Master’s degree thesis

LOG950 Logistics

Lead time reduction and the correlation between delays of components and final products in ETO manufacturing companies within the scope of Industry 4.0; a case study of Brunvoll AS

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Abstract

One of the general engineer-to-order (ETO) company's key competitive factor is the delivery performance, of which lead time is a key factor. Lead time reduction is a well-known challenge that has been of great focus for centuries, and several studies regarding this subject have been conducted. However, one interesting research problem is the study of how to reduce the lead time within the scope of Industry 4.0. As a part of the Manufacturing Network 4.0, a project initiated as a response to the extended need for new knowledge and methodologies for the Norwegian manufacturing industries within the scope of Industry 4.0, previous studies found delays of components produced at the ETO company called Brunvoll. Delays of components might extend the lead time of the final product, thus we wanted to investigate the issue further. Some initial discussions with a previous production planner at Brunvoll indicated that even though some components were delayed, it was stated likely that the on-time delivery for final products (complete thruster systems) is close to 100 %. We wanted to investigate this as well.

To study timing issues we collected primary data from Brunvoll's ERP system. This provided a great amount of quantitative information regarding delays of components throughout the value chain in addition to delays for the final product. In order to critically analyse and discuss the results from the quantitative data, it was considered necessary to perform qualitative interviews with key informants from Brunvoll. Findings showed that 12 % of the complete thruster systems were finished before or within planned finish date, which means that Brunvoll face some challenges with the ERP system and the production planning. Further on, based on confirmed delivery date and actual finish dates, 62 % of the complete thruster systems were delivered before or within confirmed delivery date. This is a great indication that Brunvoll is not close to 100 % on-time delivery. Further findings showed that there is no significant correlation between delays of components processed at one machine (M53) and delays for complete thruster systems. Additionally, upstream and downstream tiers of M53, called AOVF3 and GRA, were studied, concluding that production tends to be delayed also at AOVF3 and GRA.

Our findings are based on ERP data and qualitative interviews. The quality of the historical data in the ERP system are most likely affected by poor reporting to ERP and other circumstances (internal and external) which influence the above results. Because of the findings that has been mentioned, the applicability of ERP systems within the ETO sector was discussed with respect to project manufacturing planning and control (PMPC) requirements. It was concluded that most of the requirements at Brunvoll are fulfilled, however, the need for real-time data and automatic reporting is considered great. Therefore, it is recommended that Brunvoll implement Industry 4.0 Technology, such as passive RFID-tags and sensors to reduce the risk of “historical data”, poor reporting and other circumstances.

Acknowledgements

This master thesis represents the final stage of the Master of Science degree in Logistics at Molde University College, Norway. The thesis has been conducted revolving the subject of lead time reduction in ETO manufacturing companies and has been written during the spring semester of 2018.

First off, we would like to sincerely thank our supervisor, Associate Professor Bjørn Jæger, and our co-supervisor Karolis Dugnas at Molde University College. They have provided this master thesis with valuable opinions and feedback, guidance and recommendations.

Secondly, we would like to send our respects and appreciations to Brunvoll AS and their representatives for the great amount of information shared and their patience and time during our research. Without their cooperation this master thesis would not have been able to create such critical discussions and conclusions.

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1.0 Introduction

Lead time reduction is a well-known, however, still a highly relevant logistical challenge for manufacturers. During the second industrial revolution Henry Ford reduced the lead time for assembly of a single vehicle from 12 hours to around 90 minutes, which was revolutionary for make-to-order (MTO) companies. Compared to MTO and other manufacturing strategies, engineer-to-order (ETO) companies have always had longer lead times. Therefore, an interesting research problem is whether Industry 4.0 IoT-Technology can contribute to reduce lead times. This master thesis thereby intends to study how to reduce the lead time of an ETO company within the scope of Industry 4.0 IoT-Technology. Because several studies regarding the lead time reduction challenge have been conducted, this thesis is motivated by a previous case study of an ETO company, Brunvoll, that manufactures complete thruster systems.

First, the research problem will be stated, and previous research will be presented to explain the background for this master thesis. Then, the context and focus of the study is elaborated. Further on, six research questions are created to support the research problem. Thereby, the case company is presented and the company's IoT-Technological maturity is discussed. At the end of the introduction chapter a structure of the study is provided. During the second chapter relevant literature regarding the logistics field, supply chain management and technology is defined and explained. The third chapter expresses the methodology for this thesis, providing the readers with the research method and design in addition to data collection and sources. During this chapter, the reliability and validity of the study is argued and stated. Based on the methodology of this study, case study findings are analysed and structured dependent on the research questions. Thereby, discussions of the research problem and research questions are expressed, leading to the conclusion of this thesis.

1.1 Research Problem

The underlying problem of this master thesis emerges from the high degree of complexity of the ETO manufacturing strategy. ETO manufacturers make and engineer products to order, and several ETO companies are often characterized by long product life cycles, complex products with multiple levels of subassemblies in their Bill of Materials (BoM), highly skilled labour, manual data entry, and so on. Therefore, such companies tend to benefit from an efficient and visible supply chain (iBASEt, 2014). ERP systems should improve the flow of information through a company's supply chain and thereby improve its visibility. However, because of the complexity of ETO manufacturing companies, the applicability of such systems within the ETO sector is an area of interest.

One key competitive factor in the ETO sector is the delivery performance, which consists of two components for improvements: reducing lead time and increasing the reliability of lead time estimates (Hicks, McGovern, and Earl, 2000). This thesis will study the delivery performance, in terms of lead time, of an ETO company, and further on, explore possible measures for continuous improvements which can reduce the lead time. Additionally, it will be investigated to what extent robotics, chips/tags, sensors and similar technology within the scope of Industry 4.0 can contribute to improved production planning and thereby reduce the lead time. Therefore, an interesting research problem is:

How to reduce the lead time in ETO manufacturing companies within the scope of Industry 4.0 Technology?

1.2 Background and Previous Research

This master thesis is an extension of previous research conducted in contribution to the Manufacturing Networks 4.0 project, which was initiated as a response to the requirements of new knowledge and methodologies for Norwegian manufacturing industries in the context of the fourth industrial revolution. Wollen's (2017) thesis studied the internal manufacturing process at Brunvoll, which is an ETO company that produces complete thruster systems. The unit of analysis in Wollen's study was limited to one machining center (M53) and one component type (Gear Housing).

From Wollen's (2017) results we discovered the following interesting finding: 74 of 86 work orders were delayed. This indicates that only 14 % of the work orders were delivered on time. The following figure graphically illustrate the findings of Type 1 process dynamics (work order delays):

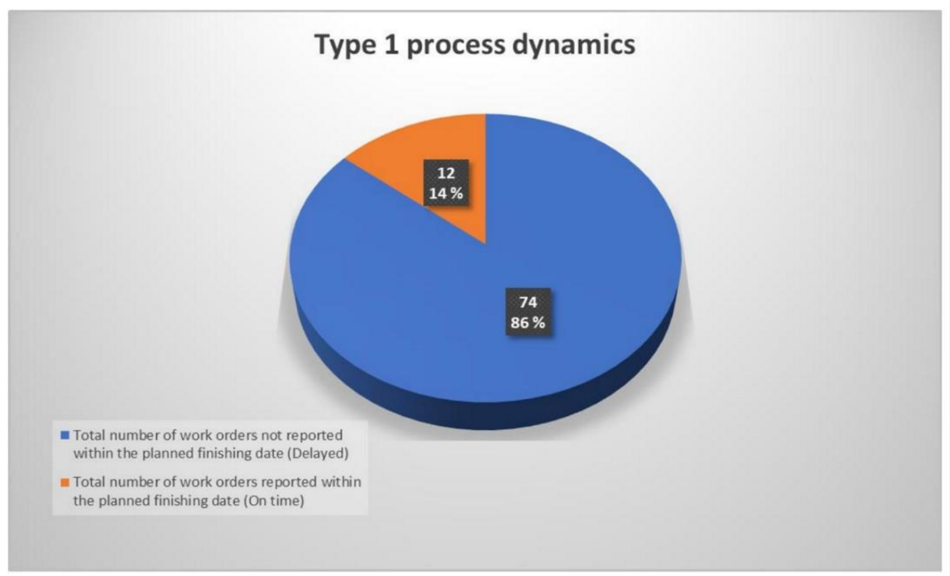


Figure 1: Type 1 Process Dynamics (Work order delays)

The occurence of work order delays are determined by the date at which the work order was reported completed compared with the planned finish date. Reporting the business event when the actual event occurs is therefore important. Wollen (2017) stated that some work order delays were not possible to detect, either due to high complexity regarding extracting historical information, or because the information required was not captured by the Infor M3 ERP system.

The findings regarding work order delays were discussed with the former production planner at Brunvoll, Karolis Dugnas. He suspected that even though 86 % of the gearhouse components were delayed, the complete thruster systems were most likely delivered to the customers on time. Based on the discussion with Dugnas and the specific results from Wollen's research, it was considered interesting to do a further study of Brunvoll's delivery performance.

1.3 Context and Focus of the Study

As a part of an effort to reduce the lead time, this master thesis will first study the correlation between the on-time delivery of work orders processed at individual machines and the on-time delivery for the end-to-end manufacturing process of Brunvoll's complete thruster system. Reducing the lead time, i.e. the time from an order is received until it is delivered, is a major goal for Brunvoll. Product planning and re-planning depends on accurate and reliable information from ongoing production processes. However, initial investigations have shown that planned finish dates in the ERP system largely deviate from reported finishing dates for a central machining centre (M53). Based on discussions with Karolis Dugnas, it has been stated that Brunvoll's products most likely are delivered on-time, i.e. the on-time-delivery of products are close to 100%. Improving production planning in order to reach the goal of reduced lead time will be very difficult under such circumstances. Therefore, we investigate whether the final products actually are delivered on-time as stated, followed by an analysis and discussion of the applicability of ERP systems in the ETO sector and how Industry 4.0 IoT-Technologies might contribute to reduce the lead time.

1.4 Research Questions

The research problem presents the research focus, however, it does not imply how it is going to be answered. As Henry Ford said in 1926: “The easiest of all wastes, and the hardest to correct, is this waste of time, because wasted time does not litter the floor like wasted material” (Levinson, 2014). Therefore, the research questions (RQ) 1-6 are created as supporting RQ’s for the research problem. RQ 1, 2, 3 and 4 intends to focus on the on-time delivery of components and final products for Brunvoll. Further on, RQ 5 and 6 will provide discussions regarding Brunvoll and ETO companies in general, the applicability of the ERP systems in addition to how Industry 4.0 IoT-Technology can improve reporting in ERP systems and thereby reduce the lead time. The following RQ’s are proposed to support the research problem:

RQ1: To what extent are projects (complete thruster systems) delayed?

RQ2: To what extent do the delay of a component at M53 influence the project delivery time?

RQ3: To what extent do delays at M53 propagate to its upstream and downstream tiers?

RQ4: Why and to what degree do the delays differ at various locations?

RQ 5: How do the ERP system at Brunvoll support the project manufacturing planning and control (PMPC) process?

RQ6: How can Industry 4.0 concepts be used to reduce the lead time in ETO manufacturing companies?

1.5 Case Company: Brunvoll AS

In 1912, the Brunvoll brothers Andreas and Anders Brunvoll founded Brødr. Brunvoll Motorfabrikk. In 1918, Artur Brunvoll joined his brothers and the company moved to Molde. By then, Brunvoll manufactured low-pressure diesel engines and controllable pitch propellers for fishing vessels. However, Brunvoll faced a great business challenge when lightweight and high-speed diesel engines revolutionized the market in the early 1960's. The company's response was to introduce tunnel thrusters for purse seiners, which was a critical improvement of safety and efficiency in fishing operations. As a result of successful growth, Brunvoll is a world leading supplier of Thruster Systems, having delivered around 8000 thrusters and more than 5000 vessels (Brunvoll AS, 2018a).

Today, Brunvoll is a single-source supplier and provides fully integrated Thruster Solutions complete with drive motors, hydraulic power units, control, alarms and monitoring systems. In addition, each system can be optimized to meet the needs of the customers, or the individual vessel and operation. Brunvoll also offers both electric and diesel drive systems, and they provide service and support for the lifetime of the Thruster System (Brunvoll AS, 2018b). Their business builds upon the concept of designing, manufacturing, marketing and servicing a complete Thruster System for manoeuvring, positioning and propulsion of advanced vessels (Brunvoll AS, 2018c).

With acknowledgement of Brunvoll's business concept, one of their main goals is to generate steady and healthy long-term growth and profitability. In 2016, the company revenue was NOK 675.2 million. The company's current liabilities totaled 96.6 % of all debt compared with 97.8 % in 2015. It can be stated that Brunvoll's financial situation is good (Brunvoll AS, 2016).

In 2014, Brunvoll put a significant effort into reviewing their documented control system to meet the requirements in ISO 9001, ISO 14001 and OHSAS 18001. Figure 2 explains Brunvoll's value chain, whereas ownership and continuous improvements of all processes in and around their value chain is the key in order for Brunvoll to maintain their competitive edge (Brunvoll AS, 2014). The company's value chain consists of two main business areas; new sales/project management and after-sales service, as the figure below expresses.

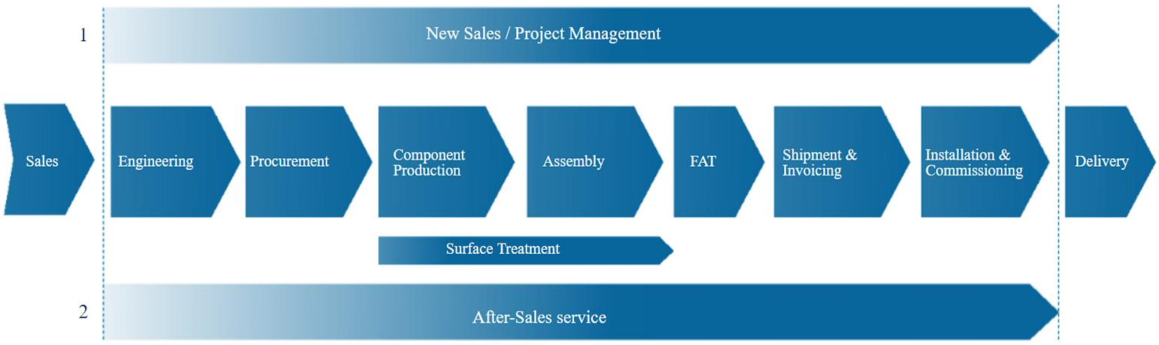


Figure 2: Brunvoll's Value Stream

1.5.1 IoT-Technological Maturity at Brunvoll

During "Industrikonferansen" in 2017, Brunvoll was awarded "Norway's Smartest Industrial Company". The jury emphasized that Brunvoll is competing in a tough global market where digitization and innovation are crucial for survival. Their increasing implementation of Industry 4.0 Technology, such as extensive use of robotics within their producing factory, has improved Brunvoll's efficiency and eased the workload for their employees (Gamlem and Sandvik, 2017). Brunvoll uses an ERP solution provided by Infor called M3 which is intended to generate visibility throughout Brunvolls value chain and system-wide transparency for all key stakeholders. Further on, the M3 solution is purpose built, designed to support multiple manufacturing strategies, such as ETO, MTO and CTO, which will be explained later during this thesis (Infor, 2018).

Previous research within the Manufacturing Network 4.0 project developed a model for IoT technology maturity. This research assessed the IoT technology maturity status for several companies, including Brunvoll. The model consists of eight levels of IoT technology maturity, from level 1 characterizing 3.0 maturity to level 8 characterizing 4.0 maturity. A company at level 1 are 3.0 mature, in the beginning phase of embracing IoT technology, while a level 8 company has reached the visionary stage of Industry 4.0. The following figure expresses Bø and Wiig's (2016) IoT-Technological Maturity Model (IoTTMM):

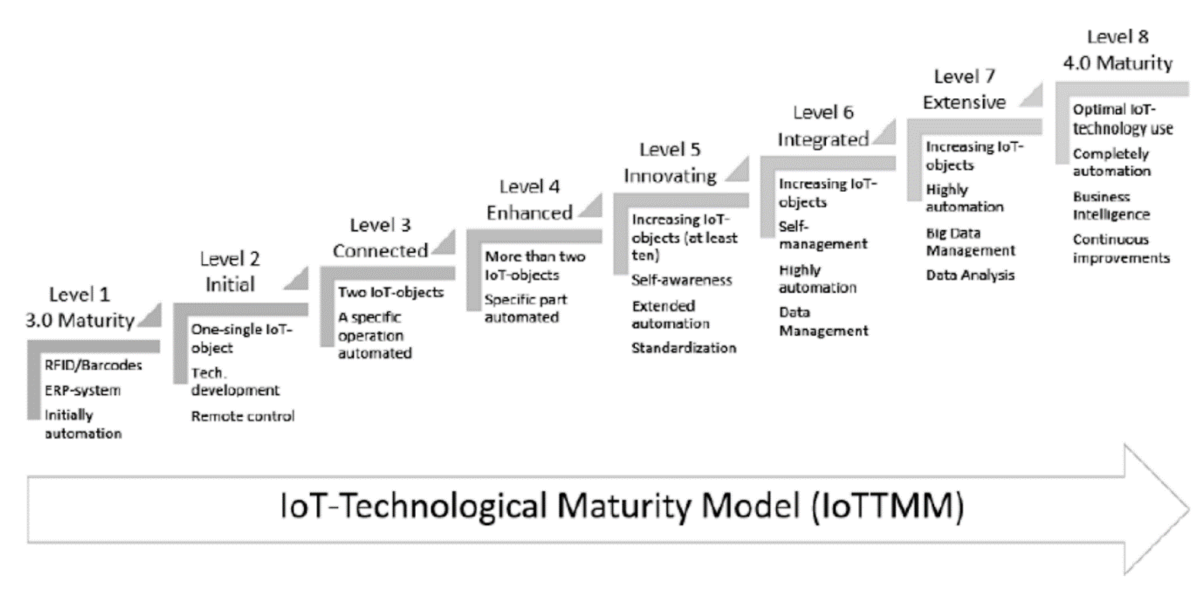


Figure 3: IoT-Technolgical Maturity Model

Bø and Wiig (2016) found Brunvoll to have a high degree of technological competence; with a high strategic focus on automation, and with investments in robotics and automated processing in the manufacturing processes. Additionally, findings showed that Brunvoll's operations are mainly supported by the ERP system, however, the manufacturing processes consists of a mix of manual and automated operations. The conclusion of Bø and Wiig's (2016) research was that Brunvoll is at maturity level 3, meaning that Brunvoll exercises an extensive use of barcodes, ERP system, at least two IoT objects and automation of specific operations (Wollen, 2017).

However, because Wollen found that only 14 % of the work orders were finished within planned finish date, it is believed that Brunvoll would significantly benefit from maturing towards Industry 4.0 IoT technology. Such IoT technology is intended to increase the visibility of manufacturing processes, which could improve the data reported within Brunvoll's ERP system. Reaching Industry 4.0 IoT technology can be considered a long-term goal for Brunvoll, and it is therefore optimal to investigate possible opportunities for it.

1.6 Structure of Thesis

Figure 4 below shows that the chapters for this thesis are divided into one theoretical part and empirical part. To begin with, the introduction chapter have been presented. Further on, Chapter 2 presents the literature review which is sectioned into two sub chapters; Logistics and Supply Chain Management and Technology and Logistics. The first sub chapter presents theories and concepts connected to the logistics and supply chain management field, while the second sub chapter correlates the logistics field with technology and Industry 4.0. All in all, this chapter is intended to provide theoretical support for this study's research problem and RQ's.

Chapter 3 will explain the methodological approach for how to answer the research problem and RQ's. In addition, forms of data collection for this case study will be expressed. Chapter 4 will present the case study findings based on the methodological approach. This chapter is structured based on RQ 1, 2 and 3: These RQ's will be answered based on the findings from the data collection. Further on, Chapter 5 is responsible for the analyses based on the case study findings. During this chapter RQ 4 will be analysed and discussed based on the qualitative interviews with key informants from the surface treatment department, machining department and the planning department at Brunvoll. Later in this chapter, the summary of findings and analyses will be presented based on RQ 1-4. During Chapter 6, RQ 5 and 6 will be discussed based on the methodology and case study findings and analyses. The applicability of ERP systems within ETO manufacturing companies is discussed and different Industry 4.0 measures are presented. At last, this has provided a great groundwork for the seventh chapter which consists of the conclusion for this thesis.

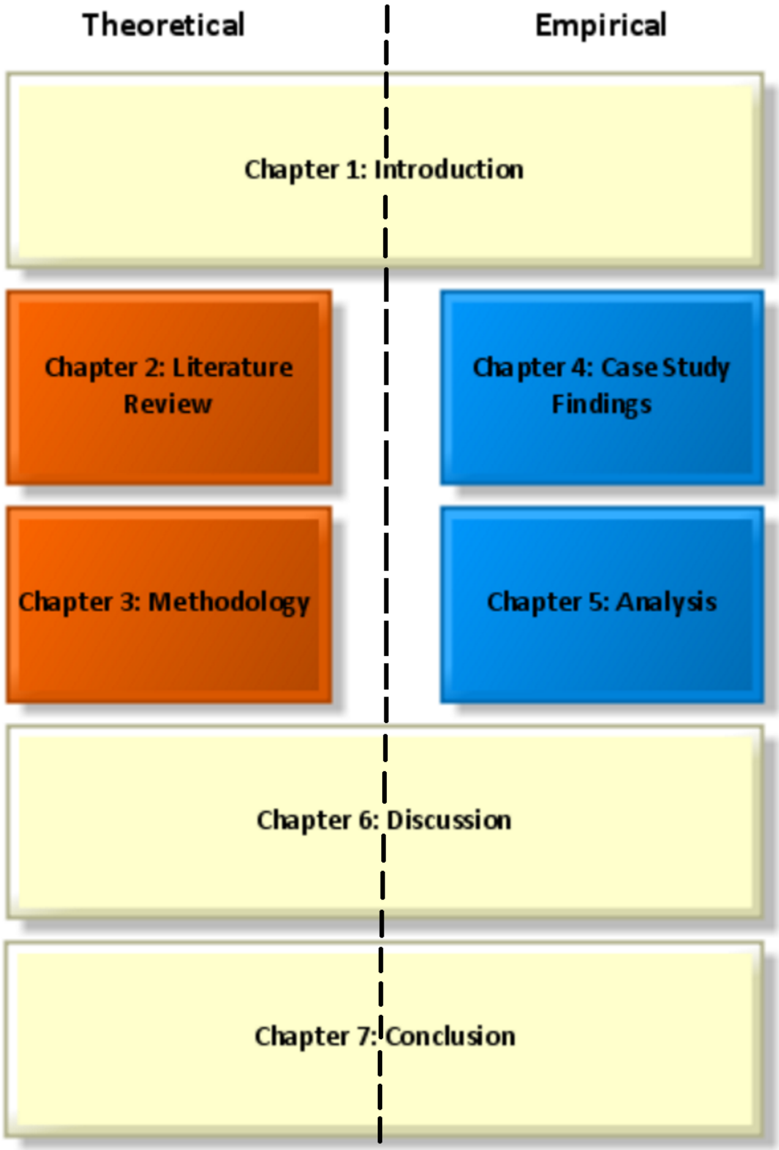


Figure 4: Structure of Thesis

2.0 Literature Review

The literature review will present theories, definitions and concepts relevant for this thesis. This review will be structured into two different sections. The first sections is Logistics and Supply Chain Management, revolving around the logistics field of study containing definitions of logistics, supply chain management and supply chain visibility in addition to theories regarding delivery performance and so on. The second section is about Technology and Logistics, representing the technological evolvement of the logistics field considering concepts such as Industry 4.0, communication technologies, the automation pyramid, GS1 standards, and more.

2.1 Logistics and Supply Chain Management

During this chapter, relevant logistics and supply chain management (SCM) theories and literature will be presented. Some theories and definitions will be actively utilized during the analyses, however, others are necessary to generate basic knowledge to understand concepts.

2.1.1 Definitions of Logistics and SCM

The term logistics can be described as the management of efficient flow of materials, a generic term ensuring that materials, or products, are located at the right place at the right time. Supply chain management is a term used to describe something similar to logistics, however, not the same. The Council of Supply Chain Management Professionals (CSCMP) defines logistics management as:

> *Logistics management is that part of the supply chain management that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.*
> (Jonsson, 2008)

CSCMP's definitions holds that the term logistics covers planning and execution at strategic, operational, and tactical levels (Ayers, 2010). The definition also implies that logistics can be studied as an individual part of one company, or as a flow of materials through several companies. What is meant by the forward and reverse flow and storage of goods and services, that logistics follows the flow of raw-material to finished goods delivered to end-customers including the return flow of e.g. defective products, recycling of used products and similar (Jonsson, 2008).

In the recent years, the term supply chain management (SCM) has arised, regularly used as a similar concept to logistics. However, SCM can be defined as followed:

> *Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers.* (Jonsson, 2008)

According to CSCMP, SCM can be understood as an "integrating function" that links business functions and processes, within and across companies, into a cohesive business model. This function includes all the logistics activities, manufacturing operations and coordination processes and activities, such as marketing, sales, product design, finance and information technology (Jonsson, 2008).

2.1.2 The Value Chain

Michael Porter introduced the term value chain in his books about competitive strategy and advantage. Within a company, the value chain includes inbound logistics, operations, outbound logistics, marketing and sales, and service. This means that the value chain encompasses customer-touching activities. Each company has its own value chain comprising different supporting activities, such as procurement, technology developments, human resource management, and infrastructure (Ayers, 2010).

Value Chain is defined as the series of activities that adds value to the product (KeyDifferences, 2015). Based on the definition, the value chain builds upon the concept of adding value in order to gain competitive advantage. The sequence of the term is displayed in the following figure:

Figure 5: Sequence of Value Chain

2.1.3 Supply Chain Visibility

The existence of definitions of supply chain visibility among academic sources are great. However, the construction of the term is regularly mixed with terminology such as traceability and connectivity. One definition that has been used several times is the following:

> *Supply chain visibility is the capability of a supply chain player to have access to or to provide the required timely information/knowledge about the entities involved in the supply chain from/to relevant supply chain partners for better decision support.* (McIntire, 2014)

The difficulties of defining supply chain visibility may be a cause of the term being extremely wide; if you ask a group of people for the definition of supply chain you will get a great variety of answers. The same thing happens when you ask for the definition of supply chain visibility. However, the following axioms may help to gain a greater perspective of the term supply chain visibility:

1. Visibility means increased awareness of the states of the supply chain activities and related events.
2. Visibility is inward looking: it is not focused on becoming more aware about competitor supply chains, for example.
3. Visibility offers the power to convene facts but not to control actions, it provides awareness but not execution.
4. Visibility is in service of both tactical decisions and strategic decisions.
5. Visibility is achieved through a combination of process and technical means. (McIntire, 2014)

Previous research of supply chain visibility showed that the use of information technology, or IoT technology, enables the connectivity of the company, which will further on enable the visibility of the company's supply chain. The following figure explains this statement (McIntire, 2014):

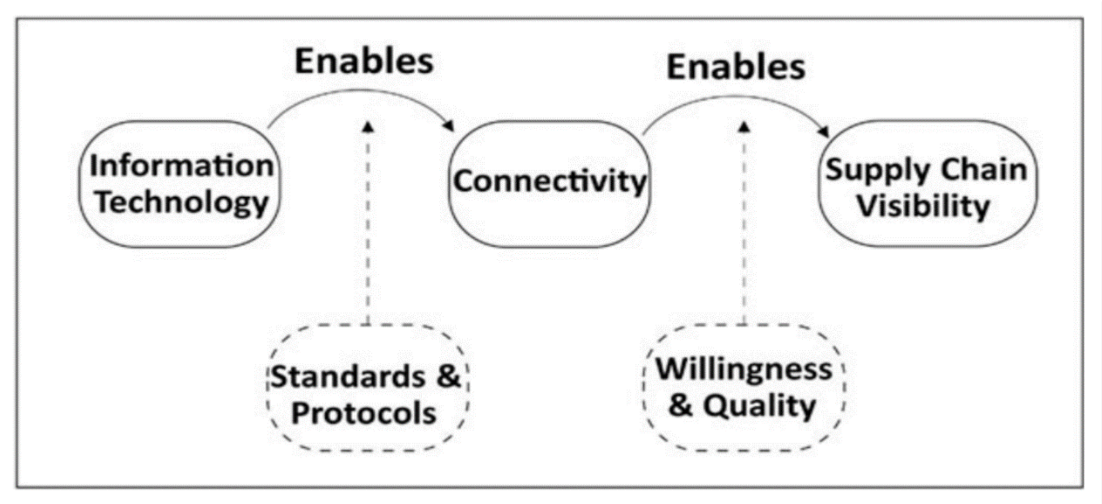


Figure 6: Organization Factors Leading from Technology to Visibility

Such digitization of a company's supply chain is beneficial for increased visibility and control. Therefore, increasing the supply chain visibility can be considered a critical strategy for companies which aim towards reduced costs and improved operational performance, such as reduced lead time (Aberdeen Group, 2013).

2.1.4 Manufacturing Network

Manufacturing networks can be viewed as a significant part of manufacturing management. In the early days, manufacturing management was restricted to focus only on the plant level and dealt with the organization of the manufacturing site. However, today, manufacturing management has evolved to revolve around the general management of a manufacturing company. Therefore, research has moved from the conventional focus towards the field of globalised manufacturing. Such research has thereby studied the definition of network as "... an independent and complex system in which the players interact with one another" (Friedli et al., 2014).

Further on, based on previous studies, Friedli et al. (2014) defines manufacturing network as "... a factory network with matrix connections, where each node (i.e. factory) affects the other nodes and hence cannot be managed in isolation". The geographic spread of the network can be defined in four stages: national, regional, multinational and global. The following figure explains the number of organizations within a network:

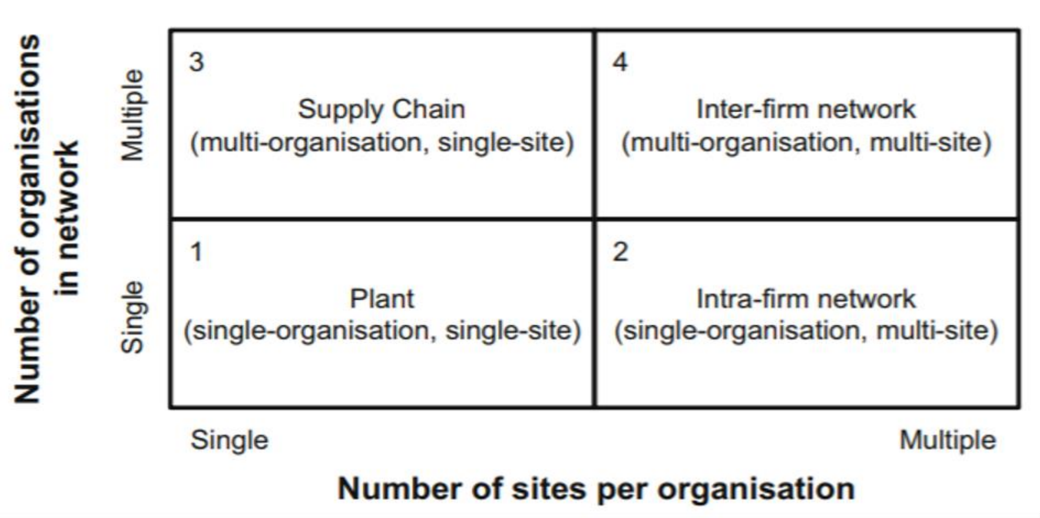


Figure 7: Classification of Value Networks

The manufacturing network may thereby be said to revolve around connecting enterprises globally or locally (single) by their production systems, permanently or temporarily. Such collaboration between global enterprises or locally within enterprises has become of greater interest during the years, especially for manufacturing companies who wants to share their value chain with one another in order to conduct joint manufacturing (Friedli et al., 2014).

The study of the manufacturing network has been dominated by two perspectives; operations management and supply chain management. The operations management perspective focuses on the organization of plants, the network itself, and its coordination. This perspective is normally limited to the internal network system, defining the nodes and their capabilities. The supply chain management perspective, however, revolves around the focus of logistics and management of material flows. This perspective helps widening the manufacturing network by integrating external and internal suppliers and customers, mainly addressing the physical links between the nodes (Friedli et al., 2014).

2.1.5 Delivery Performance

One way of measuring how successful a supply chain is at providing products and services to a customer is through delivery performance. This metric can be defined as:

> *The level up to which products and services supplied by an organization meet the customer expectation.* (Rao, Rao and Muniswamy, 2011)

The potential of a supply chain is to provide products and service to one or several customers, and to do so successfully by delivering to the customer needs and requirements. This metric is valuable in supply chain management as it integrates the measurement of performance directly from supplier to the end customer (Rao, Rao and Muniswamy, 2011).

Delivery performance can be measured as the percentage of customer orders delivered, or fulfilled, on time. The meaning of "orders fulfilled" is that the supplier delivers the order to the customer expectation and requirements. What is "on time" can be either the date of request by the customer, or a date of which both the customer and supplier has agreed upon, i.e. commit date. Which date is preferred depends on the supplier's ability to deliver to the customer's requirements; if the supplier is flexible to adapt to the customer's requirements regarding delivery date, it is possible to define "on time" as *customer request date*. However, when a supplier is not able to deliver to the customer request date, it is possible to define "on time" as the *customer commit date* (Hedin, Jonsson and Ljunggren, 2006).

2.1.6 Manufacturing Lead Time

Manufacturing lead time can be defined as "the time taken from the time production is authorized, to the time it is completed and the material is available for use to fill demand by the customer or the next stage" (Graves, Kan and Zipkin, 1993). Lead time in manufacturing can be considered as the time that elapses from a customer order, or manufacturing order, is received to completed delivery. The lead time consists of administration and order processing times, dispatch and transport times, and, in the case of engineer to order or make to order approaches, engineering or manufacturing times will be relevant. Whether or not one of these times should be included in the lead time depends on different factors. For instance, whether or not the transport time should be included is determined by the responsibility limits for the delivery. Different customers acquire different transport times, and therefore, it can be appropriate to define the lead time up until dispatch and then include this in the customer-specific transport time.

The lead time is typically expressed in days or weeks. The longer the lead times, the more negative consequences, such as decreased flexibility as a result of extended response times for the order, and increased capital tied up and associated costs because the materials are in transit for a longer period (Jonsson, 2008). The manufacturing lead time is a typical area within ETO companies which should be improved. Along with many other elements in lead time that can be excessively long are backlogs in production scheduling. ETO and MTO companies traditionally operate with consistent backlogs. This is a result of the fact that such manufacturing companies cannot predict the incoming work orders coming in each week (Wight, 1970).

2.1.7 Manufacturing Strategies

Engineer-to-order (ETO) is one of the four major manufacturing strategies. The others are assemble-to-order (ATO), make-to-order (MTO) and make-to-stock (MTS). The ETO approach is complex in the context that the company designs and manufactures their product based on very specific customer requirements. For ATO and MTS approaches, procurement is performed before the sales order is received. However, for ETO and MTO approaches the procurement process and production is in progress after the sales order is received. The unique factors of the ETO strategy is that the manufacturing company cannot procure or produce any of the products in the Bill of Material (BoM) any sooner than at the time of the receipt of the sales order. It must be clear exactly what is going to be produced before the procurement and/or production process begins (Brightwork Research & Analysis, 2017).

It is typical for an ETO approach that critical information and specifications moves between the customer and the ETO company. If the exchange of information and specifications is poorly managed, there may occur critical problems and confusion between both parties. It is common for ETO companies that they experience trouble with “leftovers” from material;

where should the leftovers be stored? How can we best reuse the leftovers as the material may be expensive? In order to create a visual understanding of the different manufacturing strategies, the following figure might be helpful (Dakhli and Lafhaj, 2017):

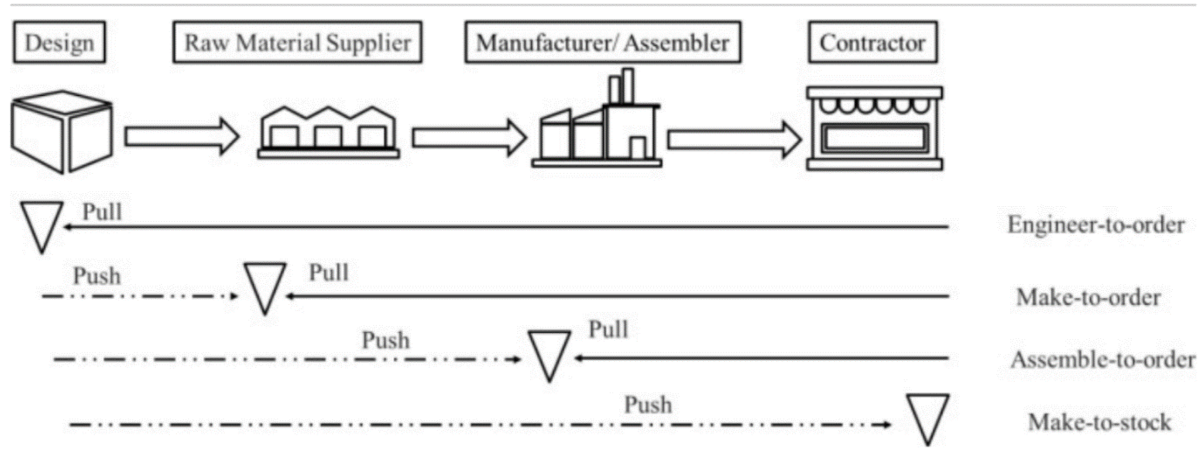


Figure 8: Manufacturing Strategies

Figure 8 explains that the MTS, ATO and MTO approaches requires a push strategy, whereas production is not based on actual demand. ETO is the only manufacturing approach which is completely based on a pull strategy, meaning that production is fully dependent on actual demand (Dakhli and Lafhaj, 2017). Uncertainty regarding demand is a typical issue for ETO companies. In addition, as ETO and MTO manufacturers must to some degree design a new product, such companies typically suffer from problems regarding long lead and cycle times, complex products with deep bills of BoM, high requirements of skilled labor, complex production, and lack of automatic data reporting (iBASEt, 2014). Such issues should be considered while studying how to reduce the manufacturing lead time for ETO/MTO companies.

2.1.8 Project Management

The case company, Brunvoll, is an ETO manufacturing company. This means that their manufacturing processes are built around projects. One definition of projects is the following:

> *A project is temporary in that it has a defined beginning and end in time, and therefore defined scope and resources*. (Project Management Institute, 2018)

As the definition explains, a project must have a definite starting and ending point. Each project is unique, meaning that it is not a routine operation. However, it must meet specific objectives. These objectives should meet the following criterias; the project must be completed in time, within the budget and meet the prescribed quality requirements. In order to fulfill these criterias, it can be critical to manage the projects. Project management can be defined as:

> *The planning, monitoring and control of all aspects of a project and the motivation of all those involved in it, in order to achieve the project objectives within agreed criteria of time, cost and performance.* (Lester, 2006)

This definition is closely correlated with the term project. In addition, as far as the management aspect is concerned, the term "motivation" is fundamental for this definition. If all, or at least most, of the participants of the project are competent - and - motivated to produce a satisfactory outcome, the project will be successful (Lester, 2006).

2.1.8.1 Project Life Cycle

Most projects go through a life cycle, which varies depending on the size and complexity of the respective project. The production projects at, for instance, Brunvoll are complex due to specific customer requirements. Defining an ETO network and the associated project life cycle can therefore be challenging. The planning and control of such networks is affected by the actions of the suppliers and the customers, which could result in excessive inventories, long lead times, low customer satisfaction, and poor resource allocation (Sriram, Alfnes and Arica, 2017). For a company to meet its needs, for instance reducing lead times by improving its performance, it can be useful to develop a project life cycle diagram. The following figure shows an example of how a project life cycle diagram might look like (Lester, 2013):

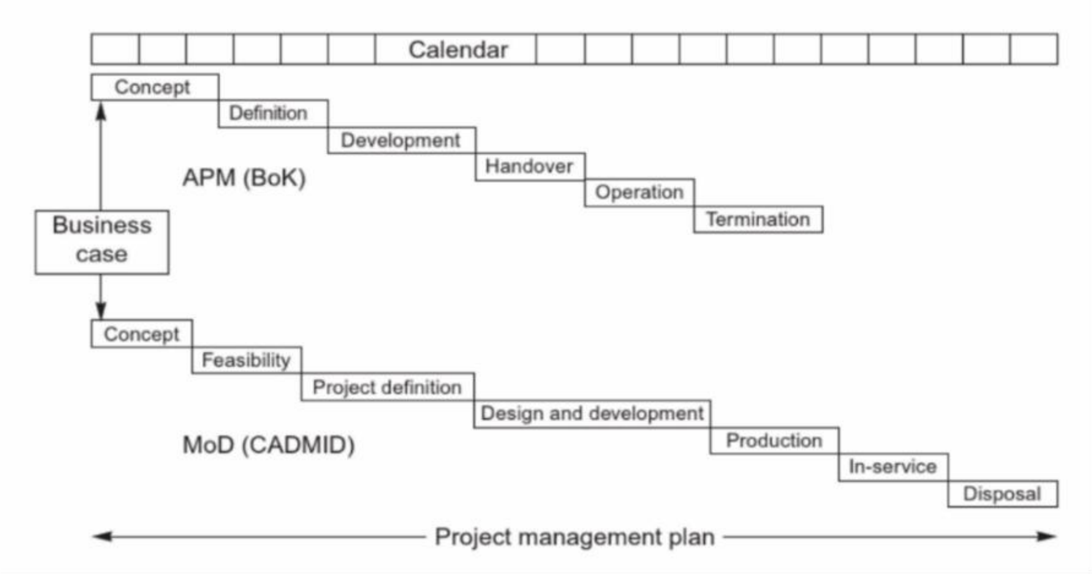


Figure 9: Project Life Cycle Diagram

The first life cycle example of APM in their latest Body of Knowledge is a simple generic life cycle which consists of only six phases; concept, definition, development, handover, operation and termination. The second life cycle, formulated by the Ministry of Defence (MoD), is relatively more complex and shows the typical phases for a typical weapon system. Additionally, the diagram includes a calendar scale - which is not strictly necessary, however, it can be useful for reporting which phases are complete or partially complete in relation to the original schedule.

Creation of such project life cycle diagrams is useful in order for the company to meet its particular needs. In addition, since the life cycle covers all the phases within the project, the term project life cycle is restricted to those phases that constitutes the project, e.g. the concept, design and development, and production (Lester, 2013).

2.1.9 Manufacturing Planning and Control

The manufacturing planning and control (MPC) system concerns planning and control of all aspects of manufacturing, including materials management, scheduling machines and people, and coordinating suppliers and key customers. These activities are dynamic, meaning that they change with time, and the MPC system is intended to be adaptive to respond successfully to changes regarding customer requirements, supply chain, strategies and so on. The following figure provides a simplified visualization of the MPC system (McGraw Hill Education, 2018):

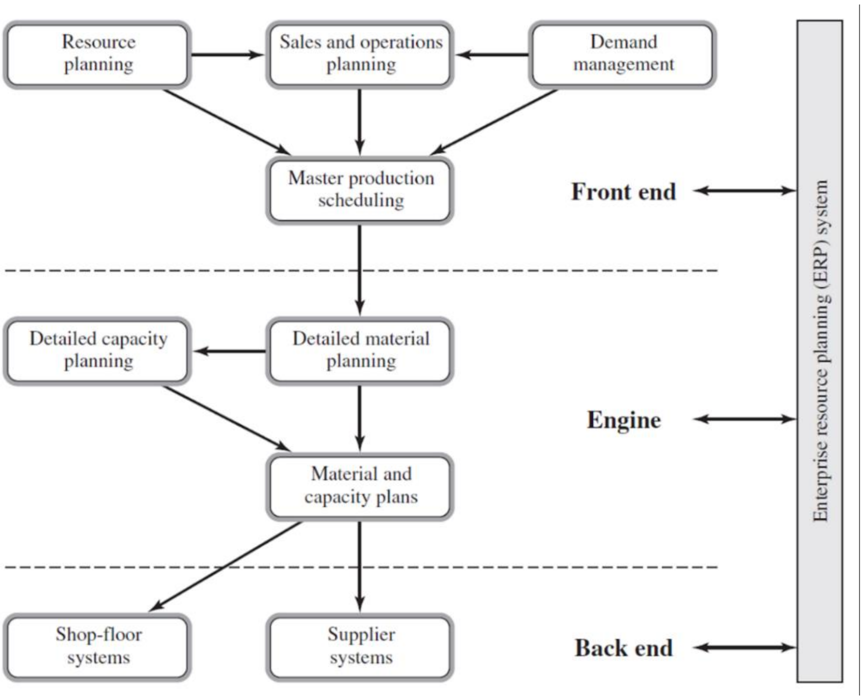


Figure 10: The Manufacturing Planning and Control System

Figure 10 is a general visualization of the MPC system that normally would be used by a company for planning and controlling its manufacturing operations. It can be stated that the Figure 10 shows a model that can be viewed as a key part of any packaged ERP system. The model is divided into three phases; the front end, which is the set of activities and systems for overall direction for manufacturing planning and control. The middle, or engine, encompasses the set for detailed material and capacity planning. The back end contains the MPC execution system, which is configured depending on what products are manufactured and which production processes are employed (McGraw Hill Education, 2018).

2.1.10 Project Manufacturing Planning and Control

Project manufacturing planning and control (PMPC) is a modification of the MPC framework, which was explained earlier in this chapter. This framework, however, illustrates the planning processes in project manufacturing and their interconnection. The PMPC framework should be implemented in an MPC environment, and will thereby act as a decision support system. For the PMPC system, the *demand management* function covers the sales management lines and defines projects as either "planning groups" or single projects based on the resemblance of different orders. The *engineering management* function, where design and configuration activities are performed, is coordinated with the demand management function. When the detailed engineering activities are finished in time, the project schedule and tasks are updated, meaning that the customized parts or components are specified. Projects generate demand for specific parts, or components, which eventually requests for resources (Sriram, Alfnes and Arica, 2017).

Aggregated demand planning, inventory management, and network activity and resource planning is performed in the *sales and operations planning* function. Project tasks are then attached to the demand parts or components related to each project. These components are further on assigned to the capacities defined in the *master production schedule* or *material and capacity planning* functions (Sriram, Alfnes and Arica, 2017).

Master production scheduling is performed on the modules that are defined in the product structure. This planning process can be considered critical in project manufacturing when it comes to planning of long lead time components. In addition, the planning of sub-assemblies is critical because it can require pre-production, or it needs to be ordered in advance (Sriram, Alfnes and Arica, 2017).

Material requirement planning is dependent on the project activities and the different reservation levels assigned to the components - or component groups. Some of these components are project specified, some are assigned to project groups, while other components may be identified as "common supply", meaning that they are adaptive to all projects and project groups. The production and purchasing orders are placed when the detailed capacity is checked against the plans. Figure 11 provides a visualization of the PMPC system and how the different functions are integrated (Sriram, Alfnes and Arica, 2017):

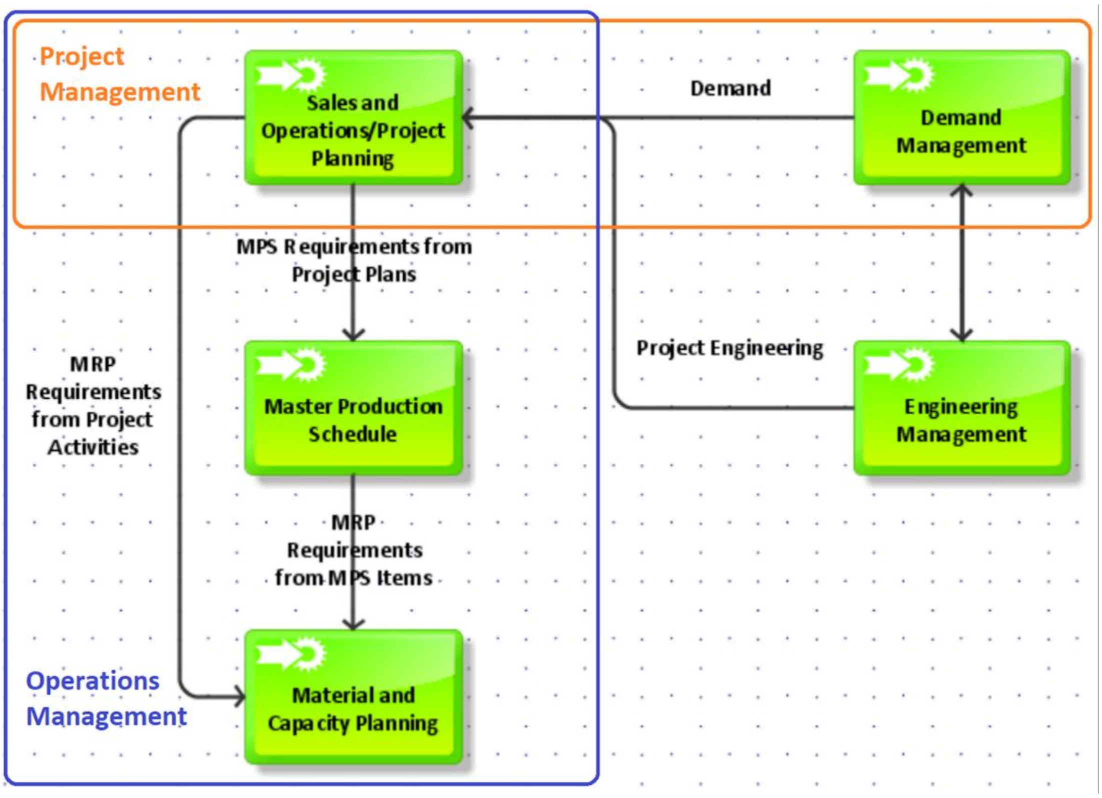


Figure 11: Production Manufacturing Planning and Control (PMPC)

Because project tasks are attached to the demand components, and these components are attached to the assigned capacities, the PMPC system is adaptive to engineering change requests received from the customer. Changes related to material management and respective adjustments to the project schedule is critical when changes in engineering is requested. Since the project tasks are linked to the supply chain, activities and project schedule, the changes performed as a result of the engineering change request can take effect in an integrated and automated manner (Sriram, Alfnes and Arica, 2017).

2.1.11 Production Layout

How a company transform a raw material and purchased components into a finished product can be organized in a number of different ways. The organising will be dependent on the structure of the product groups and work centres, or departments, whereas goods flow through during the process of manufacturing. In order to gain a best possible layout for the product groups and departments, four different types of production layout will be presented (Jonsson, 2008).

2.1.11.1 Functional Production Layout

The functional production layout is characterized by the production resources being organized by function; all machines and work stations, or departments, are located in the factory according to their production functions. This means that the machines are arranged according to the nature, or type, of the operations rather than the sequence of operations (Jonsson, 2008). Figure 12 visualizes the functional production layout (Chand, 2018):

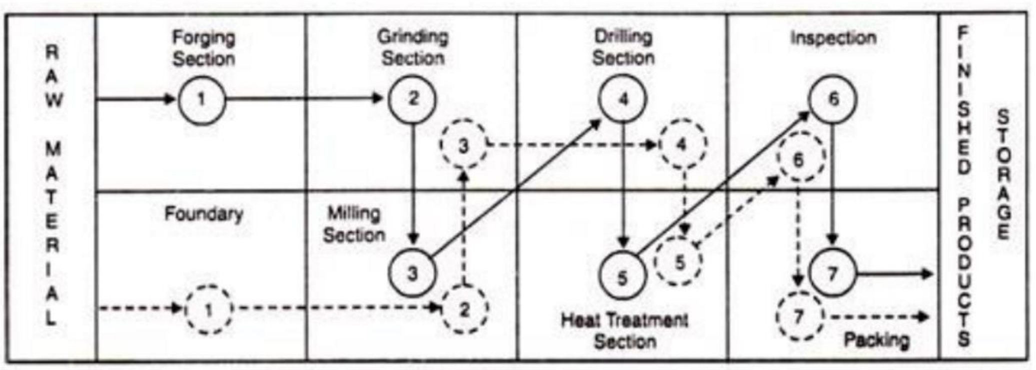


Figure 12: Functional Production Layout

This functional layout is preferable for standardized products when the range of parts manufactured is wide and every part is produced in relatively small numbers (Jonsson, 2008).

2.1.11.2 Line-shaped Production Layout

When production resources are organised by product/component and are located in the same sequence as the production steps that are carried out during the manufacturing, the line-shaped production layout is appropriate. The production resources are therefore arranged based on the product itself, and not the function of the production resource. Such as layout is common for assembly lines and complete process plant for chemical-technical production (Jonsson, 2008). Figure 13 explains how the line-shape production layout is organized (Chand, 2018):

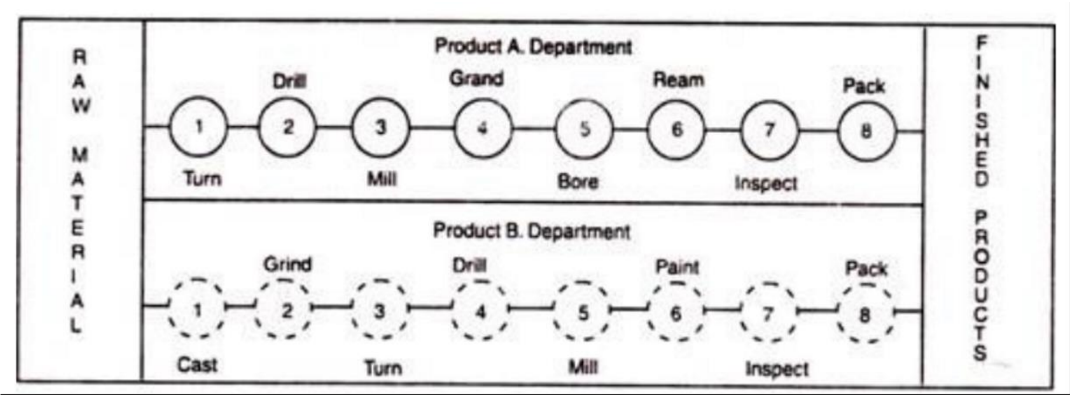


Figure 13: Line-shaped Production Layout

In order to gain the most out of this layout, the products should be standardized. It is also appropriate with large quantity production (Jonsson, 2008).

2.1.11.3 Cellular Production Layout

The cellular production layout is built around grouping the components by similarity of manufacture. Ideally, the machines and departments are organized to produce finished components within the group (Jonsson, 2008). The cellular production layout is presented in the following figure (WhatIsSixSigma, 2018):

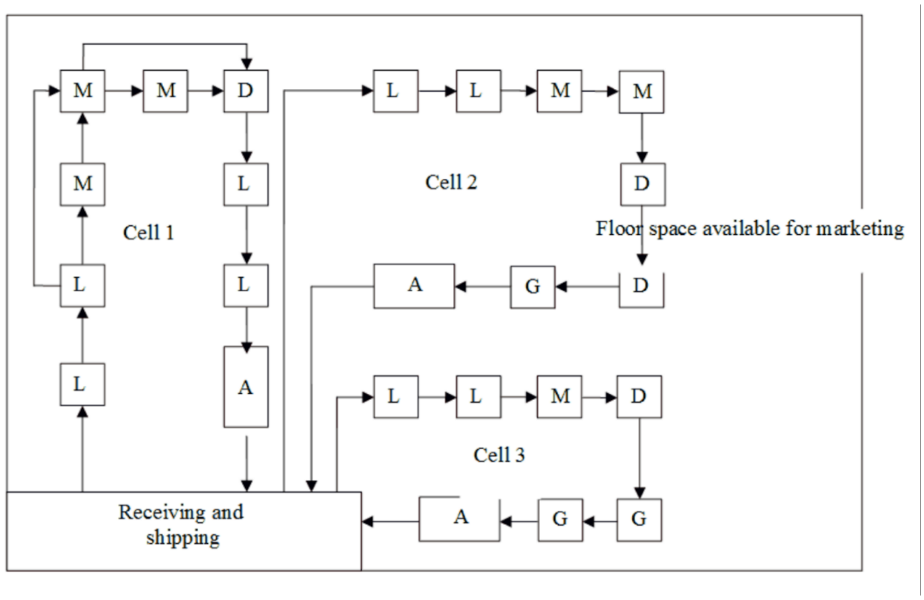


Figure 14: Cellular Production Layout

The different manufacturing processes of each component or product is presented in cells (production units). In contradiction to the line-shaped production layout, there is no requirements of organizing the machines or departments in a fixed order (Jonsson, 2008).

2.1.11.4 Fixed-position Layout

In the case of, for example, large turbines, aircrafts and ships, it is difficult to move the product during the manufacture. For such products, the fixed-position layout is used. This layout revolves around the product; the production resources are moved to and organized around the evolving product (Jonsson, 2008).

2.1.12 Production Capacity

All companies experience some degree of fluctuations in demand, which can cause an imbalance between the capacity available for producing goods and current demand. It can be possible for a company to adapt to such fluctuations by, for instance, increasing/decreasing the stock of products, or unfilled orders by making changes in delivery time. Decreasing stock levels is not possible when manufacturing to order, and increasing the lead time is not sufficient in a business-to-business situation.

The capacity of production benefits from flexibility. Functional flexibility can be explained as "to what extent different workstations are functional" (Jonsson, 2008). In other words, flexibility means that the workstations, or departments, have the ability to perform more than one manufacturing function. It might be possible to claim that lead time is dependent on capacity utilisation, while the extent of capacity utilisation is dependent on numbers of alternative workstations, or departments (Jonsson, 2008). The following figure explains this correlation (Howell, Ballard and Hall, 2001):

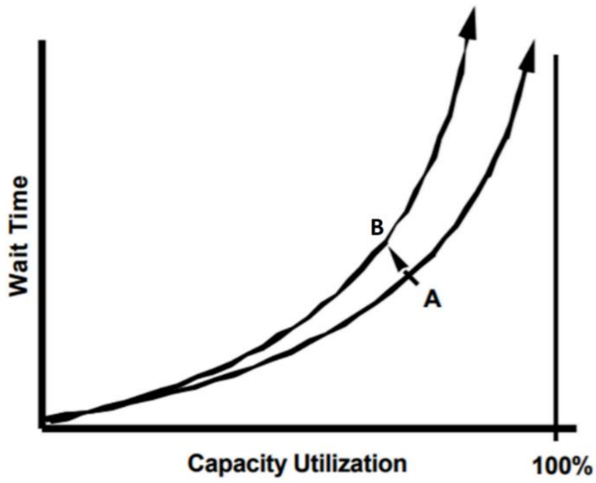


Figure 15: Lead Time and Capacity Utilization Dependency

Wait Time can be considered Lead Time in this context. Figure 15 expresses the situation whereas capacity utilization drops (from curve A to B) and the project duration (Wait Time/Lead Time) increases. This involves the idea that if the capacity increases, the wait time will be reduced. If a manufacturing company obtains the ability to perform more than one manufacturing function at the same department, the lead time, or wait time, is ideally decreasing.

2.1.13 Workforce Agility

The workforce agility can be defined as a business' ability to rapidly change and adapt to changes in the work environment. "Business" refers to the value created for a customer, and not the equipment, facilities, processes or technology a company sells. To become agile, the companies have to focus on the value added to the customers and to the structure of the workforce and management. "Structure" refers to how the work gets done. The workforce needs to manage multiple working models such as temporary teams, home offices, contractors, globalized teams etc. Managing agile workforces can be a challenge since there often are fewer rules and less command control. Leaders or managers might claim that such circumstances can be taken advantage of. However, a more agile workforce is expected to bring greater engagement from the workers, diversity and financial savings (Jacomo, 2017).

In order to achieve flexibility in an organization's manufacturing processes, it is a requirement to have agile workforces. Upton (1995) concluded that "operational flexibility is determined primarily by a plant's operators and the extent to which managers cultivate, measure, and communicate with them". Further studies of manufacturing flexibility concluded that in order to achieve manufacturing flexibility, it is required to develop and maintain a "highly skilled, technologically competent and adaptable workforce that can deal with non-routine and exceptional circumstances" (Muduli, 2013). In the context of business agility, the highly skilled, competent and adaptable workforce should be able to properly respond to changes within due date. The workforce should also be able to exploit changes and identify opportunities. Additionally, the workforce is supposed to be technologically competent in order to communicate with the participants of the manufacturing processes through information systems (Muduli, 2013).

2.2 Technology and Logistics

This chapter is intended to present different technological concepts and communication technologies. Additionally, these concepts and communication technologies will be correlated with the study field of logistics.

2.2.1 The Fourth Industrial Revolution

As a consequence of the steam engine and other technological developments during the mid 17 century to late 1800's, the first industrial revolution took its place. As technology matured, the second industrial revolution was incurring. This technological age was driven by electricity and involved an expansion of industries and mass production. Since the middle of the 20th century we have been living simultaneously with the third revolution, which by some would be called the digital revolution. This digitalism age involved development of computers and information technology (Rouse, 2018).

Finally, as the technology has matured even greatly, the fourth industrial revolution has come to life. This evolution is also called Industry 4.0, and refers to the network of technologies of which connects brilliant machines, advanced analytics, and people (General Electric, 2017). Industry 4.0 is intended to revolutionize manufacturing through greater accessibility of data, greater speed, increased efficiency, and cost savings (Inductive Automation, 2018a). The following timeline is intended to show the evolution throughout the times:

Mid 1700 - late 1800's	**1900's - early 2000's**	**2000's**	**Today**
Steam engine Technological developments	Electricity Expansion of industries Mass production	Computers Information Technology (IT)	Communication technologies Big data

Figure 16: Revolution Through the Times

2.2.2 Communication Technologies

There exist several methods for technologies to communicate, and some of today's most popular methods are explained below.

2.2.2.1 Internet of Things (IoT)

In the context of Future Internet it can be important to define things and to recognize what a particular thing is and represents. From a philosophical perspective, the term "things" can be concluded not to be restricted to material things, but can be applied to virtual things and the events that are connected to "things" (Friess et al., 2011). In context of IoT, however, the word "things" can be explained as "a real/physical or digital/virtual entity that exists and move in space and time and is capable of being identified" (Friess et al., 2011). In order for things to be identified, they are often assigned identification numbers, location addresses and/or names.

Based on the definition of the word "things", Internet of Things can be concluded to be an integrated part of Future Internet. Friess et al. (2011) defines IoT as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network". In the IoT, "things" are expected to participate actively as information sharers within business processes and in social processes. Services, or interfaces, use Internet to facilitate interactions with these "smart things". Such interfaces makes it possible to create queries and to change the state of "things" and any associated information (Friess et al., 2011).

2.2.2.2 Industrial IoT (IIoT)

Industrial IoT (IIoT), or Industry 4.0, may be interpreted as an application of IoT, and refers to the network of technologies of which connects brilliant machines, advanced analytics and people (General Electric, 2017). In relation to Industry 4.0, IoT may be understood as more consumer-oriented by increasing automation in homes, schools, stores and other industries. The industrial application of IoT, however, is intended to revolutionize manufacturing through greater accessibility of data, greater speed, increased efficiency, and cost savings (Inductive Automation, 2018a).

2.2.2.3 Human-Machine Relation

The Human-Machine Relation revolves around the collaboration and interaction between the human and the machine. It is possible to divide human-machine relation, or the Man-Robot Collaboration (MRC), into five different stages. The first stage is when the manufacturing process is performed by a robot, but there is some sort of hard guarding that separates the operator and the robot. This means that the operator is not in physical contact with the robot. The second stage is when the operator can enter the robot-area periodically, and laser (virtual) is the only thing that separates the operator and the robot. However, the manufacturing process is still performed by the robot alone. Further on, the third stage is when both robot and operator are involved in the manufacturing process. The operator can enter regularly during manufacturing and it is still only laser (virtual) guarding that separates them. The fourth stage is when there is nothing that separates the robot and operator, they are both involved in the manufacturing process and the robot is able to stop when it is in contact with the operator. The fifth and final stage is similar to the fourth, however, it will be possible for the robot and operator to move safely in the same space simultaneously (Business Wire, 2018).

2.2.3 Enterprise Resource Planning

Enterprise Resource Planning (ERP) is a system that, in industry terms, can help a company manage its business activities and to some extent also execute business operations automatically. One of the most important goals of an ERP system, or software, is to facilitate the flow of information throughout a company's value chain and to integrate business processes. This facilitation and integration is intended to generate data-driven business decisions. In addition, ERP software suites are developed in order to collect and organize data from various levels within a company. A well implemented ERP software will be able to help a company standardize and automate its business processes, which further on can improve the company's visibility and efficiency. Improved efficiency can be extremely beneficial for a company as it saves time and money, in addition to ensuring that "everyone" is working with the same and, hopefully, correct data (Rouse, 2017).

2.2.4 ERP Applicability in the ETO Sector

It has been stated that most ERP software was designed for traditional manufacturing rather than for project-oriented environments such as ETO (Gross, 2012). Therefore, several studies regarding ERP system applicability for ETO-companies have been conducted. Similarities in such studies revolves around considering essential requirements to obtain a successful ETO ERP software.

2.2.4.1 Decision Support Requirements of MTO Companies

Several studies regarding ERP system applicability for ETO-companies have been conducted. It has been stated that most ERP software was designed for traditional manufacturing rather than for project-oriented environments such as ETO (Gross, 2012). Aslan, Stevenson and Hendry (2012) defines MTO as an "umbrella term" that refers to companies which produces customised products to particular customer specifications, however, do not repeat the orders on a regular basis. The decision support requirements therefore include ETO-companies as well as the MTO sector, while it excludes the MTS and ATO approaches. MTO may therefore be interpreted as ETO. Further studies have argued the applicability of ERP systems in such

MTO sectors, however, the following requirements for the stages of production planning and control are critical to consider in order to assess an ERP system for such project-based companies (Aslan, Stevenson and Hendry, 2012)

Customer Enquiry Stage: As each customer order may be different, customer enquiry is the stage where the production planning and control begins, referring to the front end phase from Figure 10 regarding the MPC system. Due dates and pricing alternatives are generated in response to the customer enquiries. This is a complex stage as many customer enquiries awaits confirmation while the capacity planning must take the potential future load into account. Additionally, complete Bill of Material (BoM) structures may not be available during this early planning stage, and only gradually become certain. The IT solution should therefore be flexible to enable appropriate capacity planning given BoM uncertainty (Aslan, Stevenson and Hendry, 2012).

Design & Engineering Stage: When the order is accepted, the design and engineering stage begins. This stage can be linked to the engine phase of the MPC system. Flexibility in design and engineering as well as information regarding previous orders is required of the system (Aslan, Stevenson and Hendry, 2012).

Job Entry Stage: Capacity planning and control for confirmed orders and purchasing of materials is relevant for this stage. This stage also refers to the engine phase of the MPC system (Figure 10). There are four critical requirements; the IT solution should enable changes in BoM; the IT system must visualize the effects of forecasts on actual plans; the system must be able to plan capacity; project management techniques and IT support (Aslan, Stevenson and Hendry, 2012).

Job Release Stage: Controlling the release of particular jobs to the shop floor is essential to avoid "untimely" release of jobs, known as the "lead-time syndrome". This stage is connected to the shop-floor system in the back-end phase of the MPC system. During this stage, further production planning and control can be needed in order to ensure that the sufficient capacity is available for jobs to be released. This controlling is important for jobs to be released in time for them to meet their due dates (Aslan, Stevenson and Hendry, 2012).

Shop Floor Dispatching Stage: During this stage, the detailed shop floor scheduling is determined and jobs are sequenced on the shop floor. This is closely correlated with the back-end phase of the MPC system as well. Typically, jobs are sequenced by job prioritisation, however, several studies argue that simple mechanisms, such as first-in-first-out, may be considered a preferred strategy in MTO sectors. This strategy may be dependent on highly skilled labour to plan and control the production (Aslan, Stevenson and Hendry, 2012).

2.2.5 Classic Automation Pyramid

The concept of the automation pyramid has existed since the 80's, however, the use of modern techniques in production and manufacturing plants have increased as the automation technologies have evolved (Kunbus, 2018). During the years there have been an extensive integration of such technologies with electronics, computer science, communication and so on. This integration is efficiently represented in the automation pyramid (SMC International Training, 2018):

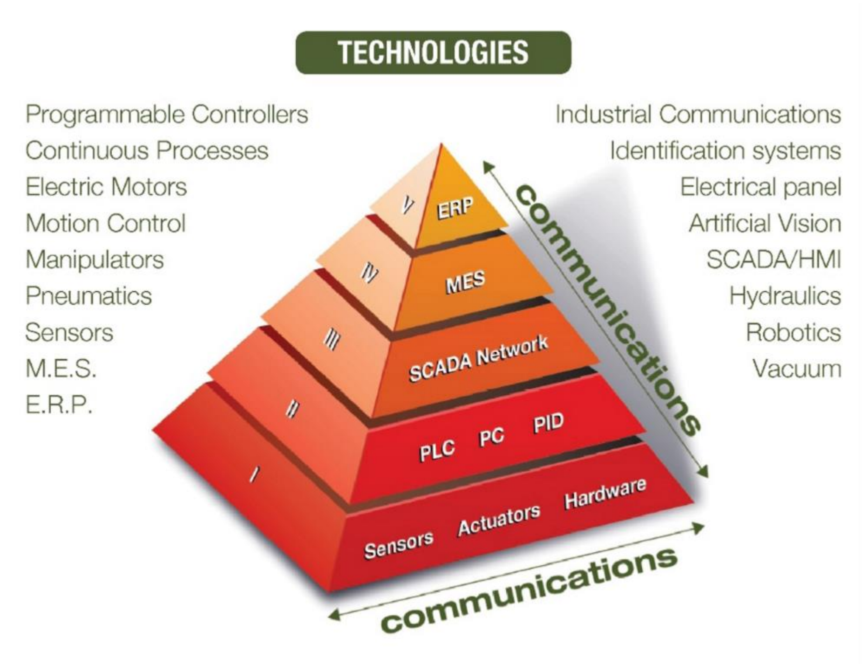


Figure 17: The Classic Automation Pyramid

Figure 17 shows five technological levels that should be considered in an industrial environment. These technologies interrelate both within one level and between different levels through industrial communication. The first level, or field level, comprises the physical devices that exists within an industrial environment, such as sensors, actuators and hardware. These technologies create the foundation for identifying, capturing, sharing and using critical information and data within the industry supply chain or value chain (SMC International Training, 2018).

The second level, or control/process level, includes logical devices, such as programmable logic controllers (PLC), computers (PC) and proportional integral derivative (PID) (SMC International Training, 2018). The tasks for this level are typically handled through PLC's, i.e. controls with programmable storage and/or through a computer. Additionally, the general management of control and regulation groups, as well as the execution of the corresponding processes from these groups, are performed at the control level. Selected data is forwarded to the higher level, the system level. Further on, the data from the field level is processed and visualized (Kunbus, 2018).

The third level, or the system level, corresponds to supervisory control and data acquisition systems (SCADA) (SMC International Training, 2018). The SCADA system allows industrial organizations to control industrial processes locally or at remote locations, interact with field level technologies, record event logs, and monitor, gather and process real-time data (Inductive Automation, 2018b). At the system level, the tasks are similar to the tasks performed in the control level, however, these are executed in a more comprehensive and qualified way as multiple control and regulation groups are managed (Blankenberg, 2016). Data specified at this level is sent to the next level. The fourth level of the pyramid, which may also be called the operational management level, includes manufacturing execution systems (MES). This system function as an interface for detailed production planning, material management and key performance indicator (KPI) documentation (Rhebo, 2018).

The fifth and top level is the managing/enterprise level for general production planning and order management through the company's integrated ERP system. This level is intended to control and plan the production (Blankenberg, 2016). The structure of the automation pyramid may vary depending on the industry, the company itself and other factors (Rhebo, 2018). The MPC system can be applied to the ERP software for planning and control manufacturing operations.

2.2.6 The S-curve

According to Garland (2009), the S-curve can be defined as “a display of cumulative costs, labor hours, performance or other quantities plotted against time”. The curve has the shape of a “S” which is flatter in the beginning and end, and steeper in the middle, which is typical for most projects. The beginning of the curve represents a slow, but accelerating start of a project, while the end represents a declaration as the process runs out. This would also be typical for a new company. Considering performance, it usually increases up to a certain point, and then it stagnates. To increase the performance even more, it can be necessary to apply new technology and innovations (Garland, 2009). The following figure explains how the S-curve works (Strategic Toolkits, 2018):

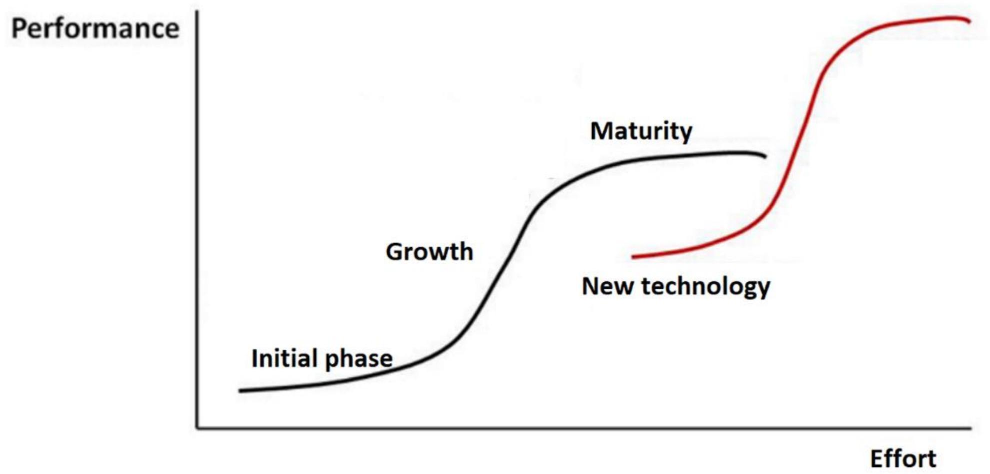


Figure 18: The S-curve

2.2.7 Global Standards for Supply Chain Visibility

Earlier in this thesis, supply chain visibility was defined as the supply chain players capability to access or provide required timely information about the entities involved in the supply chain. The value of visibility is closely correlated with the fact that providing real-time information and data about the “things” in the supply chain can significantly improve a company’s business processes. Global Standard (GS1) is a not for profit organization that has developed a System of Standards framework that enables visibility of items or assets in the supply chain. This framework is based on common ways to uniquely identify, capture and share information relating to the movement or state of the entities (GS1 AISBL, 2012).

2.2.7.1 Identify

GS1 has developed several identification keys (ID Keys) that are globally unique. For instance, to identify products and services, GS1 uses Global Trade Item Number (GTIN) as ID Key (GS1, 2018a). These ID Keys provides a common language in order to communicate information about products that are moving in a supply chain. All GS1 ID Keys can be expressed in several forms of data carriers, such as barcodes, text, data matrix’s, RFID tags, Electronic Data Interchange (EDI) messages or similar (GS1 AISBL, 2012).

2.2.7.2 Capture

In combination with the ID Keys, GS1 has developed a standard for Automatic Identification and Data Capture (AIDC), which defines how the industry uses barcodes and/or RFID technology to enable visibility of product flow within the supply chain. The AIDC standards may be interpreted as a framework for how companies can encode the GS1 ID Keys on approved data carriers, such as GS1 Barcodes and EPC/RFID tags. In addition, the framework explains how such encoding is done for different business applications. For instance, the GS1 DataMatrix is primarily used in the pharmaceutical industry. Further on, by specifying consistent interfaces to readers, printers, and other hardware and software components, the AIDC standard ensures that the information can be read in different business applications. Such flexibility is groundbreaking for successful global standards for automated identification of trade items, logistic units, locations, assets and service relations (GS1 AISBL, 2012).

Barcode scanning or reading of RFID tags speeds up the collection of data and information, and it eliminates manual data collection errors, such as illegible handwriting or data entry errors. By capturing data from the GS1 Barcodes or EPC/RFID tags, the GS1 standard enables users to automatically identify all product configurations, packaging, transportation, distribution, inventory, display location and sales touch points (GS1 AISBL, 2012).

2.2.7.3 Share

In order to share critical information, the GS1 System has developed three standardised types of data that supports multiple ways to share data; Different data pools, such as eCom for Electronic Data Interchange (EDI), Electronic Product Code Information Services (EPCIS), and the Global Data Synchronization Network (GDSN) can be used to share master, transactional and event data. The table below provides a list of GS1 standards that supports data sharing (GS1 AISBL, 2012):

Data Type	GS1 Standards	Type of supply chain information
Master Data	• Global Data Synchronisation Network (GDSN)	e.g., product description, dimensions, brand owner, product classification...
Transaction Data	• eCom (EDI): EANCOM, GS1 XML Business Message	e.g., purchase order, despatch advice, invoice, payment...
Event Data	• Electronic Product Code Information Services (EPCIS)	What, where, when, why - e.g., received or shipped, picked & packed, conditions of goods during shipment, availability of goods at specific location...

Table 1: GS1 standards for Automated Information Exchange

GS1 ID Keys represents the core data to the product-based messages. The GDSN standard help the trading partners in the supply chain to synchronize data that is held in their respective databases. Further on, the EPCIS standard let the supply chain players store and exchange physical event data, including information about what, where, when and why for the physical observations. This standard can also store information about the physical characteristics of the items, such as temperature, and it can inform of associated purchase orders in addition to explaining the business reasons for why the product was moved. The EPCIS database or repository provides the advantage of real-time visibility of items throughout the supply chain (GS1 AISBL, 2012).

The GS1 standard has developed eCom guidelines for EDI implementation for several industries, such as retail, food and beverages, industrial/commercial industry and public sector. The GS1 eCom guidelines serves a roadmap for enabling computer-to-computer communication for strategic business processes, for instance order-to-cash, sales reporting, financial, organizational structure, transportation and product planning (GS1 AISBL, 2012).

2.2.7.4 Use

The GS1 standard is a framework for connecting physical assets or items with the digital world. The GS1 ID Keys is a global language standard that is developed in order to identify objects, assets, locations and similar, and to automatically capture characteristics of the ID Keys with use of GS1 barcodes or EPC/RFID tags. The standards for sharing enables interoperability, transparent data, traceability and visibility throughout the supply chain, which are critical factors for providing a fundament for IoT technologies (GS1, 2018b).

3.0 Methodology

This chapter will present the research method and design for this thesis. In addition, the different data sources and methods for data collection will be discussed. The primary and secondary data sources will be identified, and the reliability and validity of the data collection and methodology for this thesis will be evaluated.

3.1 Research method

The word 'research' has many definitions, however, one way of defining the word is to break it into two syllables'; *re* and *search*. The prefix means 'again', 'anew' or 'over again'. The latter is defined as a verb meaning 'to closely examine' or 'to carefully test and try', or 'to probe'. Together, the prefix and the verb forms a noun that describes a "careful, systematic, patient study and investigation in some field of knowledge, undertaken to establish facts or principles" (Kumar, 2011). Some disciplines and experts adds furtherly that research is a systematic, controlled and critical investigation to find answers to your research questions. In order to achieve this objective, it is possible to use any of the research methods, for instance qualitative and/or quantitative research methods.

The following table shows the different research methodologies and how these are characterized according to type of data used and analysis performed on the data (Ellram, 1996):

	Type of Analysis		
Type of Data		Primarily Quantitative	**Primarily Qualitative**
	Empirical	Survey data **Secondary data**	**Case studies** **Observations**
	Modelling	Simulation Linear programming Mathematical programming Decision analysis	Simulation Role playing

Table 2: Basic Research Design

As the table explains, the type of data can be empirical, meaning data collected for the purpose of analysis from the real world, such as case studies or surveys. The data may also be modelling data, meaning artificial manipulation of either hypothetical or real-world data by using a model (Ellram, 1996).

This master thesis intends to answer the research problem regarding how to reduce the lead time in an ETO manufacturing company within the scope of Industry 4.0. Further on, the research problem is supported by six RQ's. In order to answer RQ 1, 2 and 3, it was concluded that quantitative data from the ERP system is necessary. Using qualitative interviews with key informants at Brunvoll as well could provide an indication to the degree of quality of the quantitative data, in addition to bringing valuable information outside of the ERP system. The quantitative data is also intended to generate discussions and answers to RQ 4, 5 and 6. By the nature of this master thesis, which can be claimed to be a sequel of Erling

Johan Wollen's master thesis, the type of data and type of analysis has been bolded out in Table 2. Therefore, the type of analysis is primarily quantitative.

3.2 Research Design

According to Yin (2003), research design is "the logic that links the data to be collected (and the conclusions to be drawn) to the initial questions of study". This thesis is constructed as a case study, which is a quantitative and qualitative research method that qualifies for empirical data collection. Every empirical study should have an implicit, if not explicit, research design. The design of the research should be used as a tool to logically connect the empirical data to the thesis' initial research questions and to its conclusions. It is therefore possible to define research design as "a logical plan for getting from here to there" (Yin, 2003).

Operations research is a scientific method which can be applied to the management of organized systems in business, industry, government, and other enterprises. This research method is typically applied in areas such as supply chain management, manufacturing plants, transportation networks, and so on. Therefore, it is normal that application of operations research deals with decisions regarding planning and control of scarce resources, for instance skilled workers, machines, and materials (Cornell University, 2018). The operations research perspective aim towards a wide audience, from management scientists, industrial engineers, computer scientists, etc. Similarly, all types of submissions, from short to longer research papers, including case studies are welcomed (Elsevier, 2018). Considering that this thesis is a case study, operations research is applicable.

Yin (2003) states the importance of defining the unit of analysis in a case study. The unit of analysis is related to the fundamental problem of defining what the 'case' is (Yin, 2003). A 'case' can be an individual, such as clinical patients, students, political leaders, an event or entity, an institution and so on. The context and the unit of analysis of this case study is the internal manufacturing processes at Brunvoll. Because this thesis is an extension of Wollen's research, the unit of analysis has been limited to one manufacturing node (machine M53) at Brunvoll. Further on, based on discussions with the previous production planner at Brunvoll, it was concluded interesting to study the upstream and downstream nodes of M53 as well (Surface Treatment and Grinding). This is intended to provide answers to what extent the delay of components processed at individual machines, e.g. M53, deviate from the on-time delivery for the final product at Brunvoll.

3.3 Data Collection

Data collection is the process of collecting information from all relevant sources in order to find answers to the research problem (Research Methodology, 2017). It can be possible to divide data collection into two categories; primary and secondary data collection. Primary data can be interpreted as observed data or data collected directly from first-hand experience, while secondary data can be defined as published data, for instance data collected from the internet, articles, books, and so on (BusinessDictionary, 2018). In the following, the data collection method for this thesis will be presented.

3.3.1 Primary and Secondary Data Sources

This thesis builds upon collection of both qualitative and quantitative data sources; qualitative data is collected through observations and interviews, while quantitative data is collected through SQL extractions from the ERP system at Brunvoll. These three primary sources were situated by key informants at Brunvoll, whereas the informants consisted of production planner, master planner, supervisor machining department, ERP consultant, and supervisor surface treatment.

The secondary data is based on gaining more knowledge and information in order to build and present a thorough theoretical framework which will be helpful for even writing this master thesis and for creating a great analysis and critical discussion of the collected data. The following table is developed in order to get a greater overview of the data sources for this thesis and the objectives for the different sources:

	Data sources	Objective
Primary	Observations of the manufacturing processes at Brunvoll	Qualitative data collection to achieve a greater perspective of manufacturing processes and visibility of Brunvoll's supply/value chain
	SQL data from the ERP system (Infor M3)	Quantitative data collection to discover possible delays and on-time delivery
	Qualitative interviews with key informants at Brunvoll	Qualitative data collection to discover possible cause(s) for delays and on-time delivery
Secondary	Websites, textbooks, journals and articles, white papers, strategic documents, annual reports, research reports, master and PhD-dissertations	Gain more knowledge and get a greater perspective, in addition to building a well-informed theoretical framework.

Table 3: Primary and Secondary Data Sources

3.3.2 Quantitative Data Collection

The key informant playing the role as ERP consultant was able to provide this case study with critical information from the ERP system Infor M3 through Structured Query Language (SQL) extraction. SQL is a computer language that is used in programming and designed to manage a great amount of data in relational database systems (Wikipedia, 2018). This is the thesis' primary quantitative data source, and it is crucial for finding answers to the research problem and RQ's for this study. The SQL data that was provided consists of customer order related data from 01.01.2017 to 31.12.2017. Further on, the sheets contain data concerning planned and actual finish dates, transactional data, such as project number, order number, work order number, and delivery dates, in addition to master data regarding item number and names, elements etc. A sample of the SQL data is shown in Appendix 1.

3.3.2.1 Interview Design

There are several different forms for interview design which can provide a great range of data. Three different forms of qualitative interview design were considered; the informal conversational interview, the standardized open-ended interview and the general interview guide approach. The first type of interview design is, as the name states, informal, and thereby not as structured as the other designs. The second form, the standardized open-ended interview design, is extremely structured and planned. The general interview guide approach, however, is less structured than the second interview design in the form that the flexibility is greater. This design is more open for changing the planned questions during the interview, providing a high degree of freedom to the interviewer (Turner, 2010). For this thesis, it was concluded that the general interview guide approach is a fitting choice of interview design. It was believed that structured interview questions would provide great guidelines for the interviews. However, it was also considered viable to make changes or create new questions during the interviews because the interviewers are inexperienced with interviewing. In addition, because new information could occur during the interviews, it would be sufficient to have the flexibility of changing the questions. The table below expresses the time table for the interviews and the key informants whom were involved:

	Date	Key Informant	Data Source
Observation 1	20.02.2018	Karolis Dugnas	Guided observation of Brunvoll's manufacturing facility
Observation 2	16.03.2018	Supervisor Machining Department	Guided observation of Brunvoll's manufacturing facility
Interview 1	04.04.2018	ERP consultant	SQL extraction from ERP system (qualitative data collection) and qualitative interview
Interview 2	10.04.2018	Supervisor Machining Department	Qualitative interview
Interview 3	10.04.2018	Supervisor Surface Treatment Department	Qualitative interview
Interview 4	10.04.2018	Master Planner and Production Planner	Qualitative interview

Table 4: Data Collection Time Table

An interview guide is presented in Appendix 2. The first qualitative data source was observations of the manufacturing process at Brunvoll in order to gain greater knowledge of Brunvoll. In addition, it should be mentioned that another group writes a master thesis about Brunvoll as well, meaning that some of the interviews were conducted together with the other group. Performing the interviews in collaboration with the other group provided more information for the thesis that might not have been considered if the collaboration were not existent. Further on, after the interviews, there was need for answering some follow-up questions. Such questions were asked over emails with all the key informants mentioned in the table in addition to the Shipping Manager at Brunvoll.

Observation 1 and 2

Observation 1 was a guided tour with the former production planner, Karolis Dugnas. This was to gather information about Brunvoll's production and to define research topics and possibilities. Further on, this lead to Observation 2, directed by the Supervisor Machining Department where we were introduced to the gearhouse value chain in addition to machine M53. During both observations, we were able to ask relevant questions regarding the flow of subjects, components and information both outside the ERP system and within the system.

Interview 1

Interview 1 was conducted after we had received the SQL query data. The interview was a review of the data set and general discussions about what might cause delays in the production at Brunvoll.

Interview 2

Before interview 2-4 the SQL query data set had been analysed and some patterns and tendencies had been detected. Therefore, the interview with the Supervisor Machining Department revolved around asking questions regarding the findings from the data set and possible reasons for the detected patterns.

Interview 3

The interview with the Supervisor Surface Treatment Department also revolved around the findings from the data set. One trend was detected; the production at the surface treatment department seems to start later than planned. In order to find answers for these results, relevant questions were asked.

Interview 4

The Production Planner and Master Planner were asked questions about project planning, project life cycle and so on. In addition, these key informants were asked questions regarding delays and on-time delivery of complete thruster systems in relation to the planning process. Questions about reporting in the ERP systems were also answered.

3.4 Reliability and Validity

Reliability is the degree to which assessments are consistent. It therefore refers to the repeatability of the findings; if the study were to be done several times, would the results be the same? If so, the data are reliable (USF, 2018). The quantitative data studied in this thesis was collected from the time period between 01.01.2017 and 31.12.2017. If a re-test of this data were to be performed, it is likely that the results would be the same. However, conducting an identical study, but using data from either previous years or future years would generate different results. Although, it is believed that the same trends and patterns would be similar with the results from this thesis.

Validity is related to the accuracy and credibility of an assessment. It therefore refers to whether the assessment measure what it is supposed to measure (USF, 2018). In addition, the validity revolves around the study's ability to be generalising. A thesis with high degree of generalisation has high external validity (University of New England, 2000). This thesis intends to study a project-based company (Brunvoll) and, thereby, make up a conclusion about the relationship between ETO strategies and ERP systems regarding PMPC. Some of the case study findings and factors of this thesis can be interpreted as generalizable as they may represent natural characteristics of ETO-companies. For instance, the ERP system might not be applicable in ETO environments, occurrence of errors in data because of historical data, and problems with human-machine-relations, might be considered general problems within the ETO sector. Therefore, results from this thesis can provide useful data for the general project-based company.

The extent to which the study is able to eliminate confounding variables is referred to as internal validity. The internal validity is typically only a concern for exploratory studies, whereas the best way of achieving a high degree of internal validity is by conducting pilot studies, or for causality analysis' (University of New England, 2000). However, this thesis is in the tradition of operations research, whereas causal relationships are typically obvious. Stating this, the validity of this thesis is implicit taken care of because operations research is applied, and therefore, operational issues are normally measured. This thesis intends to focus on Brunvoll's ERP system and what is actually happening on the shop floor. In order to do this, both qualitative and quantitative data collection methods were applied. The quantitative data provided information regarding the ERP system at Brunvoll, while the qualitative data gave critical insight to factors occurring outside the system. Based on these data sources, this thesis intends to find answers to bias between the ERP system and the PMPC to ensure high internal validity.

4.0 Case Study Findings

This chapter will present the findings from the case study which will be analysed to answer the RQ's. The findings and analysis will be structured based on the relevant RQ's in order to generate a clear construction of the thesis. Based on interviews with key informants, such as the production planner, process planner, supervisor machining department, and supervisor surface treatment, it was possible to build up a great groundwork that would support the discussions and findings from the SQL extraction. The ERP consultant was interviewed as well as helping to provide critical quantitative data for this thesis.

4.1 Research Question 1

RQ1: To what extent are projects (complete thruster systems) delayed?

4.1.1 Project Life Cycle

In order to gain a greater perspective on the planning process for projects, the following internal project life cycle was created based on qualitative interviewing with the Master Planner and Production Planner at Brunvoll. This figure can generate a greater understanding regarding the course of the projects, which can provide great depth to the analysis and further discussions when it comes to why planned and reported finish dates differ. Understanding the phases of a project can also be viable while intending to improve Brunvoll's performance by reducing the manufacturing lead time. Because this master thesis intends to study the gearhouse component's cycle during a project, the project life cycle will explain the initial phase (starting the project), planning phase, execution and closure, meaning when the complete product is delivered to the customer.

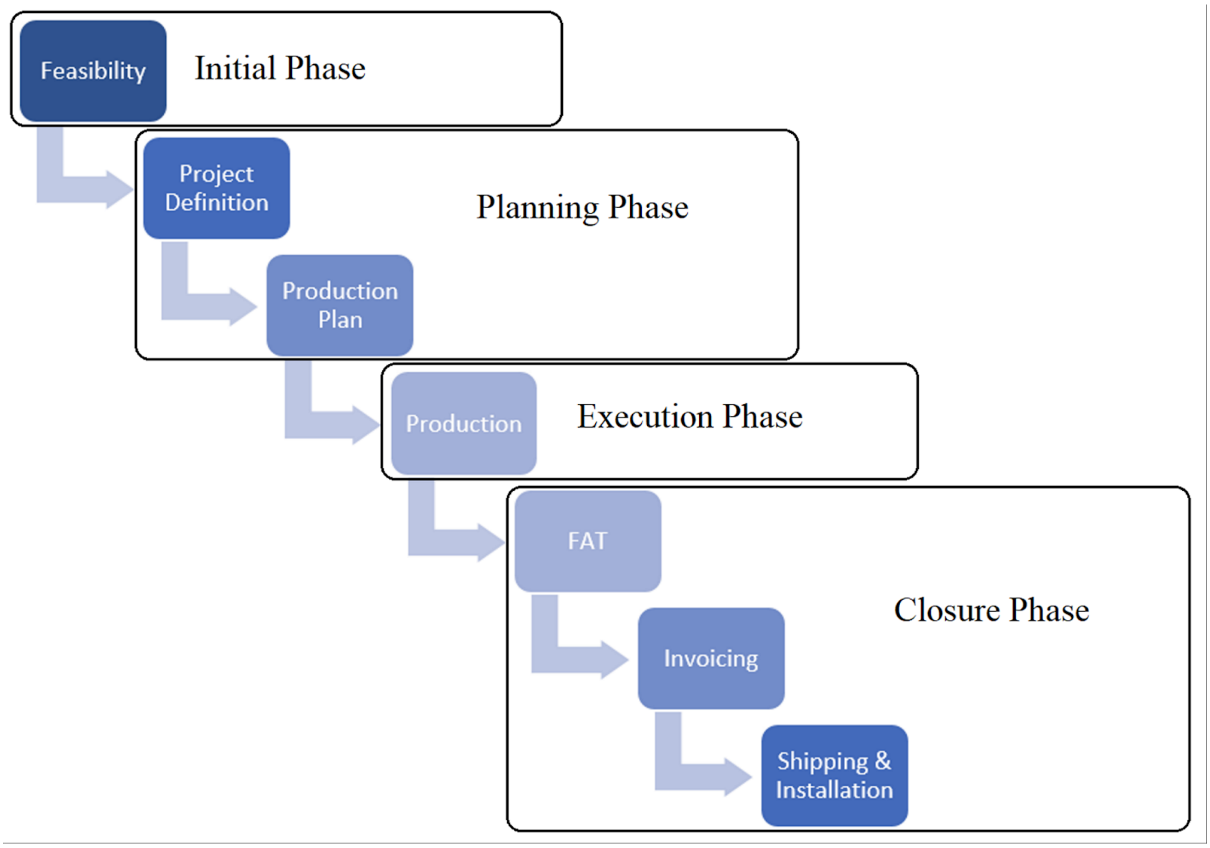


Figure 19: Internal Project Life Cycle (Phases) for Complete Thruster Systems

Feasibility: After receiving a request from a potential customer, the initial phase of the project life cycle is to consider when the customer wants the complete thruster system; are Brunvoll able to deliver to the proposed delivery date? The customers typically want to receive the thruster system as soon as possible, which should be taken to consideration. It is also necessary to study the projects that already are planned or is in progress and to consider if the new project is manageable based on other plans. This is completed within the ERP system where the Master Production Planner has correlated the requested order with the ongoing projects. The order is then ready to be confirmed (or not) and the date agreed upon, commit date, is set.

Project Definition: When the order is confirmed, the planning phase begins and the order must be defined; which activities are involved?; time perspectives?; project design?; and so on. Based on the project definition from the literature review, each project has defined resources. During this stage, the belonging components, activities, labour and other resources are defined.

Production Plan: When the project is defined, a production plan must be created. Referring to the project definition from the literature review, each project is temporary and has defined end and finish dates. These dates are defined based on the information about other projects from the ERP system. The production plan is based on a template for articles and components, whereas 90-95 % of the articles are standard for a thruster system. Further on, the production plan will create a need in the ERP system for the procurement department.

Production: When the production plan is completed, the work orders must be released and sent to production. This is the execution phase of the project life cycle, and refers to when the production of the order begins. The work orders containing the production plan is released in the ERP system. The operators print out these work orders when they start the processing.

FAT: The Factory Acceptance Test (FAT) is a testing of the quality of the complete thruster system after the production is completed. This is a part of the closure phase. The customer is offered or can demand to join the FAT.

Invoicing: Before the complete thruster system can be delivered to the customer, the invoice must be paid. This phase can actually cause delays in delivery, which will be discussed later in this thesis.

Shipping & Installation: When the invoice is paid, the complete thruster system is shipped and installed at the customers facilities. This stage results in a completion of the project life cycle. However, it can be important to mention that Brunvoll performs after sales services for the completed projects as well.

4.1.2 Finish Dates for Projects

One way of measuring delays for projects is to study the variations between planned and actual finish dates. Planned finish dates are created in the ERP system, while the actual finish dates are the date of when the project is reported completed in the system. The actual finish date may differ from the planned finish date, however, it is intended to be the same. The SQL query extracts data for 26 projects, or complete thruster systems, and based on these data we identified fluctuations/deviations between planned and reported finish dates for the projects.

Our analysis shows that 12 % of the 26 projects were reported as finished before or within the planned finish date.

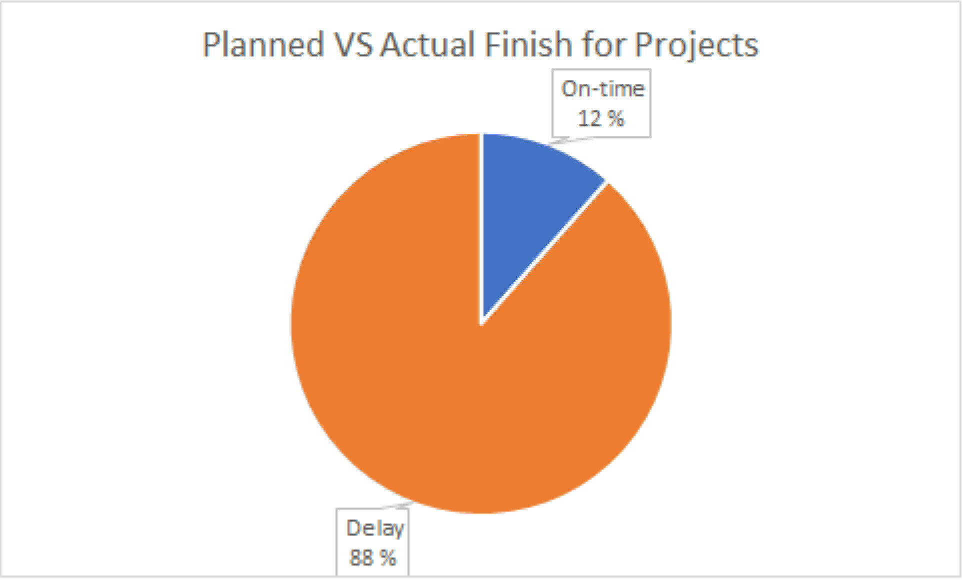


Figure 20: Planned VS Actual Finish for Projects

Figure 20 visualizes that 88 % of the projects were reported later than the planned finish dates.

The figure below shows the distribution of actual versus planned finish date for the 26 projects. Each blue dot represents one project. All blue dots below the orange line are reported as delayed, while the dots placed over, or on, the orange line are projects reported as finished before or within the planned finish date.

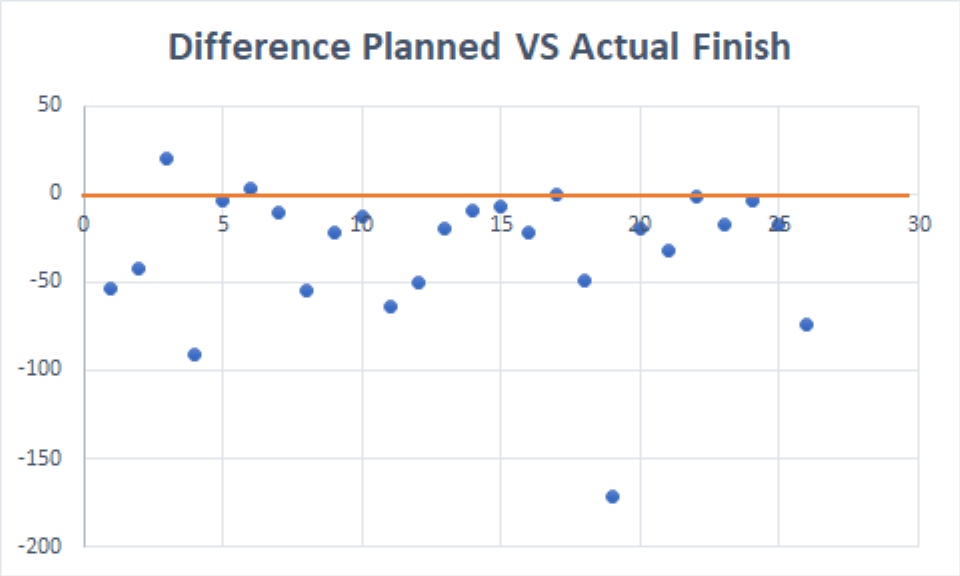


Figure 21: Difference Planned Versus Actual Finish Date

Figure 21 explains how the planned and actual finish dates varies for the 26 different projects. The mean is -31,8 days and the standard deviation is 38 days, meaning that the variation between planned finish dates and actual finish dates is very high.

Based on the literature review regarding delivery performance, what is considered on-time can be defined as customer commit date (see Figure 19). Confirmed delivery date is the internal date of delivery of the complete thruster system. This is defined based on the customer purchase order when the corresponding sales order is registered in the ERP system. The confirmed delivery date is defined based on the customer request date and to which dates Brunvoll are able to deliver the customer order, meaning that the on-time delivery is the customer commit date.

Studying the internal project life cycle figure (Figure 19), it is possible to understand that during the initial phase, the customer purchase order is reported in the ERP system. Then, the ERP system performs a backward planning for the customer purchase order until it defines a confirmed delivery date based on the customer's preferred date of delivery. Most of the times the complete thruster system is delivered after the FAT, as shown in Figure 19. However, sometimes the customer's wants to join the FAT before delivery, meaning that the actual delivery is later than the customer commit date. This is interpreted as a delay of which the customer is responsible, and do not influence Brunvoll's delivery performance. Dates regarding confirmed delivery date and the actual finish date might give an indication to what extent the projects actually were delivered on-time. Interpreting the dates provided by the ERP consultant, the following graph was created:

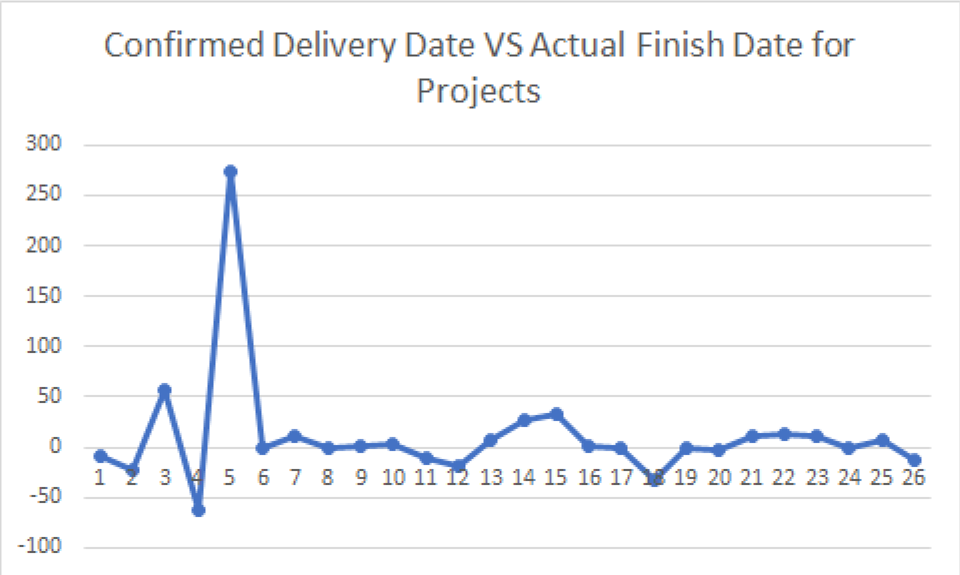


Figure 22: On-time Delivery for Projects

The blue dots represent each of the 26 projects. The dots below zero are delayed, while the dots above represent the projects delivered on-time. The mean for the projects were 11 days, and the standard deviation was 56,74 days. Based on the SQL query data, 16 out of 26 projects were reported as finished before or within the confirmed delivery date, resulting in a 62 % on-time delivery rate.

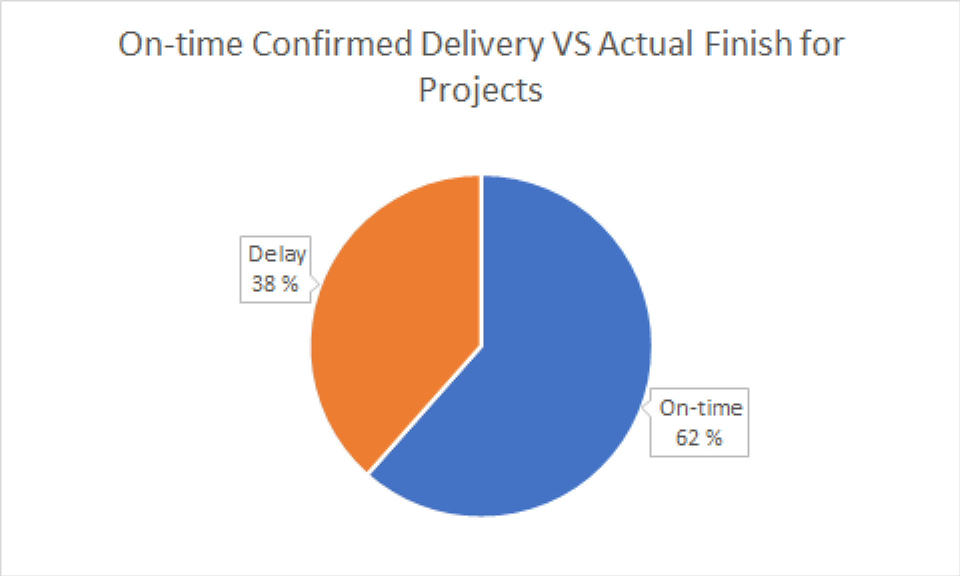


Figure 23: Confirmed Delivery Dates VS Actual Finish Dates for Projects

The figure above explains that 38 % of the projects were considered delayed based on actual finish dates and confirmed delivery dates.

4.2 Research Question 2

RQ2: To what extent do the delay of a component at M53 influence the project delivery time?

In order to discover how the planned and reported finish dates at M53 influence the planned and reported finish dates for projects, it was considered necessary to study the flow of M53 through all the 26 projects. The data was first captured based on the difference between the planned and actual finish dates for the gearhouse components processed at machine M53 in the period from 01.01.2017 to 31.12.2017. The data set revealed that almost 54 % of the work orders processed at M53 were finished before or within the planned finish date.

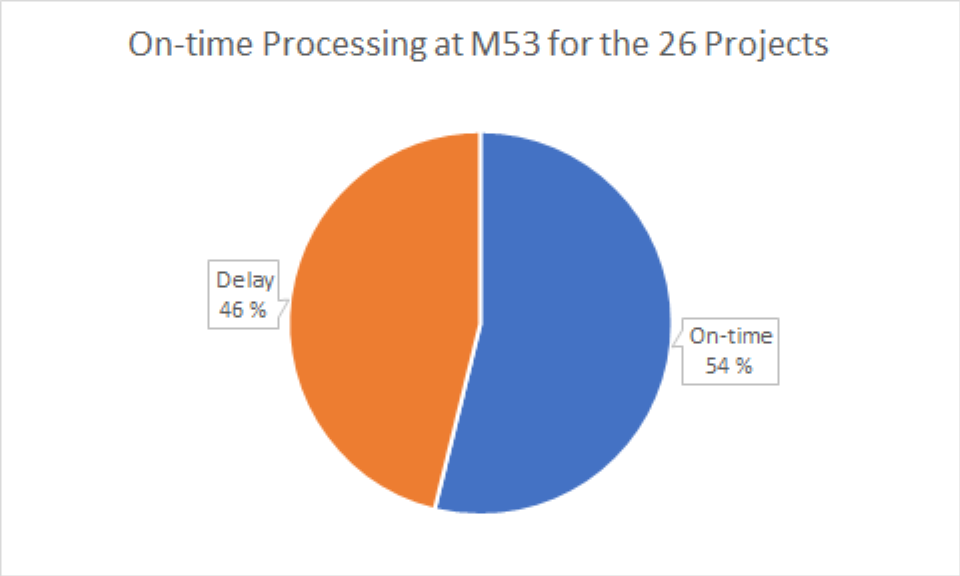


Figure 24: On-time Finish for M53

The figure above explains that 46 % machine processings at M53, related to the 26 projects, were reported as finished before planned finish date. It might be necessary to mention that this figure was calculated based on the latest finish date within each project, meaning that some processings within one project might have been finished before or within the planned date. However, some processings might have been delayed, and these have been included in this calculation because one complete project cannot be delivered without every processing related to that project being finished.

The figure below shows the deviations between planned and actual finish dates for gearhouse components processed at M53. In addition, the figure shows how many of the gearhouses processed at M53 that are finished before or within the planned finish date. Each blue dot represents one machine processing at M53. All blue dots below the orange line (0) were reported as delayed in the system with respect to planned finish date.

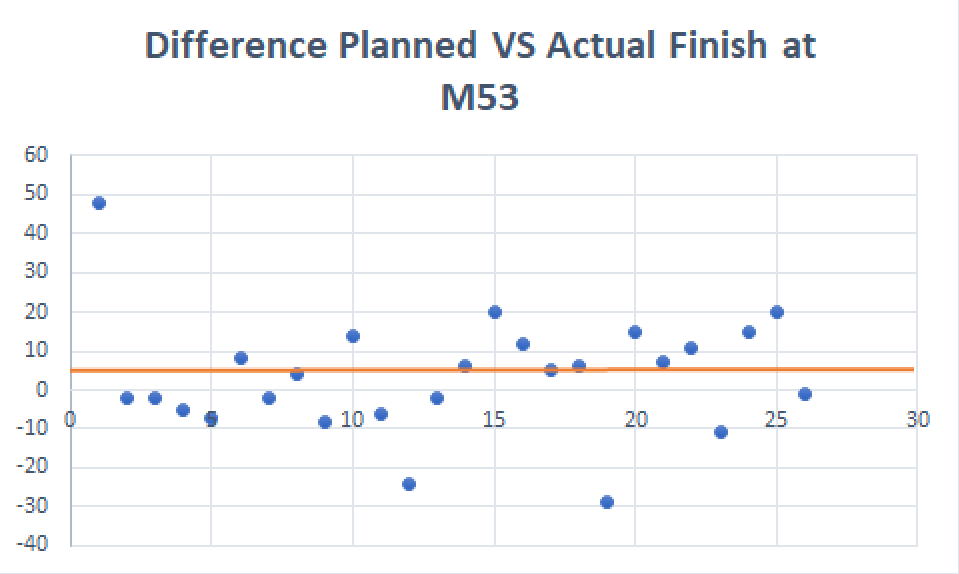


Figure 25: Variation Planned VS Actual Finish Dates at M53

This data set provided a standard deviation of 14,73 days for planned and actual finish dates at M53, a low variation in finish dates compared to planned and actual finish dates for complete projects. The following graph shows this correlation:

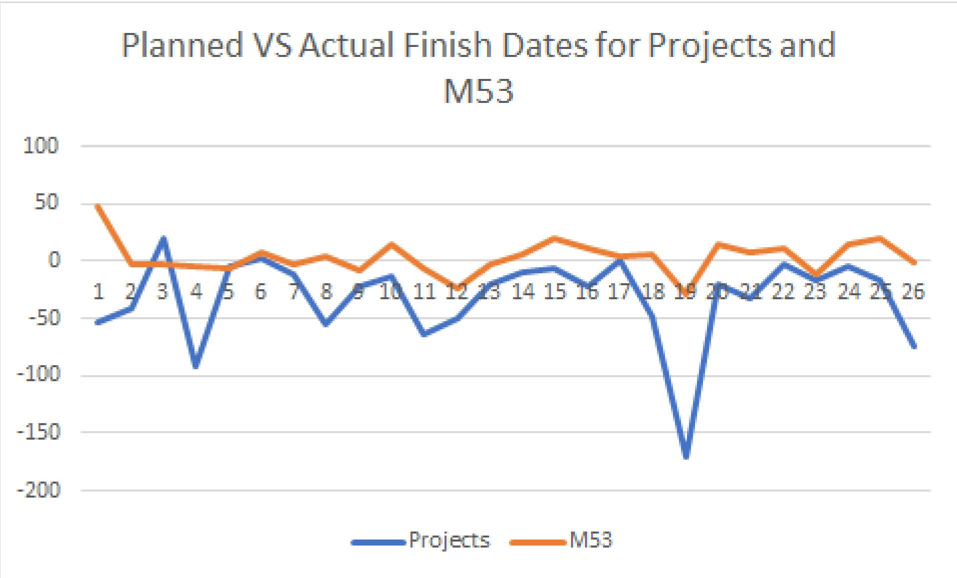


Figure 26: Planned and Actual Finish Dates for Projects VS M53

The orange graph is defined as the variation between planned and actual finish dates for gearhouse components processed at M53. The blue graph explains the variation between planned and actual finish dates for projects (complete thruster systems).

4.3 Research Question 3

RQ3: To what extent do delays at M53 propagate to its upstream and downstream tiers?

4.3.1 Production Layout and BPMN Diagram

From the previous production planner at Brunvoll, this thesis was provided with a map of the layout of the manufacturing processes. Referring to the production layout from the literature review, the layout of Brunvoll’s factory is merely based on a functional layout rather than line-shaped, cellular or fixed-position layouts. The different stations and machines are placed and organized with respect to their functions and not based on the sequence of operations. The following map shows the functional layout:

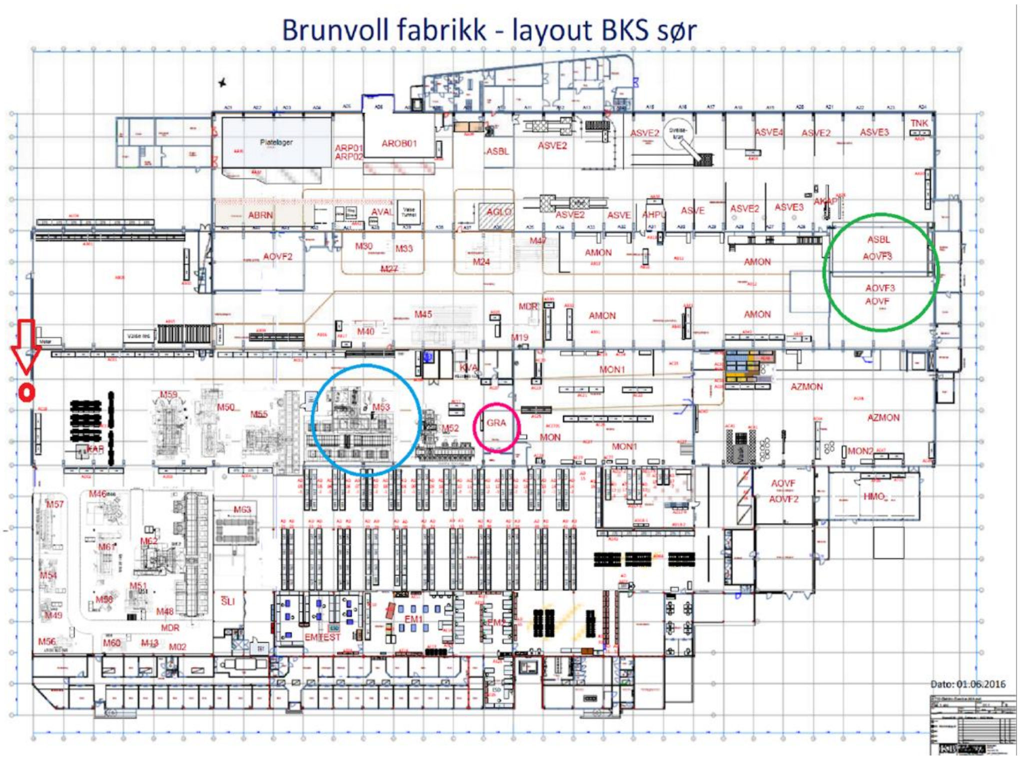


Figure 27: Layout Brunvoll

The red circle and arrow shows the outside storage for gearhouse subjects. Subjects at Brunvoll are considered as raw material which will be processed. The production process moves from the outside storage to sandblasting and priming at the AOVF3 tier (green circle). Further on, the gearhouse is sent to machine M53 (blue circle) for machining and controlling of parts. Thereafter the gearhouse is sent to the GRA tier (pink circle) for grinding of sharp edges on the gearhouse components. Based on this layout and observations of the unit of analysis, it was possible to extract the following BPMN diagram:

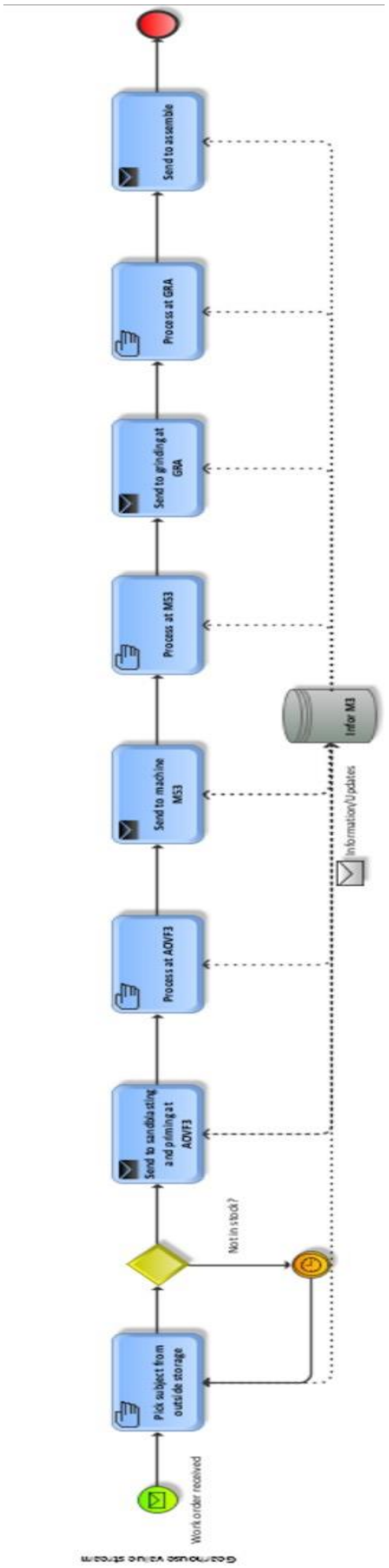


Figure 28: BPMN Diagram of Gearhouse Subject Value Stream

This thesis is restricted to study the processing from AOVF3 → M53 → GRA, and the later processing regarding assemble and installation is therefore not to be analysed. The BPMN diagram explains the connection between the ERP system (Infor M3) at Brunvoll and the relevant processes for the gearhouse subject involving processing at AOVF3, M53 and GRA. The start event for the gearhouse subject is when a work order is received. Further on, the subject is collected from the outside storage and thereby sent to sandblasting and priming at AOVF3 for further processing. Brunvoll intends to have a safety stock of 3-7 gearhouse subjects on the outside storage at all times. From AOVF3, the gearhouse component is sent to M53 for machining and controlling of parts, and then it is sent to GRA for grinding of the components. The last process, or tier, for the gearhouse component is assembly and further processing until it is installed into the complete thruster system.

4.3.2 Finish Dates for Up- and Downstream Tiers

While studying how the delays at M53 propagate to its upstream and downstream tiers it can be necessary to analyse each project individually. The SQL extraction was able to provide information about planned and actual finish dates for each upstream and downstream tier of M53, explained in the BPMN diagram. Based on this extraction, the following graphs for nine projects were created in order to visualize the findings. The SQL query provided data for only nine projects where the processing at the tiers were involved, which is why this thesis is restricted to these nine projects. Each blue dot expresses one processing of each gearhouse subject at AOVF3, red dots represents machining processing at M53 for each gearhouse component, and yellow dots stands for each processing of the gearhouse component at the GRA station. It can be necessary to mention that one project can contain one or several gearhouse subjects. The blue line, or graph, explains the flow between the processings.

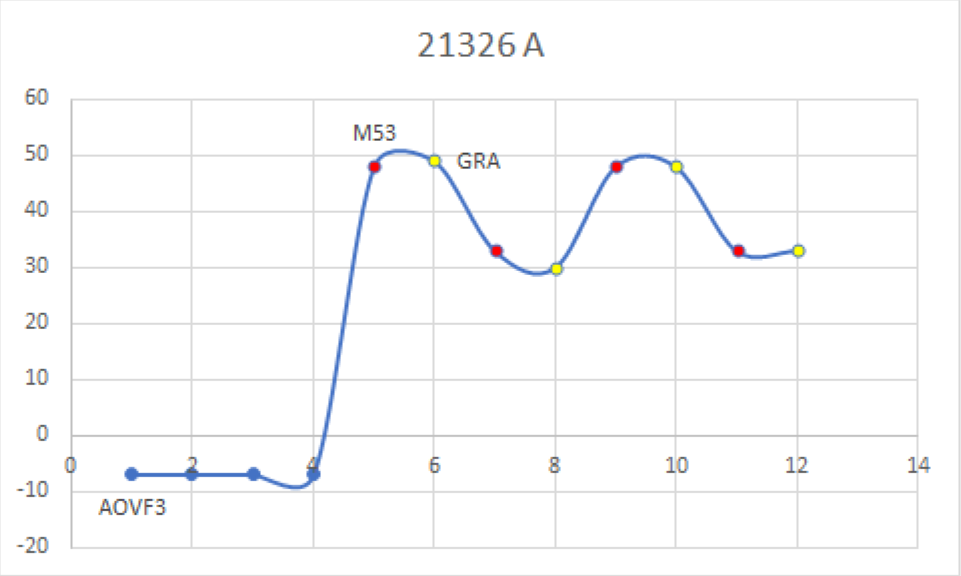


Figure 29: Project 21326 A

Figure 29 visualizes the delays at each tier based on the difference between planned and actual finish dates. The complete project 21326 A was delayed with 54 days, and the machining process at M53 was finished 48 days before planned finished date. As the graph shows, the processing at AOVF3 was 7 days delayed based on planned finish date, and the processing at GRA was finished at least 30 days ahead of planned finish date.

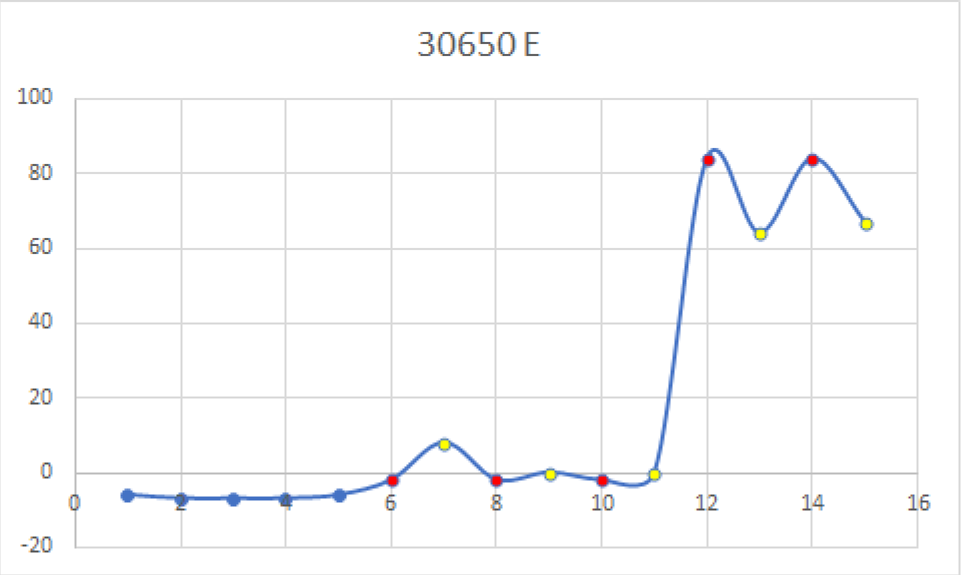


Figure 30: Project 30650 E

The different processing for project 30650 E is visualized in Figure 30. The complete thruster system for this project was completed 30 days before planned finish date, processing at AOVFL3 was delayed with 7 days, machining at M53 was delayed with 2 days at most and processing at GRA was finished 0 days before planned finish date.

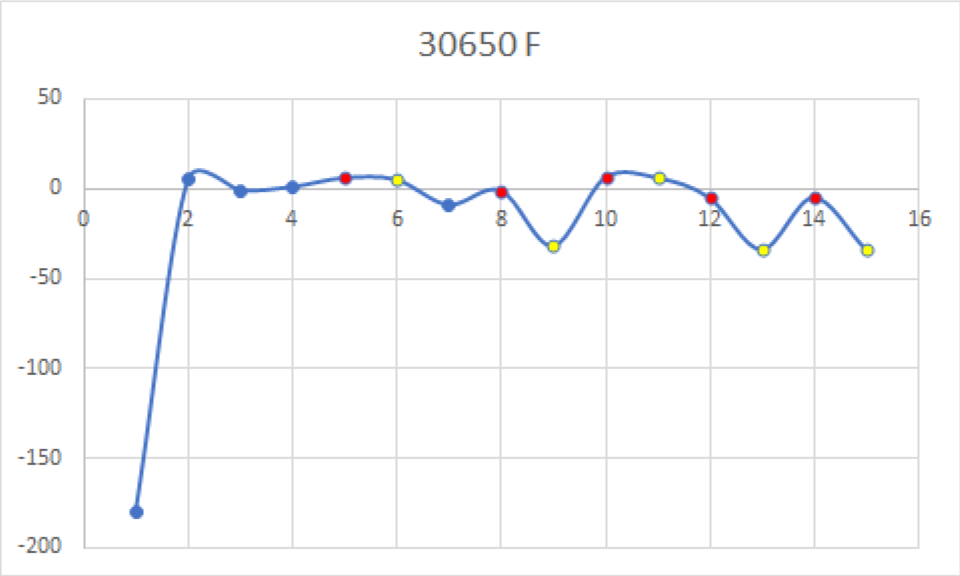


Figure 31: Project 30650 F

Project 30650 F is explained in Figure 31. The complete thruster system project was 91 days delayed based on planned finish date, processing at AOVF3 was at most delayed with 180 days, machining at M53 was delayed with 5 days for this project, and the GRA processing was 34 days delayed at most.

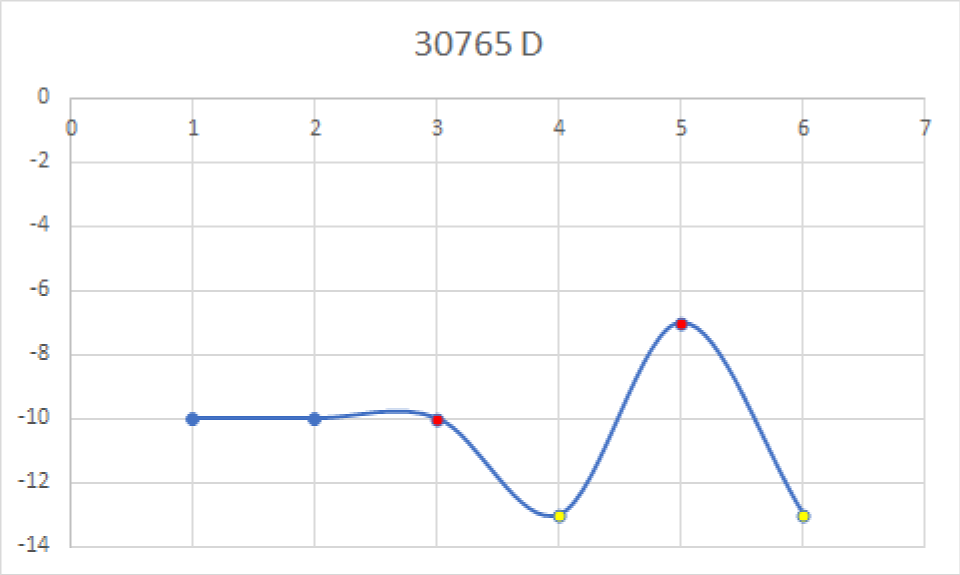


Figure 32: Project 30765 D

The related thruster system to project 30765 D was delayed with 4 days according to planned finish date, processing at AOVF3 and machining at M53 was delayed with 10 days, and GRA was delayed with 13 days.

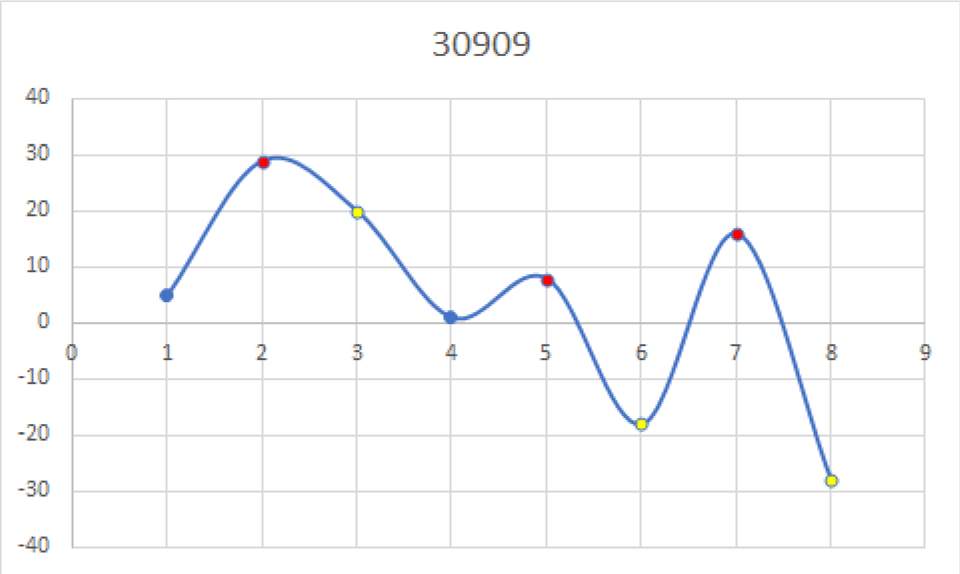


Figure 33: Project 30909

The complete project 30909 was finished 3 days before the planned finish date, AOVF3 processing was completed 1 day before planned, machining at M53 was finished at least 8 days before planned, and processing at GRA was delayed with 28 days at most.

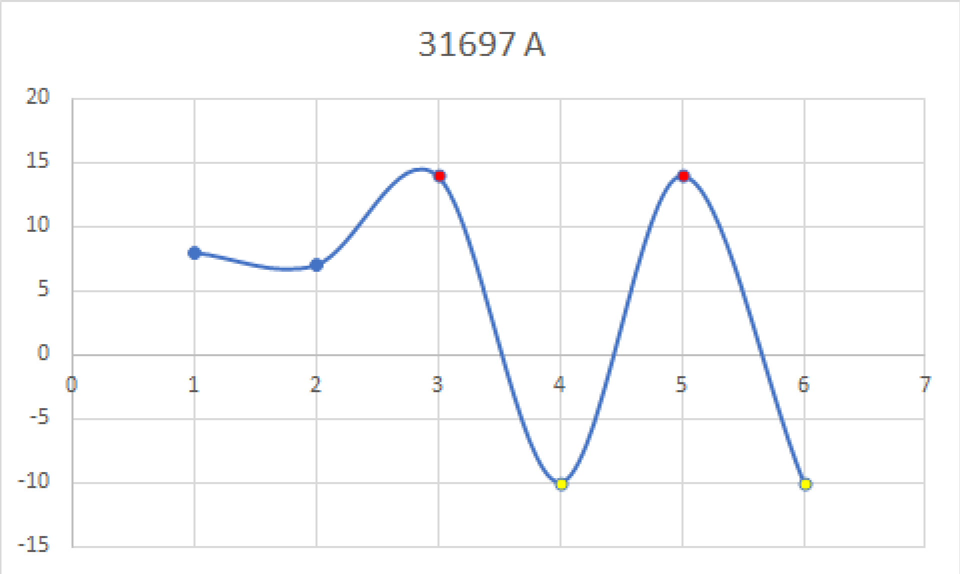


Figure 34: Project 31687 A

The complete thruster system was 12 days delayed for project 31697 A, the processing at AOVF3 was finished 7 days ahead of planned finish date, machining at M53 was completed 14 days before planned, and processing at GRA was 10 days delayed.

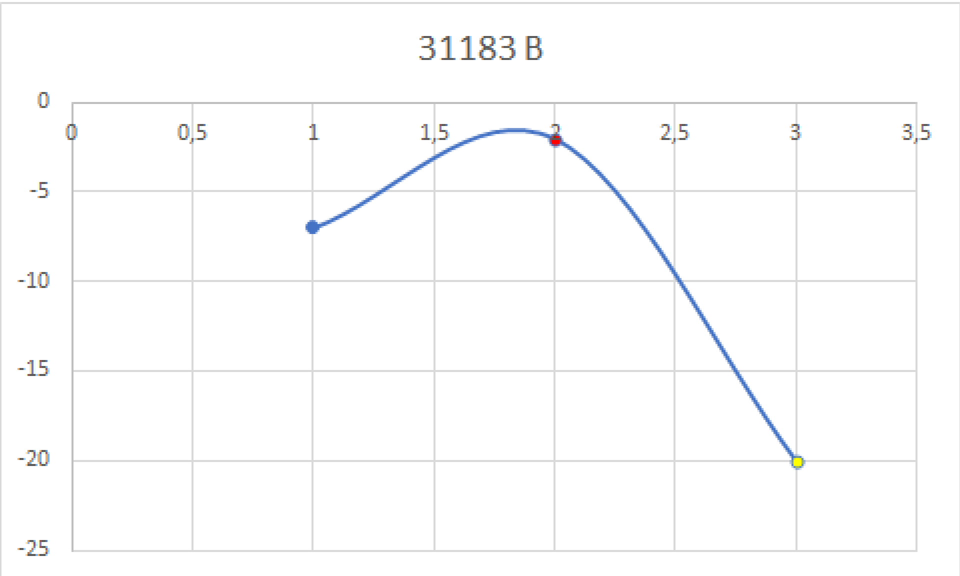


Figure 35: Project 31183 B

For project 31183 B the complete thruster system was completed 11 days later than planned, processing at AOVF3 was 7 days late, machining at M53 was 2 days late, and the processing at GRA was delayed with 20 days based on planned finish date.

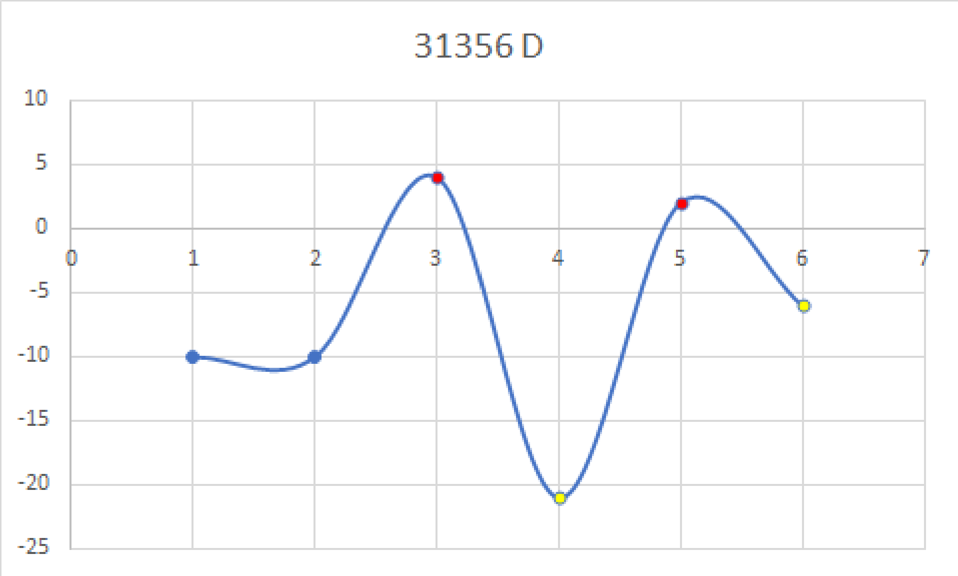


Figure 36: Project 31356 D

For this project, the complete thruster system was finished 55 days later than planned, AOVF3 was 10 days delayed, machining at M53 was completed within 2 days before planned finish date and processing at GRA was completed 21 days later than planned.

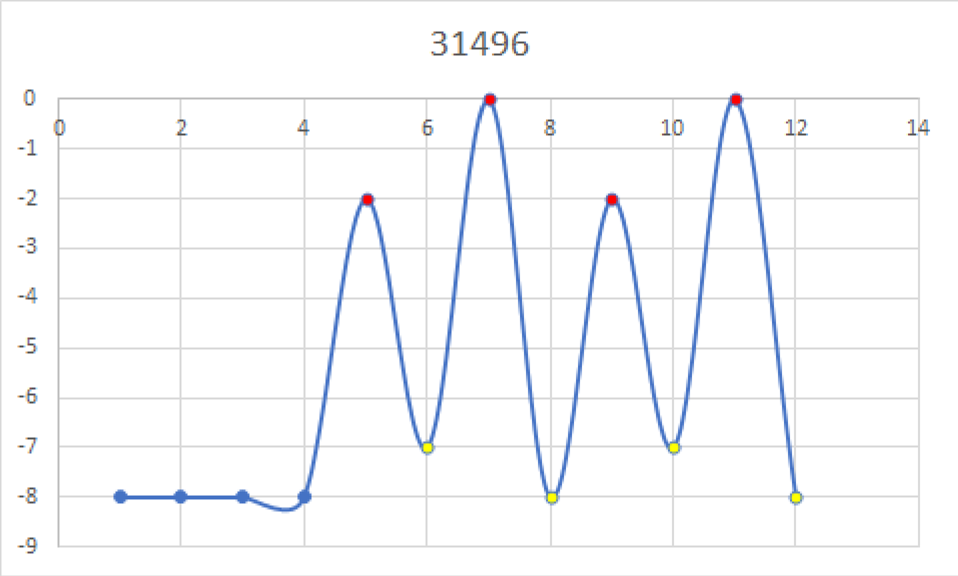


Figure 37: Project 31496

For project 31496 it was possible to discover that the complete thruster system was delayed with 22 days according to planned finish date, AOVF3 was delayed with 8 days, machining at M53 was at most finished 2 days later than planned, and processing at GRA was delayed with a maximum of 8 days.

Standard Deviation for Tiers			
	AOVF3	**M53**	**GRA**
21326 A	0	7,5	8,57
30650 E	0,49	42,13	30,93
30650 F	71,75	4,96	19,04
30765 D	0	1,5	0
30909	2	8,65	20,68
31697 A	0,5	0	0
31183 B	0	0	0
31356 D	0	1	7,5
31496	0	1	0,5
TOT Std.	74,74	66,74	87,22

Table 5: Standard Deviation for Tiers

Table 5 shows the data for how much the different processing at each tier deviates. In addition, it explains the total standard deviation at each tier. This table will be beneficial for further analyses because the total standard deviation can provide an indication regarding how often the processings are delayed or on-time.

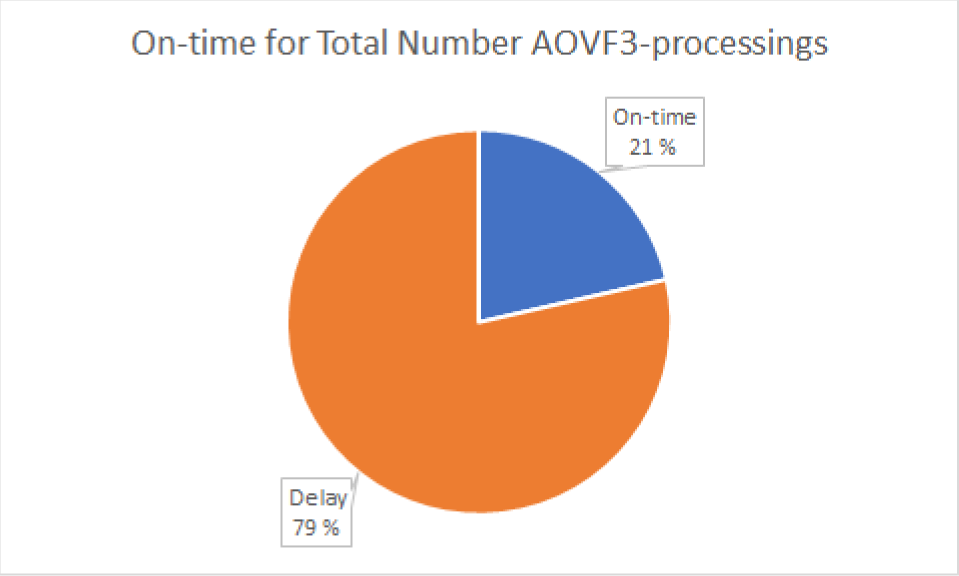


Figure 38: On-time Finish for AOVF3

Figure 38 explains that 21 % of all the processings at AOVF3 were finished before or within the planned finish date. These calculations are not restricted to the latest processing within each of the 26 projects, however, it is based on the total number of delays of every processing at the different tiers.

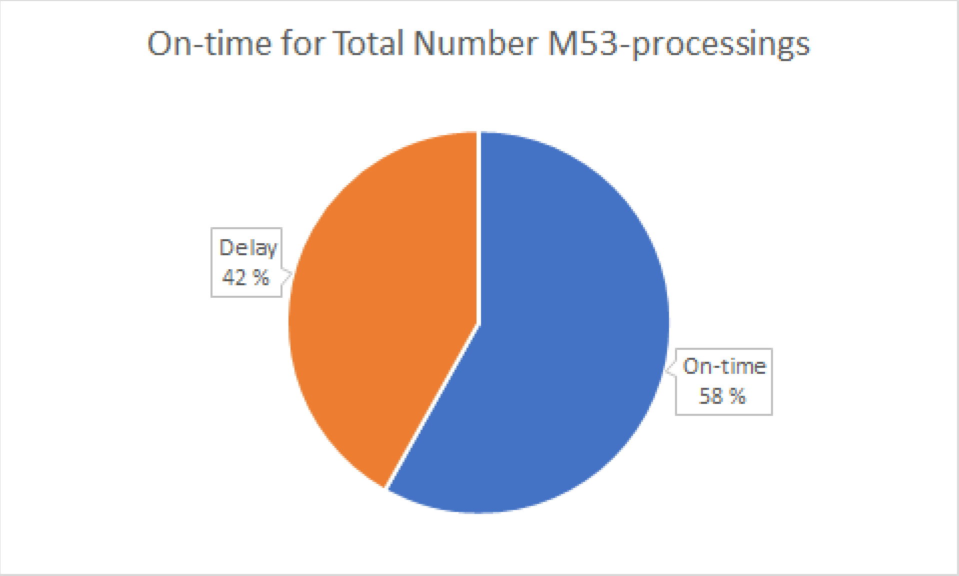


Figure 39: On-time Finish for M53

The figure above explains that 58 % of the total manufacturing processes at machine M53 were finished before or within the planned finish date.

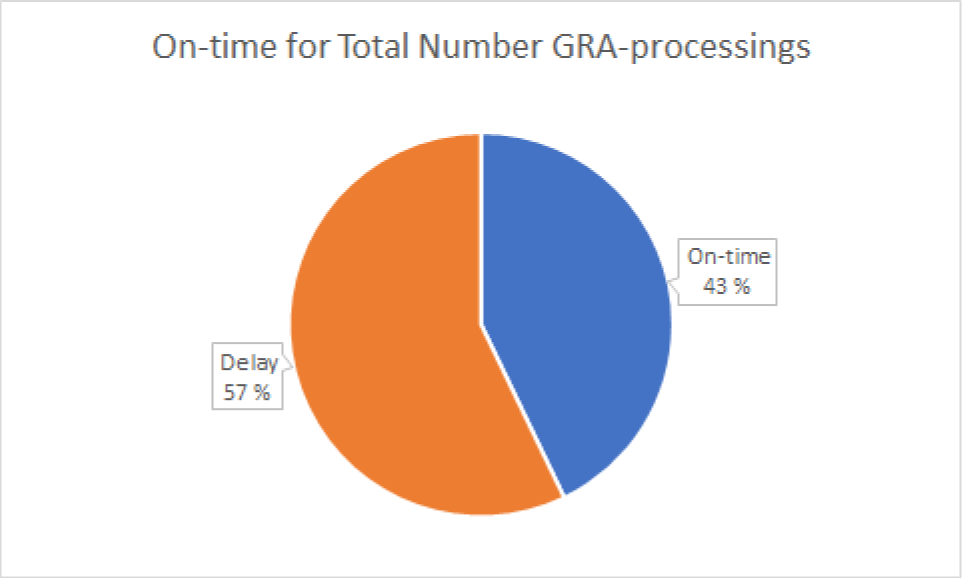


Figure 40: On-time Finish for GRA

As the figure above expresses, 43 % of all the grinding processings at GRA were finished before or within the planned finish date.

5.0 Analysis

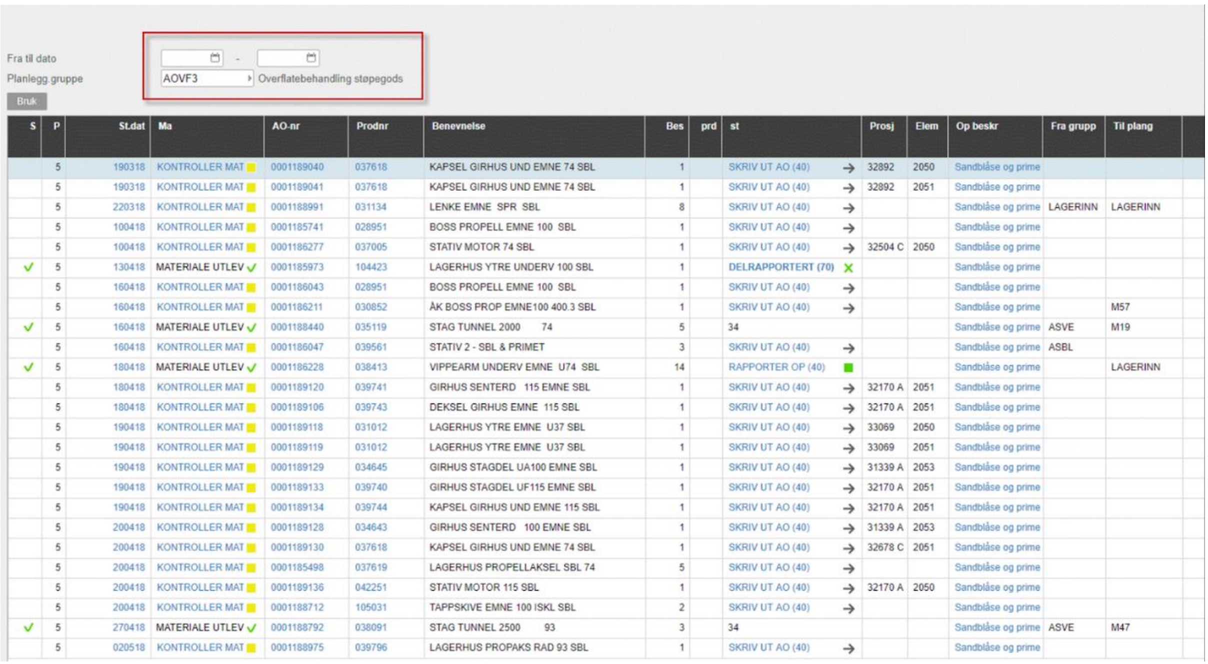
During this chapter, RQ 4 will be discussed based on the results from the case study findings, whereas RQ 1, 2 and 3 were answered. The findings from RQ 1-3 visualized the differences and patterns in planned and actual finish dates, which are crucial in order to find answers to RQ 4. Therefore, it can be stated that RQ 4 is based on RQ 1, 2 and 3; why the delays differ at the various locations or tiers. Based on the findings from the SQL extractions it was possible to acknowledge that planned and reported finish dates differ at various locations within the production halls at Brunvoll. However, in order to find answers to RQ4, it was concluded necessary to study the situation outside of the system as well. To do so, the qualitative interviews with the key informants were valuable. Answers that were considered most relevant for this RQ is mentioned during this chapter. First, the production schedules for each tier (AOVF3, M53 and GRA) are presented. Further on, the interviews are structured into the departments of which the key informants belonged, e.g. the surface treatment department chapter shows the discussion with the Supervisor Surface Treatment and so on. Lastly, a summary of the discussed factors for delays are presented.

5.1 Research Question 4

RQ4: Why and to what degree do the delays differ at various locations?

5.1.1 Production Schedules for Tiers

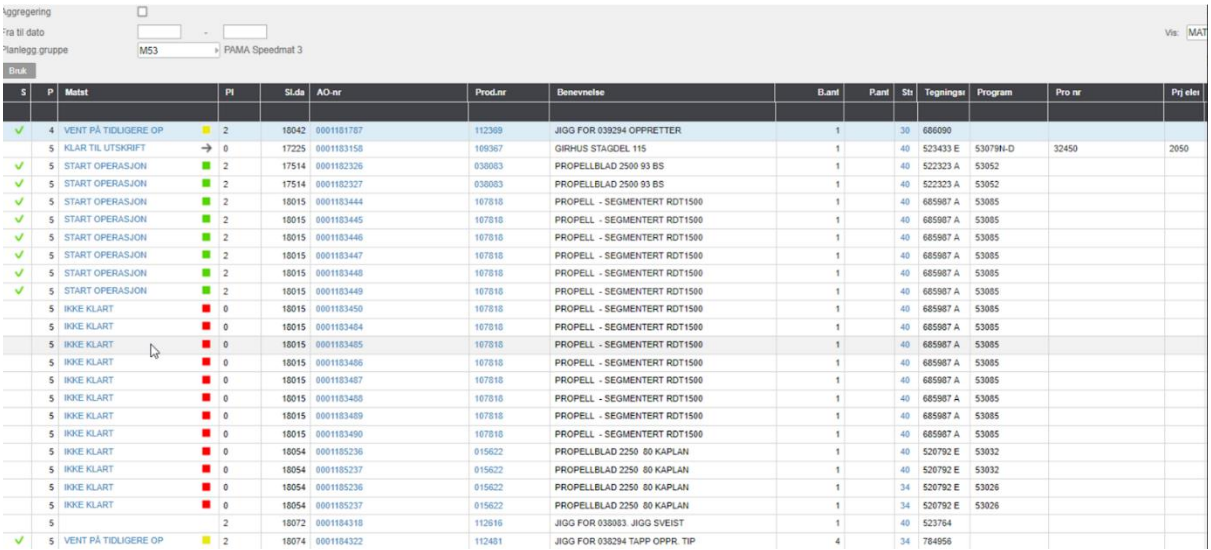
The three screenshots below show the production schedule for the three departments; surface treatment, machining and grinding department respectively. These are presented to explain the variety of subjects and components processed at the different tiers, which might provide answers to why the delays vary at different locations.



Fra til dato
Planlegg.gruppe AOVF3 Overflatebehandling støpegods
Bruk

S	P	St.dat	Ma	AO-nr	Prodnr	Benevnelse	Bes	prd	st	Prosj	Elem	Op beskr	Fra grupp	Til plang
	5	190318	KONTROLLER MAT	0001189040	037618	KAPSEL GIRHUS UND EMNE 74 SBL	1		SKRIV UT AO (40)	32892	2050	Sandblåse og prime		
	5	190318	KONTROLLER MAT	0001189041	037618	KAPSEL GIRHUS UND EMNE 74 SBL	1		SKRIV UT AO (40)	32892	2051	Sandblåse og prime		
	5	220318	KONTROLLER MAT	0001188991	031134	LENKE EMNE SPR SBL	8		SKRIV UT AO (40)			Sandblåse og prime	LAGERINN	LAGERINN
	5	100418	KONTROLLER MAT	0001185741	028951	BOSS PROPELL EMNE 100 SBL	1		SKRIV UT AO (40)			Sandblåse og prime		
	5	100418	KONTROLLER MAT	0001186277	037005	STATIV MOTOR 74 SBL	1		SKRIV UT AO (40)	32504 C	2050	Sandblåse og prime		
✓	5	130418	MATERIALE UTLEV	0001185973	104423	LAGERHUS YTRE UNDERV 100 SBL	1		DELRAPPORTERT (70)			Sandblåse og prime		
	5	160418	KONTROLLER MAT	0001186043	028951	BOSS PROPELL EMNE 100 SBL	1		SKRIV UT AO (40)			Sandblåse og prime		
	5	160418	KONTROLLER MAT	0001186211	030852	ÅK BOSS PROP EMNE100 400.3 SBL	1		SKRIV UT AO (40)			Sandblåse og prime		M57
✓	5	160418	MATERIALE UTLEV	0001188440	035119	STAG TUNNEL 2000 74	5		34			Sandblåse og prime	ASVE	M19
	5	160418	KONTROLLER MAT	0001186047	039561	STATIV 2 - SBL & PRIMET	3		SKRIV UT AO (40)			Sandblåse og prime	ASBL	
✓	5	180418	MATERIALE UTLEV	0001186228	038413	VIPPEARM UNDERV EMNE U74 SBL	14		RAPPORTER OP (40)			Sandblåse og prime		LAGERINN
	5	180418	KONTROLLER MAT	0001189120	039741	GIRHUS SENTERD 115 EMNE SBL	1		SKRIV UT AO (40)	32170 A	2051	Sandblåse og prime		
	5	180418	KONTROLLER MAT	0001189106	039743	DEKSEL GIRHUS EMNE 115 SBL	1		SKRIV UT AO (40)	32170 A	2051	Sandblåse og prime		
	5	190418	KONTROLLER MAT	0001189118	031012	LAGERHUS YTRE EMNE U37 SBL	1		SKRIV UT AO (40)	33069	2050	Sandblåse og prime		
	5	190418	KONTROLLER MAT	0001189119	031012	LAGERHUS YTRE EMNE U37 SBL	1		SKRIV UT AO (40)	33069	2051	Sandblåse og prime		
	5	190418	KONTROLLER MAT	0001189129	034645	GIRHUS STAGDEL UA100 EMNE SBL	1		SKRIV UT AO (40)	31339 A	2053	Sandblåse og prime		
	5	190418	KONTROLLER MAT	0001189133	039740	GIRHUS STAGDEL UF115 EMNE SBL	1		SKRIV UT AO (40)	32170 A	2051	Sandblåse og prime		
	5	190418	KONTROLLER MAT	0001189134	039744	KAPSEL GIRHUS UND EMNE 115 SBL	1		SKRIV UT AO (40)	32170 A	2051	Sandblåse og prime		
	5	200418	KONTROLLER MAT	0001189128	034643	GIRHUS SENTERD 100 EMNE SBL	1		SKRIV UT AO (40)	31339 A	2053	Sandblåse og prime		
	5	200418	KONTROLLER MAT	0001189130	037618	KAPSEL GIRHUS UND EMNE 74 SBL	1		SKRIV UT AO (40)	32678 C	2051	Sandblåse og prime		
	5	200418	KONTROLLER MAT	0001185498	037619	LAGERHUS PROPELLAKSEL SBL 74	5		SKRIV UT AO (40)			Sandblåse og prime		
	5	200418	KONTROLLER MAT	0001189136	042251	STATIV MOTOR 115 SBL	1		SKRIV UT AO (40)	32170 A	2050	Sandblåse og prime		
	5	200418	KONTROLLER MAT	0001188712	105031	TAPPSKIVE EMNE 100 ISKL SBL	2		SKRIV UT AO (40)			Sandblåse og prime		
✓	5	270418	MATERIALE UTLEV	0001188792	038091	STAG TUNNEL 2500 93	3		34			Sandblåse og prime	ASVE	M47
	5	020518	KONTROLLER MAT	0001188975	039796	LAGERHUS PROPAKS RAD 93 SBL	1		SKRIV UT AO (40)			Sandblåse og prime		

Figure 41: Production Schedule Example for AOVF3



Aggregering
Fra til dato
Planlegg.gruppe M53 PAMA Speedmat 3
Bruk
Vis: MAT

S	P	Matst	Pl	Sl.da	AO-nr	Prod.nr	Benevnelse	B.ant	P.ant	St	Tegnings	Program	Pro nr	Prj ele
✓	4	VENT PÅ TIDLIGERE OP	2	18042	0001181787	112369	JIGG FOR 039294 OPPRETTER	1		30	686090			
	5	KLAR TIL UTSKRIFT	0	17225	0001183158	109367	GIRHUS STAGDEL 115	1		40	523433 E	53079N-D	32450	2050
✓	5	START OPERASJON	2	17514	0001182326	038083	PROPELLBLAD 2500 93 BS	1		40	522323 A	53052		
✓	5	START OPERASJON	2	17514	0001182327	038083	PROPELLBLAD 2500 93 BS	1		40	522323 A	53052		
✓	5	START OPERASJON	2	18015	0001183444	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
✓	5	START OPERASJON	2	18015	0001183445	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
✓	5	START OPERASJON	2	18015	0001183446	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
✓	5	START OPERASJON	2	18015	0001183447	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
✓	5	START OPERASJON	2	18015	0001183448	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
✓	5	START OPERASJON	2	18015	0001183449	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183450	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183484	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183485	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183486	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183487	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183488	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183489	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18015	0001183490	107818	PROPELL - SEGMENTERT RDT1500	1		40	685987 A	53085		
	5	IKKE KLART	0	18054	0001185236	015622	PROPELLBLAD 2250 80 KAPLAN	1		40	520792 E	53032		
	5	IKKE KLART	0	18054	0001185237	015622	PROPELLBLAD 2250 80 KAPLAN	1		40	520792 E	53032		
	5	IKKE KLART	0	18054	0001185236	015622	PROPELLBLAD 2250 80 KAPLAN	1		34	520792 E	53026		
	5	IKKE KLART	0	18054	0001185237	015622	PROPELLBLAD 2250 80 KAPLAN	1		34	520792 E	53026		
	5		2	18072	0001184318	112616	JIGG FOR 038083. JIGG SVEIST	1		40	523764			
✓	5	VENT PÅ TIDLIGERE OP	2	18074	0001184322	112481	JIGG FOR 038294 TAPP OPPR. TIP	4		34	784956			

Figure 42: Production Schedule Example for M53

Aggregering

Fra til dato -

Planlegg.gruppe GRA Gradebu

Bruk

Vis: MAT

S	P	Ma[illegible]	Pl	Sl.da	AO-nr	Prod.nr	Benevnelse	B.ant	P.ant	St	Tegnings	Program	Pro nr	Prj ele
	5	VENT PÅ TIDLIGERE OP	0	17225	0001183158	109367	GIRHUS STAGDEL 115	1		34	523433 E		32450	2050
✓	5	START OPERASJON	2	17363	0001177975	000202	OLJEINNFØRING INDRE UND 45	10		40	330935 C			
✓	5	START OPERASJON	2	17434	0001182473	106572	DEKSEL PROPELL 45	1		40	334979			
✓	5	START OPERASJON	2	17501	0001179751	027388R	BOSS PROPELL 63 P	1		40	521476 D			
✓	5	START OPERASJON	2	18023	0001182811	035068	HUS TETNINGSRING UNDERV 74	1		40	333443 C			
✓	5	START OPERASJON	2	18032	0001182008	038245	GIRHUS STAGDEL UF115	1		40	522247 E		31665 B	2052
✓	5	START OPERASJON	2	18033	0001181711	108892	LOKK Ø466	1		40	335295			
✓	5	START OPERASJON	2	18052	0001182904	108892	LOKK Ø466	10		40	335295			
✓	5	START OPERASJON	2	18074	0001183890	038273	FLENS PROPELL 115	1		40	522268 C		31018 B	2050
✓	5	VENT PÅ TIDLIGERE OP	2	18075	0001183312	103088	DEKSEL GIRHUS UNDERV 93	2		34	684676			
✓	5	VENT PÅ TIDLIGERE OP	2	18075	0001184085	003456	LAGERHUS YTRE UNDERV 63	1		34	520594 M		33571	2050
✓	5	VENT PÅ TIDLIGERE OP	2	18082	0001185920	038040	FLENS PROPELL 93	1		34	522267 D		32382	2051
✓	5	START OPERASJON	2	18083	0001184230	106356	ÅK BOSS PROPELL 115	1		40	334951		31018 B	2050
✓	5	VENT PÅ TIDLIGERE OP	2	18083	0001183899	038040	FLENS PROPELL 93	1		34	522267 D		32382	2050
✓	5	START OPERASJON	2	18091	0001184208	038235	LENKE BOSS PROPELL 115	5	4	70	682362 A		31018 B	2051
✓	5	START OPERASJON	2	18091	0001184229	106356	ÅK BOSS PROPELL 115	1		40	334951		31018 B	2051
✓	5	VENT PÅ TIDLIGERE OP	2	18092	0001182923	006451	LAGERHUS MELLOMAKSEL AZ 63	1		34	331365 B			
✓	5	VENT PÅ TIDLIGERE OP	2	18093	0001184074	038273	FLENS PROPELL 115	1		34	522268 C		31018 B	2052
✓	5	VENT PÅ TIDLIGERE OP	2	18094	0001186054	000010	LAGERHUS PINJONG UND *45	1		34	331226 F			
✓	5	33	0	18095	0001181123	019360	BOSS PROPELL 100	1		70	520953 I			
✓	5	START OPERASJON	2	18101	0001185045	106310	DEKSEL PROPELL 63	1		40	334946 A			
✓	5	START OPERASJON	2	18102	0001174964	004554	BOSS PROPELL SPR	1		40	520524			
✓	5	VENT PÅ TIDLIGERE OP	2	18102	1172090	009930	BOSS PROPELL SPA	2		34	520675			
✓	5	VENT PÅ TIDLIGERE OP	2	18102	0001184487	038253	KAPSEL GIRHUS UNDERV 115	1		34	522256 A		31018 B	2052

Figure 43: Production Schedule Example for GRA

These screenshots are presented because they are valuable for further discussions. Based on the production schedules, it is possible to see that the variety of subject/component names (see "Benevnelse" in screenshots) is relatively lower for the M53 than at AOVF3 and GRA. The AOVF3 and GRA tiers tends to have several different subjects/components to be processed, while the subjects/components processed at M53 typically are more similar. This should be taken to consideration during discussions and conclusions regarding delays at the different tiers.

5.1.2 Surface Treatment Department (AOVF3)

The supervisor at the surface treatment department was questioned regarding possible reasons for the variations of the planned and actual finish dates within the ERP system. The supervisor could inform that the surface treatment department typically have to wait for external subcontractors for the gearhouse subjects. Even though the safety stock should contain 3-7 gearhouse subjects at all times, some projects might require specific measurements that are not in stock. In addition, sometimes they must wait for the customer to confirm the order before they can process the work orders. Such delays are not updated in the system, which may create a big gap between the planned and actual finish dates. Data that are not updated are called "historical data" and should be taken to consideration while studying the data from the SQL extractions. This means that it can be necessary to study the data from the ERP system from a critical point of view; the data will not provide enough information to make definite conclusions, which is why this thesis intends to collect data based on qualitative interviews with key informants as well.

Further on, the key informant mentioned that some of the operators do not understand the value of reporting in the ERP system. Additionally, some operators believe that the operators at the “next” station can do the reporting for them instead. The informant claimed that this did not have any major influence on the actual finish dates. However, it is believed that when an operator at the “next” tier report work orders for the operator at the previous tier, there can occur some errors in the data. The operator might not have enough information about the exact time and date for the completed work order to be reported, which can cause input of incorrect information in the system.

The supervisor was also asked about the acclimatization of gearhouse subjects. The gearhouse subjects are stored on the outside storage without any form of roof or protection from weather. However, the subjects can withstand corrosion, which is normally a negative process in the nature viewed from a production perspective, meaning that the subjects can be stored outside without getting damaged. In order to begin the production process, the subjects must be acclimatized - especially during winter and when the outside temperature is low. If the subjects do not have the correct temperature or are wet, they can be wrecked during the production, which is why they cannot start the production before the subjects are acclimatized. If the operators forget to pick up the gearhouse subjects from the outside storage approximately two days before further processing, the lead time can increase and delays in production can occur. Other factors can be late deliveries of gearhouse subjects that have been transported with trucks during winter. These subjects may have a low temperature from transportation, and if the delivery is late, the production at Brunvoll can be delayed even more, causing increased lead time.

Furthermore, the key informant said that they had increased their staff in order to improve the capacity at the surface treatment department, and that many of the operators work overtime to complete their projects. As a result, the surface treatment department might become more flexible, which can improve the possibilities of staying ahead of planned finish dates. Because this measure was done in the period after 2016 to late 2017, the results of increased workforce is not possible to detect in the data collected for this thesis. However, referring to the literature review about production capacity, it is believed that high flexibility generates a greater utilization of capacity, meaning that more gearhouse subjects can be processed every day.

It might be necessary to address that the complexity of the production schedule for AOVF3 is high, compared to the schedule for the machining department. Figure 41, 42 and 43 (production schedule screenshots) shows that the surface treatment department has several products/components, projects, and similar, meaning that this tier is more vulnerable to uncertainty and changes in production. Therefore, the flexibility at AOVF3 is low in contradiction to the machining department, which should be considered while discussing delays based on the case study findings and analysis.

5.1.3 Machining Department (M53 and GRA)

The qualitative interview with the supervisor for the machining department provided information regarding machine M53 and the GRA tier. It was stated that the flexibility at M53 is relatively low because the gearhouse components are big, heavy, and difficult to move. In addition, there are no other machines that are able to handle such big and heavy components. Therefore, when other circumstances occur, such as unanticipated need for service of the machine, the operators are forced to stop the machining processes at M53, which may result in delays and increased lead time. However, machine M53 can run at night without any human supervision, making this machine able to catch up with lost time when needed. Though, this is dependent on the M53 to be able to utilize its capacity.

Other reasons for variations of planned and actual finish dates at different locations may also revolve around the reporting in the ERP system. The supervisor informed that the data from the ERP system should be viewed critically as the “historical data” may give an interpretation that the work orders and projects are delayed. Because some operators ignore the reporting, the operator at the “next” tier must do it for them, which can lead to input of wrong or incorrect information and cause delays within the ERP system. This was also mentioned during the interview with the supervisor surface treatment.

During the interview, we showed the supervisor machining department the findings from the SQL extractions, presented in the case study findings, that shows the tendency that the machining department seems to catch up with lost time and that the grinding station seems to be delayed. The key informant was therefore questioned about the department's intentions of catching up with lost time. It was claimed that it was not their intention, however, their operators are dedicated, motivated and proactive. In addition, the key informant told that they aim to complete at least two gearhouse components every day because it is positive to stay in advance with such big components. The reason why the machining department seems to be in advance may also be because they handle few bigger articles, rather than several smaller. Additionally, the complexity of the production schedule is low compared to the schedules for AOVF3 and GRA, meaning that it can be easier for the machining department to process and complete several work orders.

Furthermore, they do not experience a lot of down-time at machine M53, which means that they are able to utilize the overnight capacity when needed or aspired. The supervisor claimed that there are few problems with the machine in general, however, it can be necessary to not exclude down-time as an unexpected factor entirely because it might happen even though it is very rare. One service on the machine can last for e.g. one week, so when a planned service is coming up, the operators tend to work a lot to not be delayed because of the service. This includes working overtime. Such utilization of the human capacity is a critical factor for reducing the lead time.

The supervisor was questioned regarding wrecking and quality errors of gearhouse subjects from external suppliers. Because of the complexity of gearhouse measurements, incorrect measurements can be machined and processed, forcing a wrecking of the gearhouse component. Sometimes, the quality of the gearhouse delivered from the external supplier might not be good enough. Based on the interview, casting defects such as pores in the material seemed to be a typical error related to the gearhouse. Such defects can also result in wrecking of the component. The supervisor claimed that the occurrence of low quality subjects is rare, however, it happens more often than incorrect measurements and wrong machinery.

When it comes to human capacity, the supervisor could inform that they must be aware of absence of operators or sick leave. If an operator has to take a sick leave, a lot of problems can occur in the production. The most experienced operators are difficult to replace, and absence of such experienced workforce can cause delays in production and increase the manufacturing lead time. For the machine M53, the supervisor intends to "always" have at least three operators at work, which can ensure that a halt in manufacturing do not occur, preventing delays in production.

As already mentioned, there seems to be a tendency of delays at the grinding station, and the supervisor for the machining department could inform that this might be because there is a lack of human workforce at this specific station. Earlier, there were two operators at the grinding station, however, today there is only one, meaning that one man performs a two-man job. The flexibility is therefore not very good, and it is considered a bottleneck in the production. In order to decrease the occurrences of delays at the grinding station it might be a great solution to increase the human capacity, which can make the station more flexible as well. In addition, bringing in new people can generate changes in the execution of work processes which could increase the efficiency. Further on, the lead time can be reduced as a result of the increased human capacity.

5.1.4 Planning Department

The Master Planner and Production Planner were asked questions about reasons for why some projects typically start later than planned. They were able to inform that operators sometimes want to wait for all the components for a project to arrive before beginning the processing. This might be a relevant case when it comes to the grinding station, however, it could be viable for other departments as well, such as the surface treatment and machining departments. Additionally, the planners could inform that the grinding operator must wait for every gearhouse related to one project before starting to process the work orders. Since the project cannot be delivered before every component is finished, waiting for all the components before beginning the work processes should not be a production hazard. Though, it will provide delays within the ERP system with respect to planned dates.

The planners believe that delays could be a result of poor reporting; some operators do not understand the value of reporting in the ERP system. Operators tend to think that the “next operator” can report the completed work in the system. Some operators may also be unsure about how to actually report into the system, and therefore tend to ignore reporting. As mentioned earlier, this can cause delays in the ERP system because the operator that must report for another operator might place wrong information about the work order. This can lead to propagation of actual finish dates in the system, making it look like the work orders are delayed.

Additionally, the Master Planner told that the work order are printed out on paper and attached to the components with magnets, which can be one root cause for delays in the system. Work orders on paper are likely to disappear, get destroyed during production, and so on. When a work order for a component is missing or destroyed, it can cause confusion regarding the work operations related to that component. The process of finding to which work order the component belongs can be time-consuming and frustrating, and may increase the lead time.

When the production is completed (see Figure 19: Internal Project Life Cycle (Phases) for Complete Thruster Systems), the customers can be asked, or request, to join the Factory Acceptance Test (FAT) in order to validate the quality of the complete thruster system. Some of the projects may be delayed in the system because of this project phase: Sometimes, Brunvoll must wait for the customers before performing the FAT, and such waiting time is not updated in the ERP system. Furthermore, when a customer has not paid the invoice, Brunvoll have to hold on to the thruster system and wait until the payment is received. This is another factor that is not updated in the ERP system, meaning that “historical data” is causing delays.

When questioned regarding planning, the planners informed that they always place a margin error of 14 days before dispatch of all projects. This is dependent on the complexity of each order; if the order has been produced before; if the order requires many parts/articles etc. The 14 days safety measure should make the projects able to withstand problems regarding “historical data”, other circumstances or lack of reporting. However, based on the SQL extractions and findings, it does not seem as if the safety measure is enough to prevent delays within the ERP system.

Other possible causes for delays in the manufacturing process of gearhouses might be because the production schedules are not up to date. The Production Planner said that he always aim towards controlling and updating the production schedules at least once a week, however, this is not always feasible. The consequences of production schedules that are not up to date is that the operators produce wrong articles/components to the incorrect date or project. There are three different codes within the ERP system explaining which measures to consider when production schedule related issues occur. The three codes are divided into B1, B3 and B7.

	Errors	Measures
B1	Wrecking or missing components in the system	Plan for future, order is delayed
B3	The order has been completed too early or too many components have been produced early	Postpone the project and extend the planning
B7	No longer need for the project	Order is deleted, components are stored based on costs

Table 6: B-codes in Production Scheduling

The B1-code explains that when a component is missing in the system or when the component is wrecked, the order will be delayed. One measure for this code is therefore to plan for the future in order to prevent the lead time to increase to a higher level than necessary. The B3-code occurs when several components have been produced for the previous order or that the project has been postponed. This code is corrected by postponing the project and extending the planning. Further on, code B7 occurs when the project by some reason is no longer needed, resulting in a deletion of the order. The production planner could inform that in such cases, they study the components and how far in the process it has come in order to decide what to do with them. Sometimes the cost of the component is considered; expensive subjects and parts are typically processed until finish and stored, while cheaper subjects goes into the container as garbage.

5.1.5 Summary of Findings and Analysis (RQ1-4)

It can be necessary to mention that the extracted data is based on planned and actual finish dates reported within the ERP system. This is a limitation that was considered while studying and analysing the data. Case study findings concluded that only 12 % of the projects were completed before or within the planned finish date, however, this is not a representative conclusion because of several influencing factors: "historical data", poor reporting and other circumstances. The following table is based on the discussions regarding RQ4, and explains and summarizes what is included in the three influencing factors:

"Historical data"	Poor reporting	Other circumstances
• Late deliveries of parts/components from internal/external contractors • Wait for order confirmation from customer • Production schedules are not updated • FAT • Late customer payments	• Wait for all components before processing and reporting • Forgetting to report • Uncertainty regarding how to report • Language barriers • Reading and writing difficulties • Depend on the next operator to report • Disappearance of work orders on paper	• Down-time • Incorrect measurements/machinery • Low-quality subjects from external contractors • Sick leave/absence • Forgetting to pick up subjects from outside storage (climate changes) • Degree of complexity of production schedules

Table 7: Influencing Factors for Delay

Even though there are several factors to consider while studying the on-time completion of projects, the results from the case study findings can be used as an indication to where Brunvoll can improve the performance by reducing delays, and thereby reduce the manufacturing lead time. Based on the findings, only 12 % of the 26 projects were finished before or within the planned finish date. In conclusion, the difference between the confirmed delivery date and actual finish date was analysed, 62 % of the projects were finished before or within the confirmed delivery date. This may provide a better interpretation of how many projects were delivered on-time to the end-customer, however, the "historical data", poor reporting and other circumstances do have a great influence on these results as well. Stating this, the delivery performance at Brunvoll can be claimed to be relatively low and has a great potential for improvements.

RQ 2 revolves around finding answers to how delays in M53 propagate to delays in projects. Findings showed that 46 % of the machining processing at M53 related to the 26 projects were delayed. Furthermore, Figure 26 (Planned VS Actual Finish Dates for Projects and M53) explains that neither delays nor the on-time machining at M53 seems to have any significant influence on the on-time finish of the complete project. This is also correlated with the findings whether the projects were finished before or within the planned finish date; even though 54 % of the machining processes at M53 for all the 26 projects were finished before or within the planned finish date, only 12 % of the projects were finished on-time or before planned.

Even though machining at M53 do not seem to have a significant effect on the on-time delivery of the complete thruster systems, it was considered relevant to study the upstream and downstream tiers of M53 to discover where the slack is occurring; what is the impact of delays and on-time completion of processings at the different tiers on the complete project? Based on the findings of the SQL extraction, it was possible to detect a pattern within the production process of the gearhouse subject. Processing at AOVF3 seemed to be delayed, maybe as a result of "historical data", poor reporting and other circumstances, while machining at M53 seems to be able to catch up with the time lost. It is likely that the operators of M53 are able to do this because of the relatively low production schedule complexity and by exploiting their human and machine capacity, generating high flexibility and reduction of manufacturing lead time. Additionally, situations with down-time and wrecking of components at M53 is claimed to be rare, preventing problems regarding such other circumstances that can lead to delays.

Another tendency from the findings is that the grinding station seems to be delayed as well. Based on the interviews, possible causes for the delays is that the operator at the station must wait for all the components related to the same project before beginning the grinding processing. Additionally, these components are not reported within the ERP system before the grinding operator has completed the work orders, making it look like some of the components are finished later than planned while others are finished on-time. Other factors for delays at the grinding station is human capacity: Today there is only one operator at this station, which might generate problems regarding "down-time" if sickness or other types of absence occurs.

The human capacity at the surface treatment department was increased by operators from the machining department, meaning that some of the machining operators had to adapt to new processes. Based on the literature review, workforce agility revolves around the operators' ability to adapt to changes, for instance move operators from one tier to another. During the qualitative interview, it was stated that because of a great working environment and motivated operators, the relocation of staff should be a smooth process. However, it was also informed that over the years, some operators have obtained an ownership towards their workstation and/or machine. These operators are difficult to move and they might tend to restrain from changes in general. Therefore, the supervisors at the different departments have obtained the ability to know which operators to move, or even ask to work overtime when needed. Based on this, it can be possible to state that the workforce agility at Brunvoll definitely has the potential to be improved.

Furthermore, based on the standard deviations, Table 5, of the processings at each tier, it can be possible to state that some of the tendencies might be valid. At AOVF3, the deviation is 74,74 days in total, however, this standard deviation is high because of problems regarding "historical data" from project 30650 F. The project seems to be 180 days delayed, but based on interviews, this can be considered an error in the ERP system. If studying the standard deviation for each project processed at AOVF3, it is possible to acknowledge that the deviation is low. This means that it is typical that processing at AOVF3 is delayed.

The standard deviation for machining at M53 is 66,74 days in total. Based on Table 5 (Standard Deviation for Tiers), it can be stated that the deviation between delays and on-time processing is high. However, this might be a result because the operators of machine M53 tends to operate in advance. For some projects, especially 21236 A and 30650 E, the machining processings at M53 are finished a significant amount of days before planned. In addition, for all the 26 projects, the machining processing at M53 was at most delayed with only 10 days. The standard deviation can therefore explain that the variation between planned and actual finish dates is relatively high due to exploitation of human and machine capacity at M53.

The tendency regarding the grinding tier can be explained based on the standard deviation of 87,22 days in total - the deviation at GRA is therefore much higher compared to the deviation at AOVF3 and M53. This could be a result of the decision that to increase the visualization of each project, the operator at GRA should wait for several components from M53 before starting the grinding processing. Additionally, the grinding processing was completed a significant amount of days before planned for the projects 21236 A and 30650 E, similar to what was happening in M53. However, some of the grinding processes were significantly delayed: 34 days delay at most for project 30650 F and 28 days delay at project 30909. This great deviation is therefore believed to be a result of poor human capacity and low flexibility at the grinding tier. Additionally, the production schedule complexity at the GRA tiers is great, which may provide an answer to why the standard deviation is high.

6.0 Discussion

During this discussion chapter, RQ 5 will debate the applicability of ERP systems within ETO companies. This is based on the case study findings and analysis, whereas the data and results made it viable to question the applicability of Brunvoll's ERP system. Finally, RQ 6 will generate discussions regarding how to reduce the lead time within the scope of Industry 4.0. This discussion is intended to create a general statement regarding ETO companies, the ERP system and IoT technology which could improve the delivery performance.

6.1 Research Questions 5

RQ 5: How do the ERP system at Brunvoll support the project manufacturing planning and control (PMPC) process?

6.1.1 Feasibility of ERP systems within ETO-companies

Based on the case study findings and analysis for this thesis, results indicated that the production planning system at Brunvoll may not be sufficient in ETO-environments. Such ERP systems are intended to ensure real-time data, visibility, increased task automation, and so on. However, several studies have been conducted, concluding that ERP systems may not be applicable in MTO-environments as well as ETO-companies. In order to create an applicable ERP system, it can be viable to understand the project manufacturing planning and control requirements for Brunvoll based on their project life cycle (Figure 19).

Referring to the literature review about ERP applicability in the ETO sector, the customer enquiry stage is closely related to the feasibility phase (initial phase) of projects at Brunvoll. This stage intends to collect critical information in order to define the confirmed delivery dates and to find out whether the order is feasible or not. The demand management function from the PMPC system defines projects as either planning groups or single projects based on the resemblance of previous orders. Therefore, the production planning and control requires estimation of lead times and cost/profit margins, information about other project schedules, retrieval of subject/component data, and assessment of available human and machine capacity. These information requirements are considered critical in order to detect whether the customer enquiry is feasible or not. Further on, it can be important to generate effective coordination and communication between all the departments involved in the customer enquiry stage. Stating this, it is necessary that the ERP system is successfully integrated, generating efficient communication across departments. Today, the communication between the departments at Brunvoll may not be sufficient because of poor reporting. Improving the reporting can therefore be claimed to be a critical requirement from the ERP system.

The planning phase, or design and engineering stage, requires complete, consistent and up-to-date basic thruster system information if the order has been produced before to create a BoM. In addition, the ERP system should provide access to document aspects of previous orders of thruster systems. The engineering management function in the PMPC system enables design and configuration activities and coordinates these activities with the demand management function. When these engineering activities are completed, the project schedule is updated and a BoM is specified. This means that the system automatically should request for resources. Based on the interview with the Master Planner, it was informed that around 90-95 % of the articles are standard for a thruster system, making it possible to believe that the ERP system at Brunvoll today is capable to store such historical data. This data can be beneficial for the engineering management function which creates the BoM.

Further in the planning phase, or job entry stage, it can be requested to make changes to the BoM that was planned during the design and engineering stage. The material and capacity function of the PMPC system is dependent on the project activities whether the project is a repeat or one-off order. Brunvoll tends to produce a mix of repeat and one-off orders, and their ERP system is able to create a forecast of subjects and components in the downstream supply chain. Further on, the system should be able to plan the capacity in order for due dates to be feasible. When the majority of the orders are related to large projects, Brunvoll can require project management techniques and relevant IT support. Based on the data that was collected for this thesis, it is possible to make a statement regarding Brunvoll’s ERP system and its ability to plan the capacity: The system is able to plan capacity, however, it is not dynamic for changes later in the manufacturing process.

The job release and shop floor dispatching stages are related to the execution phase whereas work orders are released and sent out to the manufacturing halls or shop floor of Brunvoll. It is necessary to control the work order release in order to avoid untimely releasement of jobs.

Releasing the work orders in time for them to meet the due dates can be done using the PMPC process to check the capacity at Brunvoll. Today, the work orders and project schedules are sequenced based on related projects: It has been decided that the operators should wait with processing until all the subjects and components of a project has arrived. Additionally, referring to the interviews, the operators tend to sequence work orders and project schedules based on job prioritisation, e.g. speeding up the production of late projects compared to projects that are proactive. However, referring to the literature review about ERP applicability, studies have argued that simple mechanisms, such as first-in-first-out, might be a preferred strategy in ETO-companies. The operators at Brunvoll are highly skilled and are therefore able to dynamically make changes in the PMPC process.

Summarizing these requirements of the ERP system and the PMPC process at Brunvoll, it can be possible to state that the system is able to provide a great amount of historical data. In addition, it obtains the ability to generate capacity planning in order to meet the due dates. However, the lack of real-time data and automatic reporting reduces the capability of the ERP system considerably. Therefore, the system does not obtain the ability to reorganize the PMPC or adapt to changes regarding capacity during the manufacturing process.

6.2 Research Question 6

RQ6: How can Industry 4.0 concepts be used to reduce the lead time in ETO manufacturing companies?

6.2.1 Why Mature Towards IoT

The production planning at an ETO-company can be a difficult and complex process. Maturing towards Industry 4.0 by implementing IoT technology can provide great supply chain visibility, which can increase the awareness of the states of the supply chain activities and events. This can further lead to an improved production planning process in addition to become even more efficient. Significant improvements in the manufacturing processes through better planning can help reduce the lead time at ETO companies. Using sensors, RFID-tags, and so on, can provide critical information regarding e.g. what is in-stock, which work orders are completed, and similar processes in real-time. Such real-time data increases the visibility of the supply chain, and provides a structuring of the processes such that finding errors or non-value adding activities becomes more efficient. When knowing the location of errors, the potential for improvements increases considerably. Eliminating such errors can increase the efficiency of the manufacturing processes, increase the utilization of both human and machine capacity, which further on can improve the delivery performance and significantly reduce the lead time.

Despite that there are numerous benefits by implementing IoT technology, why should Brunvoll mature towards Industry 4.0? The S-curve from the literature review explains that the delivery performance at Brunvoll will increase when they implement new technology. In the initial phase, the performance improvement will be lower as the technology is new and obscure. It will take some time before the users adapt to the new technology and learn the new system. However, as the experience with the technology grows, the delivery performance will improve rapidly, and Brunvoll will be able to reduce the lead time significantly. Eventually, the technology will age, meaning that the performance will reach a ceiling and the improvements will stop; it is the time for implementing new technology again. The S-curve is a great model for dynamic companies to explain why implementing new technology and maturing towards Industry 4.0 can be a great evolution.

6.2.2 How to implement IoT?

For an ETO company to implement IoT, or increase the use of automation technologies at Brunvoll, it can be sufficient to use the automation pyramid in order to generate an effective integration of the communication between the new technologies and the ERP system. Level 1 comprises the sensor-technology, actuators and hardware which generates the foundation for identifying, capturing, sharing and using critical information flowing through the manufacturing processes at Brunvoll. GS1 standards can beneficially be used as a framework for connecting the physical subjects and components with the digital world within the ERP system. Using the ID Keys can provide great information flow of subjects and components at Brunvoll, generating high degree of supply chain visibility. Barcodes and RFID-tags that are resistant to high temperature, e.g. RFID-tags with ceramic layer can sustain temperatures from

500 to 1000 Celsius, is a must for the subjects and components that are processed at the annealing furnace.

Further on, antennas, scanners, cameras, and so on, can be used to capture the information about the subjects and components. Such capturing of information can be considered efficient in addition to eliminating manual data collection error, such as possibilities of incorrect information when an operator is reporting completed work orders for the previous operator. GS1's AIDC standard can be set up as a framework for encoding the ID Keys on the data carriers (RFID-tags and barcodes). Additionally, the GS1 standard provides a GS1 System that can handle three different data pools, such as EDI, EPCIS and GDSN, to share master, transactional and event data from the ID Keys. This is intended to increase the supply chain visibility and to ensure a competent integration of communication between the different levels of the classic automation pyramid. It can be important to mention that such integration of communication can be beneficial for obtaining a sufficient PMPC system.

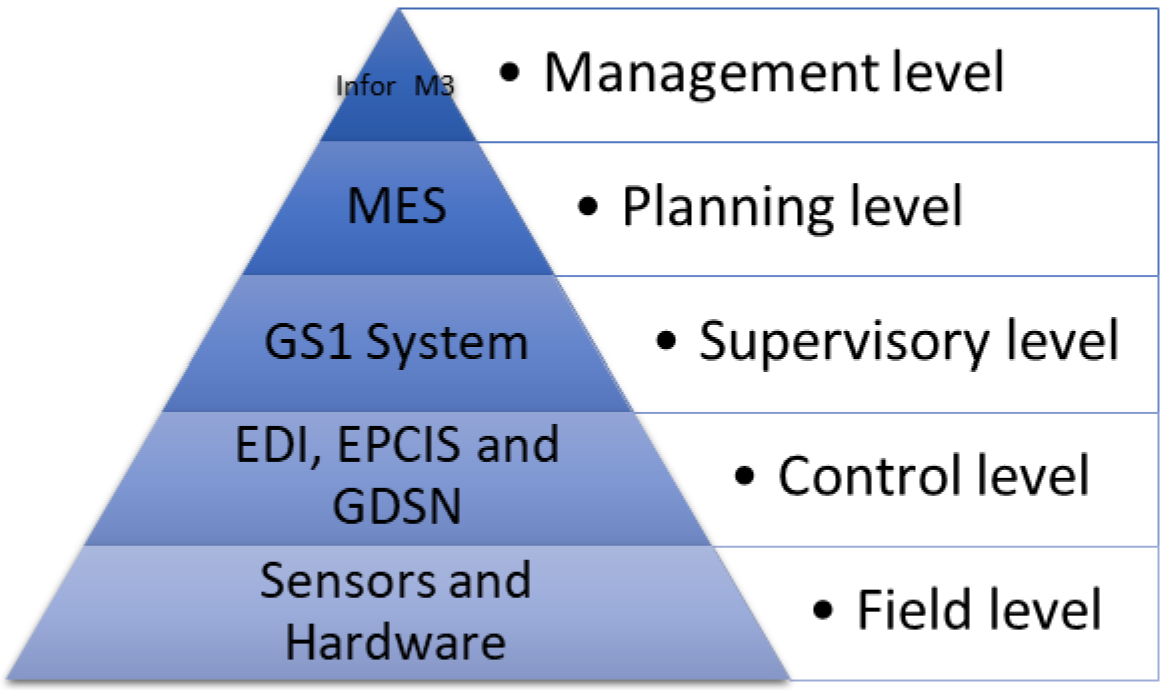


Figure 44: IoT Automation Pyramid

As the sensors and hardware captures information through the value chain, the GS1 System ensures that the relevant data is captured and communicated further in the pyramid. This can be critical for the planning phase and the PMPC system in general. At the planning level, the Master and Production Planners can use the information captured from the field, control and supervisory levels to plan the projects and share information regarding projects and work orders into the ERP system.

6.2.3 Industry 4.0 Measures

It was initially stated that in order to reduce the lead time for complete thruster systems at Brunvoll, it can be necessary to improve the production planning process. Different IoT technology can improve the information flow and therefore increase the visibility of Brunvoll's supply and value chain. Additionally, maturing towards Industry 4.0 can generate a partly or completely automatized production planning process, making it even more efficient than it is today. In the following, different measures regarding the three tiers for implementing IoT technology is presented. These measures are intended to improve the production planning process and thereby improve the delivery performance at Brunvoll.

Case study findings and analysis showed that the processing of gearhouse subjects at AOVF3 tends to start later than planned, contributing to delays from the beginning of the manufacturing process of gearhouse subjects. In addition, the processing at GRA seems to be delayed as well. It was claimed that the reason for delays at the AOVF3 and GRA tiers is because of issues regarding "historical data", such as late deliveries of gearhouse subjects from external subcontractors and waiting for customer to accept the project, poor reporting, and other circumstances, e.g. forgetting to pick up subjects from outside storage, low quality subjects from external contractors, sick leave, complex project schedules, and so on.

Even though case study analysis found that 58 % of the total machining processings at M53 were finished before or within the planned finish date, 42 % were delayed. Discussions concluded that the data should be viewed from a critical perspective as particular factors would have an effect of errors in the data. In order to eliminate or reduce number of faulty data, automatic reporting has been considered. Extending the use of barcodes and RFID-tags could lead to a more automatic way of reporting into the ERP system, preventing influencing factors, such as "historical data", poor reporting and other circumstances to occur. This measure could decrease the occurrence of faulty data in the ERP system, which could provide a greater indication of how many machining processings at M53 actually are delayed.

Automatic reporting could contribute to real-time data, prevent human errors, increase human capacity in addition to generate efficiency within the manufacturing process. The supervisor of surface treatment department could inform that there are several problems regarding reporting in the ERP system, language barriers and reading- and writing difficulties. Therefore, he believed that reporting completed work orders by scanning barcodes could improve influencing factors regarding poor reporting. The production planner mentioned that it should be possible for the operators to scan their ID-card into the system and then scan the work order based on barcodes. Since the work orders are on paper, it should be relatively cheap and effective to include a barcode on it and place cheap scanners by the computers.

Having work orders on paper may seem a little “old-fashioned” and out of date. However, many of the subjects or components that are processed, are big, heavy and difficult to handle. Therefore, placing barcodes on the subjects and components would generate difficulties regarding capturing and scanning of the barcodes. Placing robust RFID-tags that are not vulnerable to heat or rough processing may therefore be a recommendation. Such RFID-tags can be scanned using an antenna, which can capture RFID-signals within a 5-6 meters radius. Passive RFID-tags, RFID technology which do not have batteries, are cheap and quick to install in contribution to active RFID-tags, which are battery driven. Placing such passive RFID-tags on the subjects and components could replace work orders on paper, as the antenna captures the signals from the RFID-tag and export the data into the ERP system automatically. Therefore, when a work order is complete, the operators can scan their ID-cards on the computer and press only one button for completed work orders.

In addition to creating an increased automatic reporting environment internally at Brunvoll with use of barcodes, RFID-tags and scanners, it can be possible to improve the delivery performance of external subcontractors or improve the planning process through the manufacturing network. Referring to the literature review, it can be possible to state that from a supply chain management perspective, integrating the external suppliers with Brunvoll’s system (barcodes and RFID-tags) can help widening the manufacturing network. Coordination and collaboration with external suppliers with extensive use of barcodes and RFID-tags can improve the supply chain visibility and provide real-time-data, making Brunvoll able to make quicker changes in production schedules and plans, and thereby become less vulnerable for late deliveries. Based on this, Brunvoll could get the opportunity to stay ahead of project plans, making it easier to increase the delivery performance and thereby reduce the lead time.

Another measure rather than automatic reporting, is to purchase robots for the surface treatment department and at the GRA tier. This could automatize several of the operations that are processed at the AOVF3 and GRA tiers and reduce the risks regarding human errors. However, based on the product schedule screenshots, it is possible to acknowledge that the surface treatment department and GRA tier processes a high variety of subjects and components in different sizes and measures. This indicates that there would be a need of several robots in order to handle the high variety, which is extremely expensive. It must also be stated that these robots would require a big space of the production layout at Brunvoll, and it would most likely be necessary to expand the manufacturing hall, which also generate high costs. In addition, extending the manufacturing halls, moving equipment, set up the robots, and so on, would be an extremely time-consuming process for Brunvoll. It is also necessary to mention that Brunvoll might not be mature enough - yet - to implement such robotics into their manufacturing process.

7.0 Conclusion

Lead time reduction can be considered a well-known and highly relevant logistical challenge for manufacturers. This thesis was motivated by this challenge, especially within the context of ETO companies which suffer from long lead times and high complexity. Therefore, this case study wanted to investigate the following research problem:

How to reduce the lead time in ETO manufacturing companies within the scope of Industry 4.0 IoT-Technology?

Based on background and previous research, six RQ's were created to support the research problem. Based on the methodology and research design for this case study, the logic during this thesis was to connect the empirical data to the RQ's.

RQ 1: To what extent are projects (complete thruster systems) delayed?

The qualitative and quantitative data collected for RQ 1 provided systematic information regarding planned and actual finish dates for complete projects. The quantitative data gave light to the project life cycle at Brunvoll, which created a greater perspective on the planning process. Further on, the qualitative data included information regarding planned and reported finish dates for 26 complete projects. Based on analysis of this data, only 12 % of the completed projects were reported within or before planned finish date, indicating challenges with Brunvoll's ERP system and the production planning. To achieve a critical perspective of to what extent complete projects are delayed, the difference between confirmed delivery dates and actual finish dates was analysed, providing the statement that only 62 % of the complete projects are delivered on-time. This contradicts with the discussions claiming that Brunvoll has close to 100 % on-time delivery.

RQ2: To what extent do the delay of a component at M53 influence the project delivery time?

RQ 2 revolved around the difference between planned and actual finish dates for processings at M53 in addition to studying to what extent this difference influence on the on-time delivery for complete projects. SQL data analysis did not provide support to the belief that delays or on-time finish at M53 has any significant influence on the delivery performance of complete projects.

RQ3: To what extent do delays at M53 propagate to its upstream and downstream tiers?

RQ 3 studied the planned and actual finish dates for upstream and downstream tiers of M53. In order to define the tiers, a visualization of the production layout at Brunvoll was presented, which further generated a BPMN Diagram of the value stream for gearhouse subjects processed at AOVF3, M53 and GRA, which this thesis is limited to. Study of nine different projects showed the pattern that AOVF3 tends to start later than planned, M53 seems to be able to catch up with lost time at AOVF3, while processing at GRA tends to generate delays in the production process again.

RQ4: Why and to what degree do the delays differ at various locations?

Dependent on case study findings and analysis in addition to qualitative interviews with key informants, RQ 4 intended to find answers to why planned and actual finish dates differ at various locations. It was concluded that three main influencing factors; "historical data"; poor reporting; other circumstances (internal and external); were the reason for delays at the different tiers in the production process. Discussions stated that the data from RQ 1-3 should be studied critically as the three main influencing factors would have significant impact on what is reported in the ERP system or not. Based on this discussion, it was considered interesting to study the applicability of ERP systems within ETO manufacturing companies, leading to RQ 5.

RQ 5: How do the ERP system at Brunvoll support the project manufacturing planning and control (PMPC) process?

Several PMPC requirements of the ERP system were presented and discussed, concluding that Infor M3 seems to meet most of these requirements. However, as an ETO manufacturing company, real-time and automatic reporting can be of great need. This statement further lead to RQ 6 whereas discussions for how to ensure real-time data to be captured were provided. In addition, different measures for how IoT-Technology can provide automatic reporting, such as RFID-tags, barcodes and robotics, were discussed.

RQ6: How can Industry 4.0 concepts be used to reduce the lead time in ETO manufacturing companies?

As a result of the conclusions of RQ 5, RQ 6 discusses how Industry 4.0 concepts can be used to improve the PMPC and thereby reduce the lead time in ETO manufacturing companies, such as Brunvoll. First, the S-curve explains why ETO companies should mature towards IoT in an attempt to convince companies to implement new technology. Then, Industry 4.0 concepts and measures were provided. Based on the level of technological maturity at Brunvoll, it was concluded that removing work orders on paper and implement passive RFID-tags containing work order information would be sufficient. This measure is intended to improve real-time data and automatic reporting, which would eliminate several of the influencing factors stated during the RQ 4 discussion. In addition, this measure could improve the supply chain visibility significantly, making the ETO manufacturing company able to react and adapt quickly to changes in production schedules and plans. The ability to stay ahead of project plans could improve the delivery performance of an ETO company considerably and thereby reduce the lead time significantly.

8.0 List of References

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Appendices

Appendix 1

Sample of some of the SQL data received from the ERP consultant at Brunvoll:

Order no	line no	reg date	conf del date	dispatched	1_Project	1_Elem	1_WO no	1_Plan st date	1_Plan fin date	1_Act st date	1_Act fin date	1
0000097484	100	20170531	20171017	20171024	20671 F	2050	0001176906	20170925	20171010	20170918	20171016	1
0000097485	110	20170531	20171017	20171024	20671 F	2051	0001176907	20170925	20171010	20170918	20171019	1
0000097395	100	20161201	20170807	20170817	21326 A	2050	1171917	20170606	20170623	20170310	20170816	1
0000097395	100	20161201	20170807	20170817	21326 A	2050	1171917	20170606	20170623	20170310	20170816	1
0000097396	100	20161201	20170807	20170817	21326 A	2051	1171918	20170614	20170703	20170310	20170814	1
0000097396	100	20161201	20170807	20170817	21326 A	2051	1171918	20170614	20170703	20170310	20170814	1
0000097299	100	20170510	20170710	20170725	30040	2051	0001175449	20170608	20170620	20170607	20170801	1
0000097410	100	20161214	20170601	20170817	30650 E	2050	1172694	20170330	20170425	20170405	20170519	1
0000097410	100	20161214	20170601	20170817	30650 E	2050	1172694	20170330	20170425	20170405	20170519	1
0000097411	110	20161214	20170601	20170817	30650 E	2051	1170992	20170425	20170512	20170217	20170512	1
0000097415	100	20161214	20170712	20171005	30650 F	2050	0001175130	20170524	20170613	20170601	20170912	1
0000097415	100	20161214	20170712	20171005	30650 F	2050	0001175130	20170524	20170613	20170601	20170912	1
0000097415	100	20161214	20170712	20171005	30650 F	2050	0001175130	20170524	20170613	20170601	20170912	1
0000097415	100	20161214	20170712	20171005	30650 F	2050	0001175130	20170524	20170613	20170601	20170912	1
0000097302	100	20160513	20170830	20170831	30765 D	2050	1165370	20161114	20161125	20161020	20161129	1
0000097442	100	20170613	20171215	20171218	30909	2050	0001178332	20171019	20171218	20171005	20171215	1
0000097442	100	20170613	20171215	20171218	30909	2050	0001178332	20171019	20171218	20171005	20171215	1
0000097341	100	20160901	20170322	20170412	31183 B	2050	1170936	20170208	20170227	20170215	20170310	1
0000097450	100	20170320	20170829	20170901	31356 D	2051	0001175937	20170623	20170705	20170703	20170829	1
0000097282	100	20160921	20170303	20170609	31496	2050	1170235	20170123	20170208	20170124	20170302	1
0000097282	100	20160921	20170303	20170609	31496	2050	1170235	20170123	20170208	20170124	20170302	1
0000097283	100	20160921	20170303	20170609	31496	2051	1170236	20170123	20170208	20170124	20170302	1
0000097283	100	20160921	20170303	20170609	31496	2051	1170236	20170123	20170208	20170124	20170302	1
0000097386	100	20170420	20171013	20171110	31697 A	2050	0001177871	20170908	20170926	20170904	20171009	1
0000097386	100	20170420	20171013	20171110	31697 A	2050	0001177871	20170908	20170926	20170904	20171009	1
0000097406	100	20170328	20171027	20171110	31827 A	2051	0001176900	20170815	20170904	20170821	20171107	1
0000097406	100	20170328	20171027	20171110	31827 A	2051	0001176900	20170815	20170904	20170821	20171107	1
0000097494	100	20170811	20171006	20171103	31835 A	2050	0001177181	20170817	20170905	20170828	20171025	1
0000097280	100	20160629	20170403	20170412	31994 B	2050	1171192	20170220	20170307	20170221	20170327	1
0000097280	100	20160629	20170403	20170412	31994 B	2050	1171192	20170220	20170307	20170221	20170327	1
0000097281	100	20160629	20170502	20170512	31994 C	2050	1172005	20170313	20170328	20170320	20170406	1
0000097296	100	20160629	20170929	20170929	31994 D	2050	0001176504	20170712	20170821	20170705	20170828	1
0000097481	100	20170523	20171215	20171221	31994 E	2050	0001176711	20171107	20171122	20171110	20171214	1

Appendix 2

Interview guide

The interviews were conducted with five key informants of different departments at Brunvoll. The key informants consisted of ERP consultant, supervisor surface treatment department, supervisor machining department, production planner and master planner. The questions asked revolved around the typical work day of each informant, their thoughts regarding the ERP system and its applicability at Brunvoll, the flexibility, delays and findings from the SQL data. Additionally, questions regarding the value chain of the gearhouse component and the project life cycle at Brunvoll were asked.