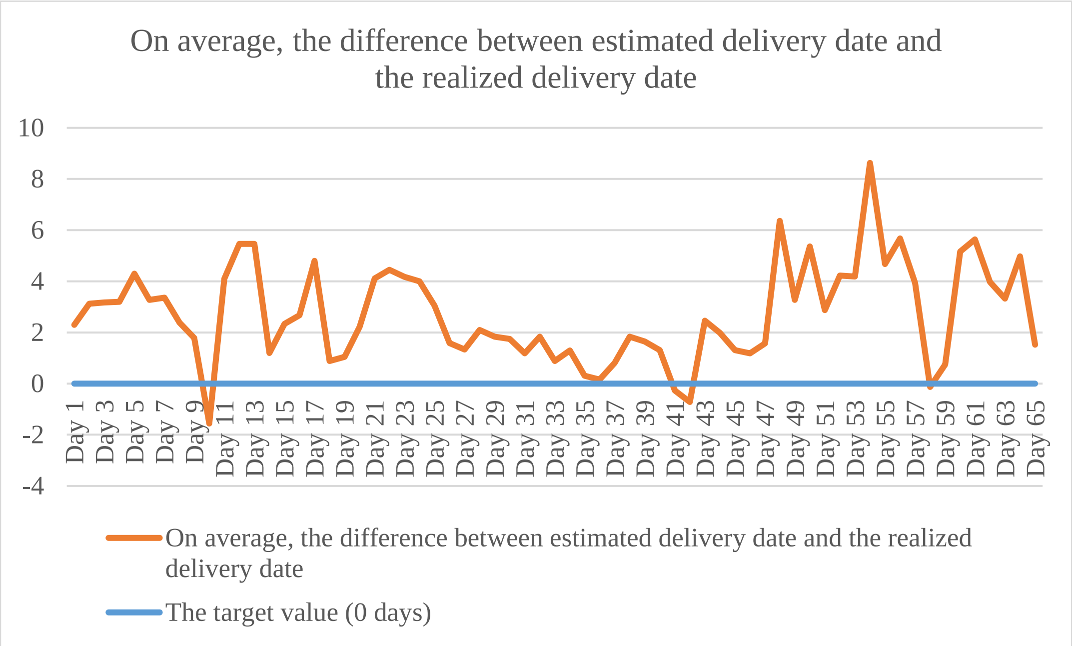

Figure 19. *The differences between the estimated and realized delivery dates.*

5.3.5 Opportunities for improvement

The opportunities for improvement in production planning can be found in multiple areas. The first regards the cooperation with the internal design office and benefiting from having internal designers, which relates to the special material ordering and production method definition. With internally designed projects, it could be possible to decrease the time between the publishing of drawings and element delivery to, for example, four weeks from the current six weeks. This would require more intense collaboration between designers and production planners for possible special material demands. There could be a production launch meeting at a certain stage to determine and discuss the special occasions.

The second area regards determining the production method. The designers (especially internal) should be trained to understand the characteristics of different production methods. This requires a more complete understanding of the whole manufacturing process, and thus the training must include knowledge about manufacturing technology. This would allow the designers to make more efficient decisions in the design process and more elements could be manufactured in battery molds, which is a more efficient production method. The designers should also be motivated to pay attention to production methods, which could be solved by including this as part of an encouraging reward system (e.g. annual bonus).

The third area concerns the most significant improvement opportunity, which is the timing of production since the case company has set a target of manufacturing an element seven days before delivery. The production planner himself exceeds this goal twofold since the average manufacturing date was 14,2 days before delivery. This could be improved, however the battery mold production schedule is much more problematic. Here the workers themselves decide their production schedule based on a list of available elements, which has led to elements being manufactured in battery molds on average 26,4 days before the date of delivery.

This could be solved through two options: Either the production becomes completely scheduled by the production planner who pays attention to delivery dates, or the scheduler (worker) becomes trained and guided for more precise decision making. If the value would be decreased to the same as the production planners' schedule for casting tables (14,2 days), this would mean a 30,4% reduction of the total average. It might be helpful to develop a rule such as "you are not allowed to manufacture an element if there is more than two weeks for the estimated delivery date."

5.4 The production stage

The production stage is a step, where all the previous events are combined to form a complete, high-quality element at the right time. There are about 40 production workers at the case company's factory under study, which includes element manufacturers, warehousing personnel and dispatching personnel. The warehousing and dispatching workers are outsourced, which means that there is a subcontractor working inside the factory. There are also two production supervisors and a plant manager for overseeing the production. The production planner also works relatively closely with production, however he/she is not overly concerned with production matters.

5.4.1 Raw material inventory management

The production supervisors are primarily responsible for ordering all the basic raw materials, while the production planner handles the ordering of all special parts since he/she is the first person who manages incoming element drawings. There is some cooperation between the production planner and production supervisors, such as the production planner might tell supervisors to order additional stock accessories if the demand is increasing. As interviewee 7 (the production supervisor) stated:

> *"The information regarding the start of a new project is usually expressed to us in a way of receiving a list of increasing demand on some stock equipment. Then we fill the stocks and thus that we ensure that we don't run out of accessories. That could be called something like a heads-up warning."*

Afterwards, the other supervisor interviewee 6 said:

> *"Because the warehousing is outsourced and it also includes the raw material inventories, there are some problems with the flow of information towards us. As the raw material management is currently based on visual inspection on inventory levels, we don't get the information soon enough if something is running out. It would be awesome if we had some kind of barcode scanning system that is linked to the database and we could monitor inventory levels in real time from the computer."*

There appears to be significant potential achievable via raw material inventory management. The inventory level monitoring could become computerized, which would enable highly automating the ordering process of stock materials using an order point system, for instance. This would significantly decrease the amount of mandatory expensive express deliveries when some accessories are depleted. Based on the production supervisors' interviews, the use of courier services with only a couple hours delivery time is not that unusual, such as when something that is needed today becomes suddenly out of stock.

5.4.2 The production process

As mentioned earlier, the production process is straightforward, and the production lead time is one day since the manufacturing of a concrete partition wall element requires one working day. In the morning, yesterday's element formwork is removed, and the element is lifted to intermediate storage near the casting platform. The platform is afterwards cleaned and oiled, which helps the element's removal off the platform the next day. Next, all the accessories and reinforcements that are listed in the element drawing are installed and the dimensions verified by the inspector before the mold is finally filled with concrete and must cure overnight. The procedures at casting tables are mostly the same as battery molds, and on the next day, the previous actions are repeated.

There are multiple support functions in production, such as carpenters, is a woodworker who fabricates the different kinds of molding equipment that are needed to create properly shaped elements. Because the precast workers only lift the elements to intermediate storage, the warehousing personnel move the elements to the storage area in the evening when the overall activity in the factory is reduced. This makes the intermediate storage empty for subsequent elements the next day. There are storage racks both outdoors and indoors, and although in the summer it does not matter where the element is stored, during the winter the element needs to spend at least 24 hours indoors to ensure that the concrete has sufficiently hardened.

Improvement possibilities can be found in multiple areas of production, but these factors are ignored in this research since production represents merely one stage in the ETO manufacturing process. In addition, production improvements could form a topic for new research, and the production stage in this case is functioning well overall since the complete element is produced in one day with relatively low chance for production errors.

5.4.3 Variable factors of production

The variable factors in the production process are usually related to the absence of staff, device failures or lack of raw materials. The production process is hectic, and if some errors occur, things rapidly become complicated. As t interviewee 6 (the production supervisor) stated:

> *"As first personnel start their work shift as early as 3am, that means if someone is feeling sick in the morning, they send us a text message while we are still sleeping. When either one of us wakes up around 6am with an arrived text message of someone not coming to work, we are already a couple of hours late. Fortunately, this happens only occasionally as we advise the personnel to inform us as early as possible, usually they call us the previous evening."*

This means that sometimes when sudden sick leave emerges, the elements might not be casted on a scheduled day due to the lack of time to seek a replacement. Other problems might occur when the equipment malfunctions. Interviewees 6 and 7 stated that there have been situations when elements have not been casted due to equipment failure. Critical equipment includes, for example, the concrete mixer and bridge crane which is used to move the concrete from the mixer to the mold. The third type of typical problems relates to the lack of raw materials, which are only noticed on casting day. This situation leads to the use of express courier services as described earlier.

5.5 Warehousing and logistics

The case company's factory area is relatively small, which means that the storage area is also limited. A partition wall element is stored in a vertical position in a special storage rack, which means that one wall occupies one storage space. As interviewee 1 (the production planner) said:

> *"In the precast concrete element industry, the elements are usually measured in square meters and far less attention is drawn to the number of single element pieces. Over all these years, I have noticed that the amount of element pieces has increased significantly while the produced square meters have remained broadly the same. One reason for that is probably the size reduction in new apartments. There are much more one-room flats being built nowadays, which require more concrete walls between apartments."*

The number of element pieces has increased, which creates greater pressure for warehousing since one element requires one spot in the rack, regardless of whether the wall is one or ten meters long. Because the number of elements produced per day slightly varies, the number of elements delivered varies widely. The number of casted elements compared to the number of delivered elements within the same three-month period is presented below in Figure 20:

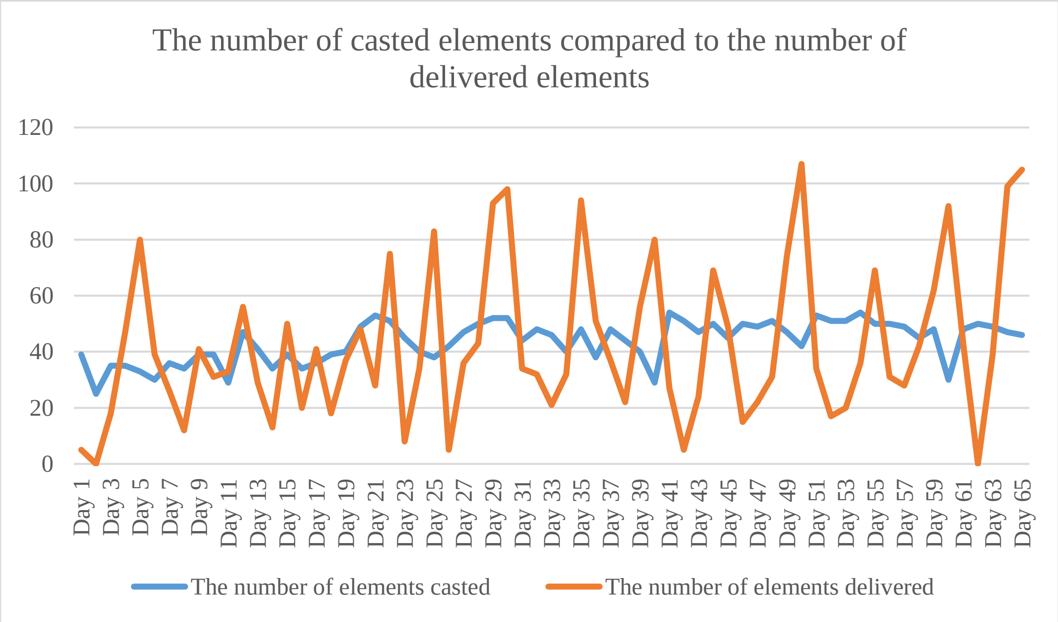

Figure 20. *The number of casted elements compared to the number of delivered elements.*

During the three-month period, in total 2835 partition wall elements were manufactured, and 2746 elements were delivered, which means that the stock level increased by 89 elements. This number can be considered as a favorable result over a three-month period. As shown from Figure 20 above, the number of elements delivered per day varies widely from 0 elements per day to 107 elements per day and an average of 42 elements delivered per day. The variance in deliveries is 14,5 times higher than the variance in production, and such a large variation in deliveries per day creates a significant challenge for warehousing and transportation. The case company has a contract with an external transport company, but the number of carriers is nonetheless limited.

5.5.1 The capacity and turnover

The case company has three different storage options for partition wall elements: In the factory area, there are storage racks both indoors and outdoors, and the third option is to have the same project elements loaded onto specific element pallets or flats that can then be transported with special element transporting trailers to other areas awaiting the delivery date. The transporting of elements to intermediate storage is not efficient but is sometimes mandatory, such as when the storage capacity at the factory is in full use.

At this factory, there are approximately 500 rack slots in the factory area and 100 flat pallets where elements can be loaded with approximately six elements per flat. This results in a total storage capacity for flat pallets of approximately 1100 elements. In the three-month period, the daily average was 46,3 produced element pieces per day. For the factory to manage with their own storage capacity, the warehouse should replenish every two weeks. This means that the element should not be manufactured more than ten working days before the date of delivery.

On the three-month period under observation, the element was casted on average 20,4 days before delivery and therefore was in storage for 19,4 days. This means that the inventory would turn over 18,8 times per year with approximately 900 elements in storage at all times. If the production scheduling were enhanced to be the same as horizontal casting tables, meaning 14,2 days and 13,2 days in storage, it would improve the turnover for 47,3% to 27,7 times per year. In addition, the approximate number of elements in storage would decrease to 600 pieces, which would mean a significant decrease in the need for intermediate storages since approximately 300 element pieces or 50 element pallet flats could be removed from other rented storage areas.

If the company’s target of having elements manufactured a week before the date of delivery were achieved, the results would be highly profitable. This would mean that the element is in storage for six days which would be a 223% improvement to the current turnover as it would be 60,8 times per year. In addition, the number of stored elements would decrease by 67% to approximately 300 pieces. This would lead to situations where intermediate storages would no longer be required and the factory could manage with only their own storage capacity.

5.6 Production capacity analysis

The high variance in the amount of daily deliveries creates great challenges in production scheduling. It was previously suggested to implement a rule for production timing: “You are not allowed to manufacture an element if there is more than two weeks for the estimated delivery date.” Would this be possible when the variance in deliveries is high and exceeding the daily production capacity?

In Figures 21 and 22, the difference between casted and delivered elements in 7 and 14 days is presented in pieces and square meters during the three-month period under examination. There are in total 13 weeks during the period, which are presented individually as one-week periods, however when combined into two-week periods, only twelve weeks are presented due to the odd total number of weeks.

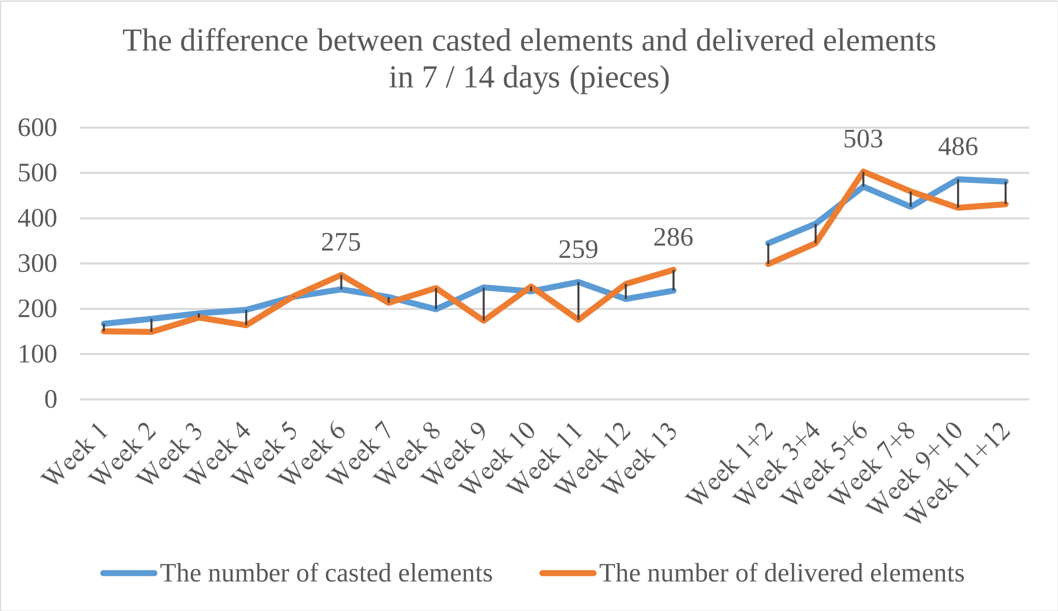

Figure 21. *The difference between casted elements and delivered elements in pieces.*

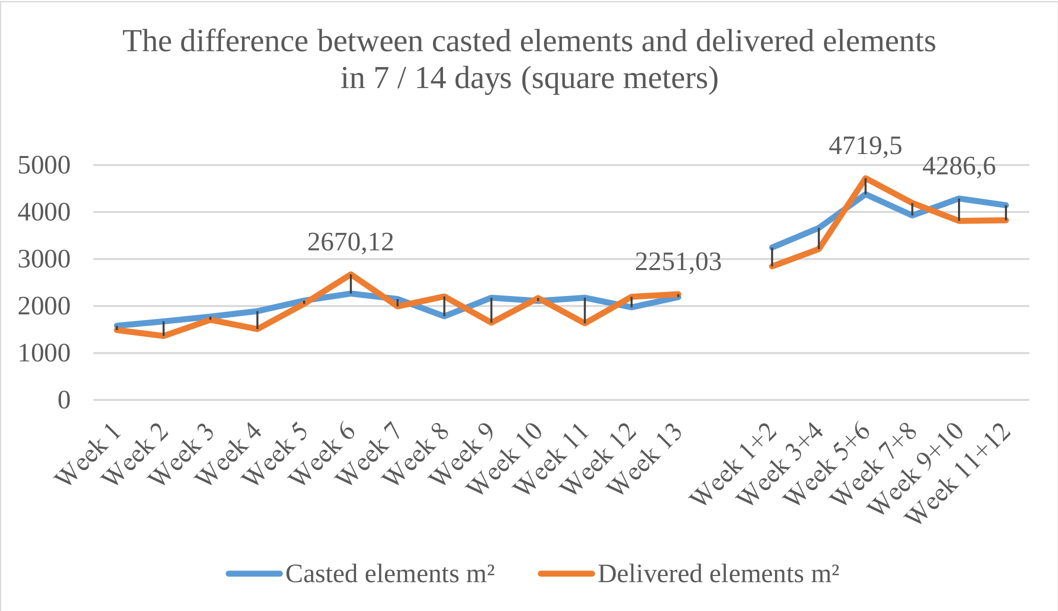

Figure 22. *The difference between casted elements and delivered elements in square meters.*

As shown from both figures above, the amounts in square meters and pieces strongly correlate to each other since the forms of the lines are nearly identical. A second finding is that when the amount of daily delivered elements varies highly, on a weekly basis it flattens significantly. On a weekly basis, the demand flattens so much due to fluctuating demand, it is not justified to manufacture elements as early as they are currently. In many weeks, the amount of delivered element pieces or square meters is lower than the amount manufactured. This means that for most of the time, the production capacity is sufficient for meeting weekly demand, and with intelligent number-based production management and timing, the benefits of decreasing working capital and warehousing would be substantial.

However, there are some peaks in demand when the normal production capacity would be insufficient. For example, in week 6 the demand for partition wall elements was 275 pieces or 2670 square meters of wall surface while the average weekly production amount was approximately 220 pieces or 2000 square meters. To survive such demand spikes in production, it would be necessary to cast elements on weekends (one day or both) in order to achieve the production capacity required for weekly demand. This means that it would be possible to manufacture elements only one week before deliveries, however this would possibly require one working weekend per approximate six-week period during the high-demand season.

When considering that the elements would be manufactured within a timeframe of two weeks before deliveries according to the proposed rule, the demand flattens even more. The two-week periods are presented in Figures 21 and 22 in week-plus-week form. Satisfying the two-weeks manufacturing rule would possibly require one working weekend per approximate twelve-week period during the high-demand season in order to manage the occasional demand spike.

5.7 Interview results of potential challenges and risks

The potential challenges of enhancing the manufacturing process in the case company do not necessarily relate to the enhancements but to improving overall operational performance and increasing internal design activities. When asking interviewee group 1 about internal and external design offices, they said:

> *"Absolutely we prefer the internal design! Our own designers have a standard way to design and the drawing layout is standard. For example, the dimension lines are at the same spot and in the same order. Our production workers are used to manufacturing elements with those drawings and a chance for misreading is much smaller. Also, our own designers can fit all the necessary information in one page while external design offices might publish drawings with information in five different pages."*

In all the interviews, the opinions about the internal design office were highly positive. The most common aspects that arose included the clarity of the drawings, the ease of possible problem solving and an overall more transparent design process, where production might even receive some information before the drawings are ready. This means that the strategy of having all the elements designed internally would be useful in many ways, and with full ETO production, the manufacturing lead time would be quickened due to the utilization of the benefits from internal design offices.

Most of the challenges of increasing the internal design activities seem to relate to recruitment problems. A precast concrete element company is not necessarily highly attractive employer to young engineers who are interested in design activities. That means that much larger design offices whose main business is designing offer much broader design activities with better opportunities for development. Even if young engineers could be recruited, their engagement with the company might become a problem since element designing can be viewed as an entry-level job, and if this is all the case company can offer in the area of design, engineers looking to develop their skills will probably seek another options in a couple years.

Regarding the overall working culture and performance, interviewee 3 stated:

> *"Most of the problems in this company are related to the issue that most of the employees aren't aiming for the same outcome. As the manufacturing process consists of different steps, there are some steps where the only goal seems to be only performing their own task and passing the project to the next one without paying any attention to consequences."*

This account shows that much could be accomplished from simple changes in the working culture. All the employees' goals should be linked to a high-quality end product with efficient design solutions and production techniques, which does not currently seem to be the case. Changing the working culture can be viewed as a challenge since there are many methods of achieving this goal. Motivating the employees can be accomplished in different ways, however reward systems seem to be highly successful in many cases. One solution could regard a reward system with carefully considered goals and objectives for employees who link their work task to other production steps and high-quality output. Other, smaller-scale solutions might include, for example, fresh fruit for employees to keep them pleased, which would have a significantly positive effect on their working performance and commitment.

6 DISCUSSION

This chapter discusses the findings and observations from this analytical research project, and the research questions are answered and compared with the literature review. Firstly, the supportive questions are answered to aid in answering the main research question.

Beginning with the design stage, externally designed projects lack visibility for the company’s own designers. Sometimes experienced designers or design managers receive questions from production personnel about externally designed drawings, because all of the design offices have their own presentation methods, which might cause confusion for production. When the production personnel were interviewed, they all preferred internal over external design, mainly due to the clarity of the drawings. Production workers are used to working with the same style drawings, for example with each dimension line in the same spot. The overall layout of the drawing is identical, and with a brief glance it is nearly impossible to distinguish individual designers.

The main difference between internal and external design appears firstly in the production planning process, where the complete drawings are delivered. External design offices do not know exactly which kind of accessories are stocked at the factory, and there might consequently be special accessories used solely due to the designer’s unawareness. In addition, the lack of communication poses a problem for external design offices. Although, external design offices publish drawings earlier than internal design (with higher deviation) based on the data analysis, there is a lack of communication between the design office and the factory before the drawings are delivered. This might lead to situations where the production planner is surprised by the element complexity without any pre-notice while the time window for production preparations is already narrow.

With the internal design office, the communication both directions (design and production) is much more natural and transparent. Situational solutions and the use of special accessories cannot be completely eliminated due to the complexity of unique buildings, however they can be discussed and solved together with the production. There are usually multiple methods of designing a special element joint, for instance. When the production personnel are involved in the decision making, they become more commitment to the selected solution and the production stage flows more smoothly, even if the element is quite complex.

According to Cutler (2009, p. 37), designers are fearful of releasing the BOM information too early due to the potential problems created by client's changes or the factory's demands. With internal design, this fear can be alleviated by increasing the collaboration with production and possibly defining special accessories, which requires delivering additional information to the production personnel.

The first supportive research question was: *"How could the case company shorten the delays between manufacturing stages (if the design work is done by an internal design office)?"*

The most important delay in the process regards the material ordering timeframe. The production planner is responsible for ordering special materials, while production supervisors ensure that the stock accessories are available. The internal design office already uses stock accessories well and special occasions are uncommon.

Based on the interviews and data analysis, the current demand of having drawings published to the production planner six weeks before the date of delivery could be decreased to four weeks via internally designed element drawings (partition wall elements and lift shaft elements). For externally designed elements, the six-weeks rule is justified by the susceptibility to surprises. Enhancing the design schedule for other element types would require additional research since the design volume for other element types is currently relatively low.

The second supportive research question was: *"What kind of cost effects might result from improvements?"*

Regarding the manufacturing process, the opportunities for improvement can be found in multiple areas. According to Cutler (2006, p. 64), the high amount of cost effects is bound to the design process. As a result, the design process has its own improvement opportunities through cost-efficient solutions and by altering the production method. The company's own designers have significant potential in guiding the structural engineers and architects towards element solutions that could be casted in battery molds, which represents the most efficient production method for partition wall elements. This would require significantly more training for designers in the overall production process, and the designers should become motivated towards such goals and provide suggestions for alternative solutions.

The most important cost-saving opportunity in the manufacturing process probably regards the production scheduling. It is easy to observe from the data analysis that elements are currently produced far too early. Based on Vincent (2011, p. 3192), JIT production systems mean that the company processes and delivers finished goods just in time for selling and buys materials just in time to be converted into goods. The implementation of JIT production would be highly profitable for the case company in this research. It was proven that the case company's factory could declare a rule of "you are not allowed to manufacture an element if there is more than two weeks for the estimated date of delivery." Implementing this rule would ensure a minimal possibility of insufficient capacity and at the same time would have a positively impact warehousing and working capital.

Other cost reduction opportunities could be found regarding the automatization of raw material management (stock accessories) and general working culture changes. At the case company's factory, there is no digitalization involved in the raw material inventory management, as stock levels are only inspected visually by the supervisor and then replenished if necessary. It is currently not uncommon for materials to suddenly run out of stock since the supervisor was not informed of high demand or he/she forgot to inspect the stock levels. Digitalization and automatization could significantly reduce the occurrence of such situations.

Changing the working culture relates to the fact that employees' different goals are not necessarily linked to the company's strategy. Based on the interviews, it is unfortunately common that employees' goals (e.g. annual bonus) are only related to the work task but fail to consider any multiplier impacts affected by the work task. Linking the chain of work tasks together with alignment to the company's strategy would provide positive results of improving quality and reducing the chance for errors.

The third supportive research question was: *"What kind of risks or challenges could occur if ETO production lead time were quickened?"*

The main risks and challenges relate to two improving opportunities. Firstly, decreasing the timeframe of publishing drawings in internally designed elements from six weeks to four weeks would slightly lower the capability to respond to surprises regarding the rare use of special accessories, for instance. In such cases, it might be necessary to define which accessories require confirmation from production before the designer decides to use them.

The second challenge relates to the improvement of production scheduling. Although the daily demand for concrete elements highly varies, on a weekly basis it significantly flattens. Implementing the suggested rule of not producing elements more than two weeks before the estimated date of delivery would theoretically lead to the requirement of one extra working weekend every twelve weeks to cover the sudden spike in demand during the high-demand season. It would also be possible to apply a rule for one-week production, but this would theoretically require one extra working weekend in every six-week period during periods of high demand.

By combining the answers from these four supporting research questions, it is possible to answer the main research question: "*How could the case company improve the current manufacturing process?*"

This study reveals that improvements could be achieved in all stages of manufacturing, including in the back-office systems. There are many minor opportunities for improvement in different stages and two major key findings. The major findings include the opportunities to improve the production scheduling and to benefit from having an internal design office. Both of these improvements would significantly aid the company's cost reduction objective.

7 CONCLUSIONS

The main objective of this thesis was to create documentation for the company's executives to provide a conception of which kind of improvements would be possible to achieve and how. The company's executives were originally considering the so-called fast-track system, whereby certain high-profile projects could be executed with significantly quicker lead times. After some consideration, the focus and objective were shifted towards improving opportunities for the whole manufacturing process. The main reason for abandoning the fast-track idea was that it has a relatively high risk of causing confusion and bottlenecks in the process when the lead time varies in different projects.

The beginning of this thesis featured a literature review on manufacturing processes and production management. These chapters were followed by the research with data analysis, retrospective simulation parts and interviews. The findings were presented and analyzed in all of the manufacturing stages using interviewee answers and opinions from the current stage employees.

The observations and improvement opportunities for the case company are clear and were presented in the discussion chapter where the research questions were answered. There are many minor opportunities for improvement during all of the manufacturing stages along with two major opportunities regarding the timing of production and published drawing schedule. The topics requiring further research include the automatization and digitalization of raw material management and linking employees' goals to the company's strategy.

Other topics for further research could be the definition of special accessories in the internal design office, which requires collaboration with production. In addition, methods of motivating designers to more closely consider production methods could be studied, because this would be highly helpful for the case company and represents a key benefit of the internal design office.

This thesis provides a deep review of the company’s internal process and suggestions regarding enhancement and cost-saving opportunities. Implementing new procedures always requires a plan for avoiding possible obstacles and errors, however this thesis does not include analyzing all the possible implementation problems in all the suggested improvement opportunities. Therefore, each of these improvement opportunities should be considered as individual projects with detailed implementation plans.

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APPENDICES

APPENDIX 1. INTERVIEW QUESTIONS

Basic information

1. Time and place of the interview?
2. Name and role in the company?
3. How long have you worked in the company?

Starting of the project

4. Are you involved in the starting process of a project?
    a. If yes, how are you involved?
    b. If no, should you be? why/why not?
5. What kind of things can you or would you like to influence on?
6. Are you satisfied with the current way of starting projects?
    a. If not, what kind of improvement opportunities there could be?

Design stage

7. Which one do you prefer, an internal or external design office?
    a. The pros and cons of both options?
8. Are you satisfied with the current internal design process?
    a. If not, what kind of improvement opportunities there could be?
9. What do you think about the strategy of having all elements designed internally?
10. Are you satisfied with the current design schedule?
11. What kind of challenges might occur if the schedule is enhanced?
    a. How it would affect to your work?

Production planning

12. Are you satisfied with the current production planning process?
    a. If not, what kind of improvement opportunities there could be?

Production

13. Are you satisfied with the current production process?
    a. If not, what kind of improvement opportunities there could be?

Warehousing and the time of delivery

14. Are you satisfied with the current warehousing process?
    a. If not, what kind of improvement opportunities there could be?
15. How does the time of delivery affect your work?

Other

16. How do you see the overall process working?
    a. In your opinion, are there some bottlenecks or some other highly sensitive steps?
17. What do you think about express deliveries and so-called FastTrack system?
    a. What kind of requirements that would that set? What kind of challenges might occur?

Comments

18. Do you have anything to add?