Master's degree thesis

LOG950 Logistics

Flexibility in ETO manufacturing Planning and Controll in an Industry 4.0 context, and a case study of Brunvoll AS

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Abstract

With increasingly global competition in different dimensions, like cost of production, product quality and technology innovation, the importance of customer demand also increase. Improved manufacturing methods, new technology with faster solutions such as collecting, analyzing and sharing data information through the supply chain. This provides a foundation for improving production planning and control. A consequence is also shorter lifecycles of the individual products, the manufacturing industries constantly need to update and upgrade their products, production plan and control along their supply chain both internally and externally to endure market position and customer satisfaction. The fact that ETO manufacturing environments require flexibility to handle uncertainties especially in a high cost country like Norway where it is hard to compete on high volume and mass production. The ETO part are to a large extent dependent on flexible solutions, all the way through the manufacturing process from the orders is signed until the new product is delivered. The level of flexibility can amplify both customer satisfaction and keep currently or/and give lager market shares.

This master thesis aim to investigate how flexibility, planning and control are managed in an ETO-manufacturer within the context of industry 4.0. This investigation have been carried out in order to identify current situations, challenges and potential improvements in flexibility, planning and control as a case study of Brunvoll AS. The research is sorted out by theoretical and practical information gathered by quantitative and qualitative data collection from literature and Brunvoll.

First, a theoretical identification of flexibility in ETO-manufacturing environment is carried out. The second part of this thesis have been to identify and analyze flexibility, planning and control at Brunvoll. Next, the thesis will look at how measurement of flexibility can improve the current situation. As a third part of the thesis, this will be put in the context of industry 4.0, to further investigate how the different technologies can impact ETO-manufacturing to become more flexible and efficient in information sharing in production, planning and control.

Findings, shows clear evidence of flexibility in many areas especially in human resources and mechanical equipment. But when it comes to planning and control there are areas where flexibility could be increased by the use of technologies, rather than by the use of man hours. Challenges in real-time registration and change orders create bias in planned dates and information sharing across departments, which leads to extra work in form of reorganization and control. Data to support these findings are gathered through interviews with key personnel at Brunvoll, and by data from their M3 ERP system. By gaining access to both historical data and interviews provides strong data to support these findings.

Acknowledgments

This master thesis is the final stage of the degree, Master of Science in Logistics – Supply Chain Management at Molde University College, Norway. This master thesis was originally a cooperation with a former PhD candidate, and a research within the scope of flexibility in ETO-manufacturing, planning and control and a part of the research project at Molde University College, project Manufacturing Networks 4.0. This thesis has been compiled during spring semester 2018.

This thesis would be impossible to carry out without the help and cooperation of these parties. At first, we will sincerely thank our supervisor, Associate Professor, Bjørn Jæger and co-supervisor, Karolis Dungnas at Molde University College. Their help through this master thesis have been crucial to finish this study, their guidance, suggestion and constructive feedback during this process is greatly appreciated. We would also like to thank Brunvoll AS for their openness and willingness to share information and time needed to do this case study research. Finally, we would like to thank everyone that have been of support during this master thesis, the process has been an educational journey.

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1 Introduction

This chapter will address the background and reason for this case study, leading to the research questions, it will also present the case company Brunvoll AS.

1.1 Background

The background for this thesis was a collaboration with a former PhD candidate, where the initiative is to identify how flexibility is managed in ETO-manufacturing planning and control. This case study will be seen in context of the fourth industrial revolution and a part of a project, Manufacturing Network 4.0, which is a research project collaboration between several Norwegian manufacturing companies, some business clusters, Norway's Technical and Natural Science University (NTNU) and Molde University College.

This case study shall also be useful for Brunvoll as a helpful tool to give strategic advantage and better ways of organize and operate further projects. This thesis is a part of the project Manufacturing Network 4.0.

Brunvoll, an ETO manufacturing company, compete to a large extent by being flexible. Where most of the products of ETO manufacturers typically consist of a standard make-to-order (MTO) components (80%), it is the smaller engineering part of 20% that gives most of their competitive power. They face an increased demand from the market for flexibility to adjust for changes *dynamically as the product is being built*. This puts forward a highly demanding situation for the operational production planning and control, since basically plans are deemed to be obsolete at the moment they are defined. Thus, the control element becomes of much higher importance in ETO manufacturing than in other manufacturing strategies. The need for real time feedback is very high. Ideally, a production planner must "plan for the unplanned". I.e. in order to handle changes (change orders) that are bound to come during construction of unique, one-of-a-kind products, one need to do some long-term plans (design) for some flexibility in the manufacturing resources to handle this.

Flexibility is a wide topic handled on all levels of the organization, in the production, and for customers and suppliers. A key point to manage it is, however at the operational level when executing the detailed planning and control. This is because this is the last management stage before the physical operations are started when work orders are released to the shop floor. The dynamic market situation needs closeness to operations.

Karolis Dugnas a previous production planner at Brunvoll and a key informant, characterized much of his job as being "a fireman, running back and forth to the shop floor extinguishing fires erupting from change orders". There are actually two main factors driving the need for flexibility at Brunvoll. One is the mentioned ETO-requirement of frequent change orders during production of new products, the other is related to handling after-sales service. After-sales service is a major part of their turnover, around 30-40 percentage, but both new sales and after-sales service are handled by the same production line.

After-sales service is a key also for new sales since many customers are loyal recurring customers choosing Brunvoll because of their flexibility, not only in construction of new thrusters, but also in their fast response to services. A ship in need for assistance due to thruster or propulsion problems, typically needs service fast to avoid high cost of being out of operation. Since after-sales service is handled by the same production line at the shop floor, and since they are given top priority, it is common to adjust (delay) the production of new products in order to incoming serve after-sales requirement. This further adds to the volatility of requests the operational production planner face.

Previous work done by Wollen (2017) shows that actual operation are, to a large extent, delayed compared to planned operations. E.g. for one machining Centre (M53) it was found that 82 percent of the work orders were delayed (Wollen 2017). A naive conclusion could be to say that the planning must be improved. However, as is evident from the above description of the ETO environment, the inherent volatility caused customer needs in sales and after- sales cannot be planned for in detail. Instead the control part becomes of higher importance. In this regard the advent of industry 4.0 technologies have provided a set of new technologies of which real time event tracking and control is a central part. Central among these technologies are wireless sensors, controllers, 3D printing, digital twins, virtual reality, augmented reality and machine learning.

1.2 Purpose of the study

The purpose of this research is to be able to define flexibility within ETO-manufacturing production planning and control as a measurable value (metric) through a case study of Brunvoll AS. After conversations and meetings with Brunvoll AS, it was stated that this research is of relevance for them, and the objective from Brunvoll, is to analyze the current situation from planning and control with flexibility as the main focus and how this can be of help and potential improvements, further development in context of new technologies and future operations.

In order to complete this case study research, some research questions have been formulated. These questions will help guide the case study in the right direction. For the remaining thesis, when flexibility is mentioned we specifically mean, flexibility in ETO manufacturing planning and control.

The first step in this research will be to define flexibility within ETO manufacturing planning and control based on a literature review, the first research question is as follows:

- *RQ 1: How is flexibility defined within ETO-manufacturing planning and control?*

Based on acquired knowledge on flexibility in ETO manufacturing planning and control, we investigate how Brunvoll define flexibility based on the information collected from Brunvoll.

- *RQ 2: How is flexibility in planning and control defined at Brunvoll AS?*

After flexibility have been defined through theory and how it is managed at Brunvoll, it is interesting to look at different ways of how to measure flexibility to better understand not only the importance of flexibility but add focus on it to increase flexibility in planning and control long-term. Therefore, looking at theory about measuring flexibility and the use of performance measurements in ETO manufacturing planning and control to see if there are benefits of measuring flexibility. The third research question is therefore:

- *RQ 3: To what extent can flexibility in planning and control be measured?*

After reviewing literature about flexibility measurements, the next step will be to look at how flexibility can be improved at Brunvoll with the help of performance measurements. This will provide with ways of measuring flexibility performance and provide Brunvoll with a better understanding of where to improve. In addition, how this will reduce lead-times and making them more robust when it comes to handling change-orders, and unexpected service orders. The fourth research question is:

- *RQ 4: How can flexibility in planning and control be improved at Brunvoll with the help of performance measurements?*

After RQ1 – RQ4 have been answered, this thesis will have defined flexibility in both theory and at Brunvoll. At the same time how performance measurements can be a tool to improve flexibility. Further, the results of the research questions will be the base of discussion in the context of industry 4.0 and how technologies can help improve the way flexibility is managed. Therefore, the fifth research question is:

- *RQ 5: How can industry 4.0 be utilized to improve flexibility?*

Based on all the previous research questions it is now time to look at how Industry 4.0 technologies can be utilized to improve flexibility at Brunvoll. This will potentially provide Brunvoll with knowledge in what technologies that can be implemented to further increase flexibility and become costs efficient. It will be interesting to see what technologies that can help improve flexibility, therefore the last research question is as follows:

- *RQ 6: How can industry 4.0 be utilized to improve flexibility at Brunvoll?*

The objective of this research is to gather insight in how flexibility is defined in theory and how flexibility is in practice. With Brunvoll as the case company, the aim is to chart flexibility and find out if flexibility at Brunvoll can be angled to an advantage. The research is not necessarily a measure to make production better, but rather to determine if they are in some way flexible in terms of production, planning and control and if this can be measured to some degree and possibly used as an advantage that in turn can help to strengthen Brunvoll’s market position.

1.3 The case Company Brunvoll AS

Brunvoll AS is a family owned company, located in Molde, northwest of central Norway. They are an independent manufacturer and supplier of complete thruster solutions in the maritime industry. The products they produce are fully-integrated thrusters complete with drive motors, hydraulic, BruCon control, alarm and monitor systems and also suppliers of propulsion systems. They offer all from standard products to specific systems required from customer. These systems can easily be adjusted according to customer needs. Brunvoll operates locally and all products are manufactured in Molde, while sales occur worldwide.

Two Brothers, Andreas and Anders Brunvoll founded the company in 1912, "Brødr. Brunvoll Motorfabrikk". At that time, the company manufactured low-pressure diesel engines and controllable pitch propellers for fishing vessels. Later, around 1960s, Brunvoll faced challenges in the market, lightweight and high –speed engines came and brunvoll had to change their product line. In respond to the change, Brunvoll introduced tunnel thrusters for purse seiners, improving not only safety but also efficiency in fishing operations. The last milestone have been the agreement signed with "Scana Propulsion ASA" containing all the shares in Scana Propulsion AS which include subsidiaries Scana Volda AS and Scana Mar-El AS who is located in Norway and three other companies located in United States, China and Singapore.

From 1912 - today, Brunvoll AS have become one of the most recognised supplier of thruster systems. According to their homepage, they have delivered some 8000 thrusters to more than 5000 vessels, and still growing. Brunvoll AS, is a well-known brand in the maritime industry, they have secured a strong market position, through constantly upgrading and researching for better and new solutions of their products, Brunvoll AS has untapped potential.

Brunvoll AS, deliver thruster systems and propulsion systems to different types of vessels:

- Cruise
- Fishing & Research
- Merchant
- Offshore

- Navy
- Special Vessels
- Mega Yachts
- High Speed Vessels

Company Vision: *Trusted Worldwide*.

As shown above, Brunvoll AS provides thruster and propulsion systems for many different types of vessels. The system can range from a few hundred components to a few thousand, relative to the type and size of the system. These systems also vary greatly in complexity. Next to thrusters and propulsion systems, Brunvoll AS provides lifelong service and support to their customers. As shown below, the Brunvoll AS value chain consists of two main values; New sales and after-sales service.

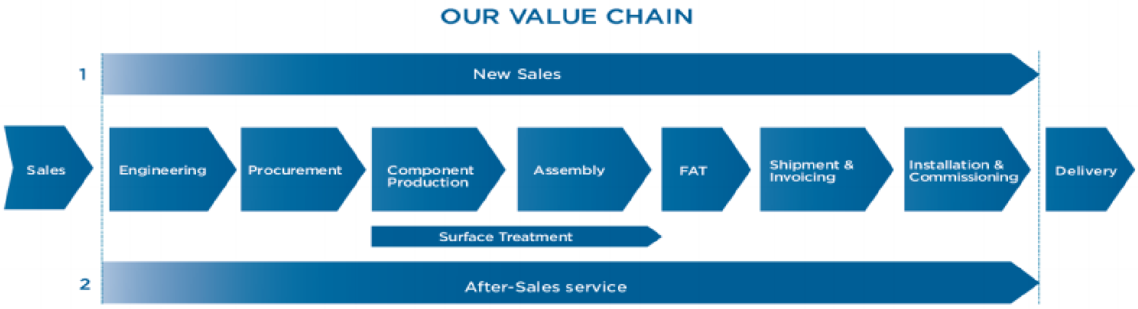

Figure 1 Value chain Brunvoll (Finnøy 2015)

As Figure 1 describes Brunvoll AS value chain, it is clear that they are an Engineer to order (ETO) manufacturer. Right after sales starts, engineering phase begins; the specifications ordered by the customer is in this phase; explained, signed, registered and prepared for procurement. Another factor that indicates that Brunvoll is an ETO manufactures is that approximately 20 percent of their production is specific project that has never been built before. Therefore 20% is the ETO part, while the rest of their production 80% follows standard make to order strategy. Since their main competitive power comes from making unique, one-of-a-kind products that require a close cooperation with their customers and suppliers their manufacturing process needs to be dynamic and highly flexible.

Besides the human resources, Production Planning and Control (PPC) at Brunvoll is mainly supported by the Infor M3 Enterprise resource planning (ERP) system, which is marketed by Infor as a highly adaptable and flexible ERP system with the ability to manage mixed-mode and complex value chains and industry-specific functionality.

1.4 The Thesis structure

The first chapter presented above addresses the background and purpose of the research, which includes the research questions that will form this thesis. Followed, the subsequent chapters is presented:

The next chapter will cover the literature that will help support the evidence gathered in this thesis. The theory will be a contributor to strengthening the findings as well as contributing to a better understanding of the thematic of the assignment. The literature has been raised after the research questions and will be able to anchor the findings from these questions. The third chapter will consist of the methodology approach used in this thesis. This method should act as a framework that will help guide the task in the right direction. The method should be a tool for procuring data and analyzes that can help answer the research questions. In the fourth chapter, the findings of data and analyses will be discussed. The fifth chapter will be the case study discussion. This discussion will contain whether there is any relevant evidence that can be linked to answer the given research questions. If the findings can be of any use or improvement for operations at Brunvoll and their production, planning and control. The sixth chapter, will address all the research questions and provide with a final conclusion. The final chapter will discuss limitations regarding this thesis and at the end give suggestions for further research and studies regarding this research topic.

2 Literature review

In this chapter a literature review will be carried out to put down a literature framework for the thesis, also three research questions will be answered based on theory:

- *RQ 1: How is flexibility defined within ETO-manufacturing planning and control?*
- *RQ 3: To what extent can flexibility in planning and control be measured?*
- *RQ 5: How can industry 4.0 be utilized to improve flexibility?*

2.1 Manufacturing and the requirements for flexibility

This part of the literature review looks at ETO manufacturing, and the challenges that follows, and how planning and control is done in such environments and the importance of being flexible.

2.1.1 Engineer-to-order (ETO) Manufacturing

Engineer-to-order (ETO) production approach is where a company designs and manufactures a product based on very specific customer requirements (Dugnas 2017). In ETO, the product tends to be very complex, and changes often occur during production. For this reason the customer, engage with the ETO Company throughout the entire design and manufacturing processes, to ensure that the specifications meets the requirements.

Table 1 Typical ETO characteristics (Sjøbakk, Thomassen, and Alfnes 2014)

Unit of analysis	Typical characteristics
Products	• Complex • Deep product structure (many components) • Low volume on product level, higher on sub-assembly and component level • Mix of standardized and customized products • High degree of customization – "one of a kind products" • High product variety • Long lead times • Frequent changes (change orders)
Processes	• Business processes divided into three stages: marketing, tendering and contract execution • Temporariness, uniqueness and multifunctional • Focus on flexibility • General purpose equipment • Non-routine work processes • Job shop/projects
Markets	• Uncertainty in demand and product mix • External flexibility needed in handling the uncertainty
Uncertainty and risk	• Three types of risk: Technical risk, time risk and financial risk • Uncertainty in product specifications, process specifications and product mix and volume
Challenges	• Long lead times • Uncertain delivery dates • Handling change orders • Production planning and control • Product quality • Conflicts in manufacturing/marketing schedules • Material waste

Table 1 summarizes typical ETO characteristics. When talking about external flexibility it is natural to think of suppliers, if the suppliers or the agreements made with the suppliers do not emphasize flexibility this will impact the rest of the supply chain. Therefore, the downstream origin of the ETO product tend to spread upstream through the involved supply network. However, flexibility is also a source of competitive advantage in a particular environment ("what the customer sees"). According to Upton (1994) external flexibility is:

"The external requirements may be seen as a source of variability to which the firm must respond. These might include, for example, cyclical aggregate demand for products;

frequent demands for customization or opportunities to gain market share by broadening the product line. Firms that are able to respond to such variability effectively are seen as flexible by the market"

The products are categorized as complex with many components and long lead times. Looking at the processes non- routine work is to be expected and there is a need to focus on flexibility, the focus on flexibility has to be in place to be able to handle uncertainties. It is typical in ETO manufacturing that there are uncertainties in demand and product mix in the markets. For an ETO company there are a lot of risks and uncertainties related to product specification, process specification, product mix and volume. Some of the biggest challenges in ETO manufacturing are handling the uncertainties. With all these uncertainties that comes with operating in an ETO environment, it is discussed to what extent the contemporary information system fit with the special needs of the ETO manufacturing environment. In particular, this goes for the ERP and MES systems which is a key system used in planning and control of the manufacturing process. Planning and control is often considered a challenge in ETO environment, this is a result the uncertainties where it is hard to plan for the unplanned. It might be said that the control factor is something that gets more important as detailed planning is impossible in the ETO-environment. These characteristics strongly relate to the case company of this thesis.

A ETO company is characterized by a high degree of uncertainty, with high fluctuations in, for instance, sales volume and product mix (Bertrand and Muntslag 1993). Further, short term dynamics in form of change orders is common for ETO companies, and the capability to respond to these is often a prerequisite for success (Little et al. 2000).

2.1.2 Enterprise Resource Planning (ERP)

It can be said that ERP systems are the most used enterprise information systems in business today. Every big company in the world is using some kind of ERP system. Enterprise resource planning systems attempt to integrate data processes in organizations by using common data centrally stored in a single database. This database functions as a hub that stores, shares, and circulates data from within the different departments and business functions. ERP systems are one of the most adopted information technology solutions in organizations (Hustad, Haddara, and Kalvenes 2016). If ERP systems are implemented effectively, they provide businesses with many benefits. According to Aslan, Stevenson, and Hendry (2012):

"ERP systems when implemented effectively, can provide business benefits such as real-time data availability, improved visibility, and increased task automation"

However, it is discussed that for Make-To-Order (MTO) and ETO manufacturing companies the capabilities of ERP systems are not a complete fit. Some researchers like Aslan, Stevenson, and Hendry (2012) have done an gap – analysis checking whether there is a substantial gap or misalignment between ERP functionality and MTO requirements. MTO/ETO manufacturers face many of the same challenges when it comes to manufacturing planning and control.

According to Ledford (2015), an ETO ERP system must have 6 features to be able to handle the challenges that ETO manufactures face:

1. Engineering Change Management Capabilities
2. Supplier and Inventory Management
3. Automated Warnings and Alert Systems
4. Continuous Milestone Tracking
5. Tight Integrating with Machines and Applications
6. Integration with All Financial Aspects

ERP companies sell their ERP systems as an integrated solution to handle your way of running business. However, not all features will meet the requirements of your specific way of manufacturing. In theory many researchers suggests that there are a lot of factors, such as company size, location or whether you are a MTO, ETO or Make-To-Stock (MTS) company, that will have an impact on how well the ERP system will work (Aslan, Stevenson, and Hendry 2015).

The misalignment between ERP functionality and MTO requirements reduce the quality of planning and control, and thereby reducing the flexibility potential in manufacturing. If you can't plan or control what is going on at the shop floor it is costly to stay flexible. For a manufacturer to stay flexible a well-functioning planning system need to be in place especially producing in a high cost nation.

2.1.2.1 Manufacturing Execution System

Many manufacturing environments have historically been serviced by paper-based registration and applications made by themselves. These ways of keeping control is not up to speed with the requirements for increased speed, agility, and traceability. The combination of paper and unlinked data silos at the shop floor increases the difficulty of integrating required plant data into a top-level view of operation (ERP-system). It is becoming more and more important to realize the need for real-time manufacturing data.

A manufacturing Execution system (MES) is an information system that use current and accurate data to trigger, guide, verify and report on shop floor activities in real time, from work order release, to manufacturing, delivery and finished goods (ibaset 2014).

MES concentrates on managing the shop-floor operations like handling real time control and operations (Zhong et al. 2013). MES is covering the parts that ERP systems might be lacking in typical MTO/ETO environments. It is the link between the shop floor and the main ERP system. A well-implemented MES system will provide with better control in the physical production area.

2.1.3 Production planning and control

Looking at ETO manufacturing companies production planning and control each customer order is viewed as an individual project, therefore the next natural step will be to look at project management theory, project systems and how planning and control plays a big part.

2.1.3.1 Project management

Business processes is mostly either ongoing processes or repetitive. The data management and project planning process lifecycle spans the life of the project, while the procurement and fulfillment process are often done repeatedly and frequently. A project is in nature impermanent and usually related to large and complex activities. In companies where they make complex products, the project management is the process where they plan and execute the making of a the products. The project management involves the tools needed, and the technique for managing the project. There can be both internal and external projects, internal projects usually benefit the organization since it is not sold to a customer and is therefore concerned primarily with costs. External projects, like building complex one of a kind products for a customer creates both costs and revenues. The project relies on resources and capabilities available, as if building a thruster involves procurement process, production process and supervising the people that execute these processes. The Fulfillment process is also involved in the external project, selling to customer (Pinto 2016).

The project is divided into different phases or stages, it starts with a trigger, this is where the customer comes in with an order, this is where project management begins. The first phase is the Planning phase, here the scope of the project is defined, where the overall sketch of the project drawn, with milestones and deadlines attached. The next phase involved is budgeting. Next, the accounting process calculate and allocate resources that are required for executing the project. This budget needs to be approved by the management. Next phase is the execution phase, where procurement and production are triggered. The accounting processes will under the project keep track of all costs and revenues and also in an external project issue customer invoice. At the end accounting process called settlement is carried out to assign the costs and revenues to the correct parties (Pinto 2016).

2.1.3.2 Project System (PS)

At the beginning of a project, you assign work breakdown structure (WBS) elements, activities and milestones. In addition, you assign milestones to you project. The network activities is providing detailed information of the WBS elements. All the activities are assigned to the top WBS element, and there are no relationships between the activities. This means all the activities will start at the same time, so the next step in a project system will be to assign relationships between activates. The next step in a project system would be to assign milestones to activities to indicate important project stages. After this it is time to release the project, this will release the project for execution. The last phases involves the accounting processes, which are described in the paragraph over (Pinto 2016).

2.1.3.3 Production planning and control ETO- environment

In ETO-environment and the changes that comes with customers demand, companies experience new challenges in production planning and control (PPC). In the ETO-environment it is hard to make long-terms plans. Everyday tasks for planners consists of extinguishing fires, due to the changes in the market where logistical quality features, delivery time and delivery reliability becomes an increasing criteria. A further decisive point is the increasing demand for flexibility with respect to the customer wishes. With these factors playing in, the focus on the control becomes more important, since planning in detail is becoming harder.

In most cases, production planning is addressed manually, even with the use of automated systems. This manual process takes a lot of time and only a few alternatives are considers, since it is completely dependent on the planners expertise (Figueira et al. 2015).

According to Wiendahl and Breithaupt (1996) A production process control approach will contribute to the development of new algorithms and ultimately develop a new architecture for PPC. This will then provide a self-controlling, dynamic process, which can respond quickly to changing environmental conditions.

Looking at theory, increasing the reliability of PPC systems is needed, and the control aspect becomes more and more important with the uncertainties that follows ETO-manufacturing. The requirements for flexibility become increasingly important in PPC, since flexibility is the ability to handle these uncertainties.

2.1.4 Flexibility in ETO manufacturing

To understand flexibility in ETO manufacturing planning and control the logical first step is to do a literature review to define what flexibility is in ETO manufacturing. This will help further research when looking at Brunvoll and how flexibility can be defined there.

2.1.4.1 Defining flexibility in ETO manufacturing

Manufacturing companies faces different challenges in today competitive market: accelerated lead times, global markets and increased competition which are variables increasing uncertainty and variability (Burger et al. 2017). To stay competitive in this market flexibility is a fundamental tool. According to (Burger et al. 2017) manufacturing flexibility is defined as the ability to adapt to changes in the environment of the manufacturing system and it is evident that flexibility is multi-dimensional and a situation specific concept. This definition covers flexibility in the whole, which includes both external and internal factors. To achieve a competitive advantage with manufacturing flexibility it is important to find a proper fit between the competitive environment, strategy, organizational attributes and technology. According to Vokurka and O'Leary-

Kelly (2000) manufacturing flexibility is a multidimensional concept, comprised of several distinct dimensions that can be aggregated in a hierarchical manner.

Flexibility is defined in the dictionary as capable of being bent, susceptible of modification or adaptation and the willingness to yield; pliable. The definition from the dictionary is mirroring all the definitions in theory but the theory have different ways of specify the definition to fit the production environment. Flexibility in the operations management literature is generally perceived as an adaptive response to environmental uncertainty (Gerwin 1993). More specifically, it is a reflection of the ability of a system to change or react with little penalty in time, effort, cost, or performance (Ayers 2010).

To understand what flexibility is in ETO manufacturing its necessary to look at what deviations exists. The main goal with flexibility is to be able to bend if deviations occurs and still be able to deliver on time without there incurring high costs.

Deviations in ETO manufacturing:

- Machine stop
- Absence due to illness
- Change orders
- Fail in real time registration
- Delays in supplier shipments
- Misplacement of goods

The different deviations have an impact on the production and how these deviations are handled is what defines flexibility.

Flexible manufacturing system (FMS) is a system where there is some amount of flexibility that allows the system to react in case of changes, whether predicted or unpredicted. This flexibility is generally considered to fall into two categories:

- Machine flexibility, which is the ability to create different product types or change the order in how processes are operated.
- Routing flexibility, which is the ability of more than one machine to perform the same process or adjust for changes in the capacity or volume.

As said, flexibility have two main categories which are machine flexibility and routing flexibility, but in the manufacturing environment that exist today different distinct dimensions of flexibility exist, these are listed in Table 2.

Table 2 Definitions of flexibility dimensions (Vokurka and O'Leary-Kelly 2000)

Machine	Range of operations that piece of equipment can perform without incurring a major setup
Material Handling	Capabilities of a material handling process to move different parts throughout the manufacturing system
Operations	Number of alternative processes or ways in which a part can be produced within the system
Automation	Extent to which flexibility is housed in the automation (computerization) of manufacturing technologies
Labor	Range of tasks that an operator can perform within the manufacturing system
Process	Number of different parts that can be produced without incurring a major setup
Routing	Number of alternative paths a part can take though the system in order to be completed
Product	Time it takes to add or substitute new parts into the system
New designs	Speed at which products can be designed and introduced into the system
Delivery	Ability of the system to respond to changes in delivery requests
Volume	Range of output levels that a firm can economically produce products
Expansion	Ease at which capacity may be added to the system
Program	Length of time the system can produce without adding new equipment
Production	Range of products the system can produce without adding new equipment
Market	Ability of the manufacturing system to adapt to changes in the market environment

Table 2 shows different dimensions of flexibility and definitions for each dimension. This provides a grained view of what defines flexibility, all these dimensions together is what reflects the flexibility throughout the company. These dimensions will be used as a tool to map flexibility at Brunvoll.

2.1.4.2 Why is flexibility important?

In today´s marked ETO manufacturers needs to be flexible to stay competitive. This is particularly important for ETO-manufactures in Norway since Norway is a high cost country where it is very hard/impossible to compete in the mass production market. Producing complex and unique products often results in high costs throughout the production. Therefore, it is important for ETO manufactures to continuously strive to be innovative in both their way of production, but also following the technological trends. Customers demand shorter lead-times and unique products which reflects the need for companies to be flexible and being able to handle changes quickly at low costs.

According to Kaschel, Manuel Sánchez, and Bernal (2006) flexibility is important for:

"system designer and managers to know the different levels of flexibility and / or determine the amount of flexibility required to achieve a certain level of performance"

As well as it is important for system designers and managers to know the different levels of flexibility it is also beneficial for the planners and engineers. Therefor it is important to start focusing on making a framework for measuring flexibility in manufacturing. Flexibility is there to accommodate changes in the operating environment. Having a flexible manufacturing system the company can use the flexibility as an adaptive response to unpredictable situations (Gupta and Goyal 1989).

2.1.5 Measuring Flexibility

In literature there are some work done when it comes to measuring flexibility. So the following section will provide a literature review on supply chain performance measurement, KPIs as a tool for measuring and finally measuring flexibility in ETO manufacturing planning and control.

2.1.5.1 Supply chain performance measurement

As the markets today is rapidly changing by highly competitive companies, performance measurements systems are challenged. Business today is a lot about competition, and whether you are able to manage in the right direction and stay in front of your competition.

Supply chain performance is perhaps one of the most critical factors in various industries. It is widely discussed whether supply chain performance measurement is fundamental to efficient supply chain management and in recent years, it has been developed frameworks and systems that have been designed to meet this. Supply chains (SCs) are involved in the entire life cycle of a product, from procurement of materials to manufacturing, distribution and eventually customer service and recycling and disposal of the product (Balfaqih et al. 2016).

Business today is not the same as it once was, and changes faster than ever before. The boundaries have been lower in terms of delivery time, product mix, quality and service, which is a response to globalization, the opportunity for outsourcing and information technology (IT). These elements have contributed to a greater motivation to find new ways, new perspectives for leading features. With an increasing drive in these elements, measurement units and matrices are required to record and improve efficiency within supply chain performance (Balfaqih et al. 2016).

Supply chain management is value creation for all involved members, companies, customers and stakeholders. All of these joints integrate through each other, which create mutual value. Everyone is to a degree dependent on each other. In a strategic view of the supply chain, it makes it important that their performance is measured. There are different ways to measure, supply chain performance. Either, you can look at the level of satisfied customers, who might be the ultimate judges when it comes to value creation as the end user, or measured through cost analysis. Evaluating supply chain performance can be a complex affair, one reason for this is that it is a transversal process, that involves several different parties that overlaps with a given logistic and strategic goal. Such an evaluation is extra important in situations where supply chains is considered as a major factor in corporate success (Estampe et al. 2013).

There are many studies that refer to performance evaluation models in corporate framework. The reason and the purpose of such an evaluation is mainly to designate measuring systems that would gather corporate strategy. Many measurement systems like some of the most well-known, such as Balance Scorecard or Excellence Models lack performance. These models aim to measuring independent entities, the problems with these models is that they do not take care of the complexity of value creation between the companies in the chain. In the light of this, other types of models were later created so that it could help analyze all sides of the supply chain. In recent times, performance measurements in the supply chain have also included supply chain operations, global supply chain and efficient consumer response (Estampe et al. 2013).

To sum up, supply chain performance and measurements are to a certain extent influenced by different variables, such variables may be, demand, lead times or for example customer satisfaction. Other things that can affect supply chain performance are management, planning decisions or how the supply chain are designed. According to Dugnas (2017) in practice, as soon as it has been created and constant supply chain performance measurement units, managers must identify critical success factors or key performance indicators (KPIs) that may need improvement.

A difficult factor with setting up KPIs can be to see the relationships that these KPIs have with each other, and how to prioritize it in terms of achievement for each KPI. Priorities of given groups of KPIs have been shown to cause bottlenecks for several companies in their jobs to improve their supply chain management. Solutions to such problems can be to adopt information systems that match the supply chain, that is, the information system that deals with the particular process can provide accurate information about the various parameters that contain specific targets for the given supply chain strategy (Dugnas 2017).

2.1.5.2 Key performance indicators as tool to measure performance (in ETO manufacturing)

According to Lo-Iacono-Ferreira, Capuz-Rizo, and Torregrosa-López (2018). Key performance indicators (KPIs) can be defined as:

"*Key Performance Indicators (KPIs) are indexes used to evaluate the crucial factors related to a defined goal, and the success of the organization in achieving this goal depends on these factors".*

There are many activities ongoing in a production process, whether it is business related tasks or technical activities. The effectiveness of such work can be seen through information from recent and historical production data. The challenge of collecting such data can be to determine exactly what the data means. A solution to such a challenge may be to introduce KPIs. In production, these KPIs can show the operational and mid-term efficiency of the production. At a strategic level, this is a more or less a well-known approach, but when it comes to production management level, this is still a new concept (Jovan, Zorzut, and Znidarsic 2006).

In order to find a suitable KPI, it is important to be able to create a KPI specific to the observed production process, while defining the background for the given KPI. This will allow managers to follow the production process most efficiently. In resent time, there have been introduced a set of general KPIs for production process level. There are five KPIs defined for process-orientated productions: Safety and environment, Production

Efficiency, Production Quality, Production Plan Tracking;, and Employees Issues (Jovan, Zorzut, and Znidarsic 2006).

But in the business world we live in today disruptive innovations are slowly adopting. New research and technologies are constantly introduced and creates new permanent trends in the consumer market. These trends impact the market structure for relevant companies, creating a urge for long-time adaptation. One way to motivate and meet these changes is to update and modify KPIs to assist and reward workers and managers activities. A KPI can help conduct, "what gets measured gets managed." This is something that will overtime help companies motivate workers adopt to new trends. Change in behavior is hard, it is always easy to do what is always been done. By introducing KPIs that have the what get measured gets managed philosophy will over time "force" workers to change to reach new goals (Sheffi 2015) p. 312.

2.1.5.3 Measuring flexibility in ETO manufacturing

According to Salloum and Wiktorsson (2009):

"Performance measurements triggers actions from management and therefore it is of utmost importance that measures are derived from corporate strategies and are integrated vertically and horizontally."

In literature, there are some but not that many examples on how flexibility can be measured or the potential competitive advantage this can give, and how the relationships between the different dimensions of flexibility work together. This has also been sought by both managers and academics. Much of the studies of which measurements of flexibility have been done are by no means generalized and therefore only relevant to the industries in question where the study of the measurements was made (Koste, Malhotra, and Sharma 2004).

As mentioned, more research has been done in measuring flexibility, but not generalized. A study that has been carried out, try to generalize the measurement of flexibility of a manufacturer, where the study is based on six different dimensions of flexibility. Based on the study, there are several types of manufacturer that are investigated. In this saying, there are discoveries that shows different ways of flexibility in the same divisions or business units. Something that may indicate that the degree of flexibility is very individual and completely depends on the situation of the company (Koste, Malhotra, and Sharma 2004).

It is important to be flexible in relation to environmental changes in operations. Flexible manufacturing systems provide companies with the tools to handle unpredictable situation. For a manufacturing system, flexibility can be seen as one of the main objects, and a critical measurement point for manufacturing performance (Gupta and Goyal 1989).

Flexibility, and measurement of flexibility can help manifest that manufacturing can be both cost efficient and customized at the same time. For example, when it is possible to reduce setup time, small batch output can be compared to large-scale manufacturing. This can contribute to changing the competitive strategy, from economies of scale to economies of scope (Gupta and Goyal 1989).

There are different ways to classify flexibility, one way can be to look at flexibility in the short term or in the long-term perspective. Another way to classify flexibility is to focus on the physical sides, such as the ability of the system to adapt or overcome changes that may occur in the environment. The capability for potential flexibility to cope with unpredictable changes. Another way to evaluate flexibility is to look at the financial consequences in terms of how the system manages to adjust changes. For example, there would be a reduction in production due to machine breakdowns or demand fluctuations, which can results in losses. These examples of financial loss can be used to measure flexibility. Another way of looking at the economic consequences, is for example, equipment flexibility, the number of different types of equipment is a way of measure flexibility, but at the same time it is important to look at the cost of having these tools or to acquire new / more tools (Gupta and Goyal 1989).

Another thing that may be important to consider is that you should not only look at the total operation of work but also measure against the parts in the operation. An example of this may be if you look at machine flexibility, here you have to look at setup-time, next to the bit of the process where the machine produces the product, and loading of operation onto the machines as an additional factor. All these details are part of machine flexibility measurement. This will provide a more accurate estimate of the production rate (Gupta and Goyal 1989).

With such a varied range of flexibility and definitions of flexibility, it can be concluded that flexibility is not an independent concept. There must be added a form of production aspect, whether it is product, production volume or quality. Other factors that play a role when it comes to measuring flexibility is time and cost. A smart way of defining and measuring flexibility may be to first determine the type of flexibility that is similar to a given production strategy for then to modify the production system thereafter.

2.2 Revolutions and technology

In this section the Industrial revolutions will be brought to light. Then IoT and CPS will be represented as two important technologies for the fourth industrial revolution.

2.2.1 Industry 4.0 aka the 4th revolution

The manufacturing industry has gone through three revolutions from 1783 – today. The first started the transformation from manual to mechanical manufacturing. The second revolution was the start of electric-powered mass production based on labor (assembly line). The third revolution provided us with the electronics and information technology that we are using to this day. However, today it is discussed that we are entering a new revolution, the fourth industrial revolution. This is already taking place in the industry today, based on sensor technology, interconnectivity and data analysis that allow mass customization, integration of value chains and greater efficiency.

Table 3 Industrial revolutions (Davis 2015)

	Time periods	Technologies and capabilities
First	1783-mid 19th century	Water- and steam-powered mechanical manufacturing
Second	Late 19th century - 1970s	Electric-powered mass production based on the division of labor (assembly line)
Third	1970s – today	Electronics and information technology drives new levels of automation of complex tasks
Fourth	Today -	Sensor technology, interconnectivity and data analysis allow mass customization, integration of value chains and greater efficiency.

Table 3 show the characteristics of each revolution. The three first revolutions have provided the world with tools and technologies to increase efficiency. However, the speed at which the technology and customer demands change so rapidly it is time to accept a fourth revolution. The expected revolution has started a lot of projects around the world including the Manufacturing Networks 4.0 project this thesis is contributing to. In Germany, they have started an initiative called industrie 4.0. However, Europe is not the only region to see the huge potential of digital manufacturing. United states have established a National Network for Manufacturing Innovation, and companies in Asia are also taking a part of the innovative way of manufacturing. In Asia, they are doing research towards smart factory for industry 4.0. The smart factory aims to increase efficiency and flexibility in manufacturing because the requirements of end consumers have had a shift towards highly customized products in small batches (Wang et al. 2016). Wang et al. (2016) defines the smart factory as:

"The smart factory is a manufacturing cyber-physical system that integrates physical objects such as machines, conveyers, and products with information systems such as MES and ERP to implement flexible and agile production."

Even though the different scopes and definitions vary slightly, they all have in common the use of digital technology to improve efficiency and flexibility in manufacturing. The term Industry 4.0 is the term used for the fourth industrial revolution, which is defined as a new level of organization control over the entire value chain of the life cycle of products; it is geared towards increasingly individualized customer requirements (Vaidya, Ambad, and Bhosle 2018). In this thesis, Internet of things is seen as one of the key components in industry 4.0, that can be a major driver to make the fourth industrial revolution flourish.

The European Parliamentary research service (ERPS) has described a number of new and innovative technological developments that industry 4.0 depend upon (Davis 2015):

- *"The application of* ***information and communication technology (ICT)*** *to digitize information and integrate systems at all stages of product creation and use (including logistics and supply), both inside companies and across company boundaries.*
- ***Cyber-physical systems*** *that use ICTs to monitor and control physical processes and systems. These may involve embedded sensors, intelligent robots that can*

*configure themselves to suit the immediate product to be created, or **additive manufacturing** (3D printing) devices.*

- ***Simulation**, modeling and virtualization in the design of products and establishment of manufacturing processes.*
- *Collection of vast quantities of **data**, and their analysis and exploitation, either immediately on the factory floor, or through **big data** analysis and **cloud computing.***
- *Greater ICT-based support for human workers, including robots, **augmented reality** and **intelligent tools**."*

These innovative technologies are a set of technologies that can help provide an understanding of what industry 4.0 consist of. However, these technological developments do not give an insight in how to solve the issues that the manufacturing industry is facing today. Therefore, more relevant technological developments specific to the research problems of this thesis will be presented. One of the main technologies for this thesis will be Internet of things (IoT).

2.2.2 Internet of Things (IoT)

The Auto-Id Lab at MIT was founded in 1999 with Kevin Ashton as one of the co-founders. He is a pioneer in RFID technology and saw the potential of huge amounts of data that could be collected using auto-id technology. Kevin Ashton is known as the person to coin out the term Internet of Things (IoT) in 1999. According to Sundmaeker et al. (2010) it can be defined as such:

"The term "Auto-ID" refers to any broad class of identification technologies used in industry to automate, reduce errors, and increase efficiency. These technologies include bar codes, smart cards, sensors, voice recognition, and biometrics. But since 2003 the Auto-ID technology on the main stage has been Radio Frequency Identification (RFID)."

Early literature on Internet of things defined IoT just as an extension of Radio Frequency identification. However, IoT points out a vision of the machines of the future, in the twenty-first century they actually sense and respond (Sundmaeker et al. 2010). Internet of Things if looked at just by its name is quite simple. The "Internet", and then you have the "Thing" part, the "Thing" part is defined as object of the physical world or the information world (ITU-T.Y.2060 2012). IoT is simply just the interconnection via internet of computing devices embedded in everyday object, enabling them to send and receive data. Looking at the potential benefits of the topic it becomes clear that it has huge disruptive potential.

It is clear that the term Internet of Things have a central role in the industry 4.0 vision. In addition, that it has developed a lot in the recent years. In EY (2016) a report on IoT they describe the Internet of Things as:

"The Internet of Things (IoT) describes the connection of devices- any devices – to the internet using embedded software and sensors to communicate, collect and exchange data with one another."

Gartner (2017) defines IoT as:

"The Internet of Things (IoT) is the network of physical objects that contain embedded technologies to communicate and sense or interact with their internal states or the external environment."

To bring IoT closer to Industry 4.0 the ITU-T.Y.2060 (2012) states that:

"The IoT is expected to greatly integrate leading technologies, such as technologies related to advanced machine-to-machine communication, autonomic networking, data mining and decision-making, security and privacy protection and cloud computing, with technologies for advanced sensing and actuation."

By looking at the different definitions of IoT, it is clear to see that it is all about connecting physical objects and virtual objects to the internet of computed devices. When bringing IoT into the vision of Industry 4.0 it is an enabler for interconnectivity between the physical world and the virtual world, and can be seen as a backbone for Industry 4.0. This will connect all concepts and technologies that will help reach the visions and goals of Industry 4.0.

2.2.3 Cyber physical systems (CPS)

Another important concept of Industry 4.0 is Cyber physical systems (CPS). Monostori (2014) defines CPS as:

"Cyber-Physical systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet."

The key element of CPS is the interaction between the physical and the cyber. It is not enough to understand them separately, it is necessary to understand their interaction (Monostori et al. 2016). Based on the definition on CPS it becomes quite clear that CPS and IoT are strongly reliant on each other. IoT facilitator for CPS as it connects the physical world with the virtual world. Then CPS can be viewed as the system that handles the information flow collected through IoT making both dependent on each other.

2.2.4 Identification standards GS1

Business today is getting more and more globalized, and manufacturing companies are more and more connected and dependent to each other. Therefore common standards on identifying products can bring together full visualization of supply chains. Unless a company's supply chain is completely vertical, they usually consist of companies with different standards on how to identify products; and how they structure and share information. GS1 is a non-profit organization that develop and maintain global standards used in logistics and supply chain management to ensure efficient flow of goods and full supply chain visibility. In a world of growing data, GS1 say that:

"Standards help single out what really matters. They provide a common language to identify, capture and share supply chain data- ensuring important information is accessible, accurate and easy to understand."

The concept of GS1 standards is divided into 4 categories:

- Identify – Include standards that define unique identification codes
- Capture – capturing the identification through bar code, RFID etc.

- Share – Sharing the data between applications and trading partners
- Use – Combine different GS1 standards to streamline business processes such as traceability

Looking at GS1 standards and how they are meant to uniquely identify things in the physical world, it has the potential to be a huge benefactor for IoT and CPS, and help realize industry 4.0.

The term Industry 4.0 defines as a new level of organization and control over the entire value chain and the life cycle of products, it is geared towards increasingly individualized product identities.

3 Methodology

The research approach for this thesis will be a qualitative research based on literature review, interviews with key personnel at Brunvoll and data provided by the M3 ERP system. In answering the giving research questions, we will use different qualitative methods, which will be described further in this chapter. The first section will describe the case study research method, after going through the case study methodology we will outline the research design for this thesis and how data is collected. At the end of this chapter, we will discuss the validity and reliability of the research.

3.1 Choice of research

According to Yin (2018) there are three types of research case studies, there is explanatory case study, descriptive case study and exploratory case study. When the task is to choose the right research method or approach for an investigation or study, there are some conditions to take in consideration which is, how the research questions are formed, how the researcher control actual behavior events, and the degree of focus on modern events opposed to entirely historical events. These conditions can be related to five social science research methods: experiments, surveys, analysis, histories and case studies.
A common way of categorize the research questions is to form them as: who, where, how and why questions. The question can be either explanatory or exploratory in nature. The "what" questions are more likely to be exploratory, these types of questions justifiable rational for conducting an exploratory study, the goal here is to develop relevant hypotheses and propositions for further investigations. Any of the five research methods can be used in an exploratory study. The "how" and "why" questions are more explanatory in nature and these types of questions are more likely to lead to the use of a case study, history or experiment as a preferred research method.

This thesis where initiated to be a cooperation with a former PhD candidate and a project collaboration with Molde University College, under these circumstances the research method was early on given to be a single case study research. There is only one company in the loop of investigation, which is Brunvoll AS. The foundation of this research method is also supported in the following theory about research methods. To answer the topic of this thesis it has been developed research questions which eventually will give knowledge about the topic of this thesis. The prepared questions are both exploratory and explanatory. The first part of the questioner will be exploratory in nature, where the meaning is to gather knowledge of what and why phenomenon. The part where earlier literature is used is more explanatory, where the aim is to explore and explain the relationship between different aspects. There is also another explanatory part of this research and that is “how” the evidence can be looked at in context of industry 4.0.

3.2 Case study research

According to Yin (2014) case study as a research method is a commonly method used in many situations. A case study has the purpose to contribute to our knowledge of individual, group, organizational, social, political and other related phenomena. Doing a case study give the researcher the opportunity to focus a “case” and retain a general and a real-world perspective, in the same way of observing a real life cycles, organizational processes, different behavior patterns etc. Going for a case study you want to understand something real in depth, but to understand something in depth it require important contextual conditions, which means that you need true solid background information, data collection that can verify your findings.
A two folded definition from Yin (2014) of a case study:

(1) *“A Case study is an empirical inquiry that investigate a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. (Yin 2014)*
(2) *“The case study inquiry copes with the technically distinctive situations in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis”. (Yin 2014)*

The twofold definition shows in what way the case study approach of research includes an overall method, covering the logic of design, techniques on how to collect data and ways to analyze data.

3.3 Research design

According to Yin (2014) A research design is a part of defining the pieces of analysis and possible case that is to be studied. The design is the logic that will link the data to be collected, conclusion to be drawn, up to the initial questions of the study. A research design can be looked at as a “Blueprint” for the research to be done. A plan that will guide the process of data collection, analyzing this data and interpreting observations. Four problems that is dealt with under research:

- *What questions to study?*
- *What data are relevant?*
- *What data to collect?*
- *How to analyze the results?*

Research design, can be looked at as a strategic design or a plan to work after, it is a framework for the research. A research design is a tool that can helpfully guide the researcher in the right direction to answer the research question and avoid a situation where data collection or evidence does not correlate the questions. Therefore, it is important that this plan or design is strong enough to make sure that the investigator have the right activity assortment so he or she does not depart from the originally purpose of the research. The research questions will be the foundation of the research design, and the design will be the tool to help answering the questions.

3.3.1 Unit of analysis

Rowley (2002) claims that analyzing case study evidence is not that easy and needs to be carefully structured. In most cases a case study database will hold a multitude of sources and evidence, all of this data is to be categorized and examine than organized to assess whether the evidence support the study/research or not. For analysis, the preferred strategy is to use the propositions that encapsulate the goals of the study, and which formed the data collection. The researcher goes through evidence seeking any corroboration of the initial propositions, and then record the relevant findings and makes up a judgement. The findings can rather be sustain or not.

The topic for this master thesis was conducted for several reasons and factors; the interest of a case study at Brunvoll, was initiated to be a part of a bigger research and a cooperation with a former PhD candidate. The scope of this research project is within flexibility in ETO manufacturing planning and control in the context of industry 4.0. Together with this, the personal interest of us as authors of this master thesis. Another factor of interest for this research is the interest from the case study company Brunvoll. Due to the problem statement that is to be solved and discussion with relevant parties involved in this study it was resolute that the analysis of the case study evidence would be of the internal process at Brunvoll, and from this in the context of industry 4.0. This thesis is considered as both explanatory and exploratory and the research has been conducted within the manufacturing environment between the different departments at Brunvoll.

3.3.2 Data Collection

The process that in the end will give empirical evidence and analysis that can answer the given research questions and expectantly give a correct output for the research problem is the collection of data. The sources of information used for data collection in this paper are further described in the next section.

3.3.2.1 Sources of data

When the step is to gather data, the primary way of collecting is through either a qualitative or a quantitative approach. This depends on how the data is described. The qualitative approach are usually described in words. When you do a quantitative approach the data collection is usually described by numbers. These two approaches are separated in the way the data is presented and in a research setting; the direction to take, depends on how the investigators research design looks like. When the approach is clear and data sampling starts, the sources that provide data can be divided into primary and secondary data sources. The primary sources represent the data collected directly from the representative aim of the research, the secondary sources are sources that already exist and will give value for the specific research (Yin 2014).

The Table 4 below show the primary and secondary data sources where qualitative and quantitative data that is a part of validate and answer the given research questions in this paper. The data collection is also divided in internal and external sources, where the internal data is collected from sources at Brunvoll and other data from external sources.

Table 4 Data sources

Data collection	Internal	External
Primary	• Depth Interviews with selected managers in different departments at Brunvoll. • Observations – Walkthrough around the building. • SQL from ERP-system, M3	
Secondary	• Strategic documents	• Previous master and PhD- papers. • Journal Articles • Websites

3.3.2.1.1 Key informants

Table 5 Key informants at Brunvoll

Key informants role at Brunvoll (department)
1. Purchase Department
2. Business Consultant ERP – M3
3. Production Planner
4. Surface Treatment Department
5. Machining Department
6. Assembly Department
7. Former Project planner at Brunvoll.

<u>Data collection objectives</u>

In Table 5 key informants at Brunvoll are represented, they provide this paper with information that eventually will help answer the research questions. The information will give an understanding of the situation at Brunvoll and map the different processes dynamics. The information should be able to give answers regarding flexibility at Brunvoll. The information will also contribute and give insight and help in developing data collection methods and analysis with the given samples of both, quantitative and qualitative data. The key informants will also be a help to validate the results by information and feedbacks.

3.3.3 Research Model

The data collection and research is divided into phases, these phases will review how the data is collected and the data collection source and what the data is for. These phases are the framework that will contribute to answer the research question in this paper. These phases are represented below.

Phase 1.

In this phase we will have an overall go-through with personnel at Brunvoll. Discuss with key personnel on how to go forward in the process, in this phase we will gather information that will lead to the right tools and preparations for outlining the right framework for the research. Data collection: Meeting / walkthrough around Brunvoll. (Qualitative research)

Phase 2.

In this phase, we will gather information that will provide us knowledge about flexibility and tools that can help us map and define how flexibility is managed at Brunvoll. Data collection: Interviews with personnel at Brunvoll, Observations. This phase should be able to answer the questions raised in this thesis (Qualitative research)

Phase 3

In this phase we will collect data that will contribute and support the answers in the previous phase. This data will help support the findings from phase 2, and be able to answer questions of this thesis. Data collection: SQL from M3 ERP System. (Quantitative data)

3.3.4 Generalization, Validity and reliability of study

For other researcher to regard this paper of research as knowledge that can be adopted into the knowledge base of a field study, it is important to demonstrate these three issues and make sure that they are fully considered. The generalization of the case study, which supports the theoretical part of the research, generalization can only be executed if the case study design has been informed by theory and by this be added as a part of established theory. This will mean that if the case study shall be a part of earlier research and recognized theory this has to be reflected in the research if the paper is to be generalized. The generalization is not statistical but analytical, this means that the developed theory used in this research paper is used as a template to compare the empirical results and analysis of the study. If you are to claim generalization there has to be two or more cases or evidence that support theory (Rowley 2002).

According to Rowley (2002), a way of testing and establish the quality of the research is to go through these four steps:

1. *Construct validity – Establishing correct operational measures for the concept being studied.*
2. *Internal validity – Only for explanatory or causal studies, and not for descriptive or exploratory studies. The test is to establish a causal relationship whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships.*
3. *External validity – Establishing the domain to which a study's findings can be generalized. Generalization is based on replication logic as discussed above.*
4. *Reliability – Demonstrating that the operations of a study – such as the data collection produced can be repeated with the same results.*

The validation of this case study research are represented in Table 6.

Table 6 Checking case study design

Tests	Case study tactic	Phase of research in which tactic occurs
Construct Validity	In this case study the collection of data is collected through key personnel at Brunvoll, through meeting, depth interviews and observation on sight. There is also acquired quantitative data by ERP, M3-system that supports findings from the other data collection.	Data collection (Qualitative and quantitative) Phase 1 and 2.
Internal Validity	Through collection of data and comparison there is findings that can verify the relationship between the process dynamics	Data analysis from SQL up against Interviews and observations.
External Validity	Findings in this thesis could be considered as generalizable as they can be compared to characteristics of theoretical statements about flexibility and ETO-manufacturing.	Data collection and literature review.
Reliability	The methodology and approach of data collection in this thesis can reflect the reliability of this research. The qualitative method, the interviews and observation done can be hard to replicate as the investigators may see or look at the aspect differently or situations that may not be able to repeat in the same way as in this research. Therefore, the evidence/findings in this thesis is not strong enough to say that it is 100% reliable.	Data collection, analysis and observations

To be able to validate the construct of this thesis there has been collected multiple sources of evidence, this evidence are collected from interviews with personnel at Brunvoll, observations and SQL from M3 ERP system. Interviews and observation is a qualitative approach that is compared to the quantitative data gathered from the SQL. To be able to validate this thesis externally, there has to be evidence that shows some degree of generalization. Findings in this thesis could be considered as generalizable as they can be compared to characteristics of theoretical statements about flexibility and ETO-manufacturing. Findings in this research shows pattern or evidence of conditions that lead to other conditions, which can be seen as internal validation, since this thesis is mostly exploratory there is parts of the thesis that is explanatory and evidence that support internal validation. To establish how reliable this case study research is, it is important to see if the research evidence or findings can repeat itself, if the findings and conclusion could be the same if the research is done multiple times.

The methodology and approach of data collection in this thesis can reflect the reliability of this research. The qualitative method, the interviews and observation done can be hard to replicate as the investigators may see or look at the aspect differently or situations that may not be able to repeat in the same way as in this research. Therefore, the biggest concern in this thesis is the approach of data collection, not the quantitative data, but the qualitative data. To be able to repeat the questioner or the observations and situations the same way another time could be difficult, therefor it may be difficult to verify the reliability in this case study research.

4 Case study findings and analysis

In this chapter, an analysis of the interviews and data collected from the ERP system will be presented in the context of research questions:

- *RQ 4: How can flexibility in planning and control be improved at Brunvoll with the help of performance measurements?*
- *RQ 2: How is flexibility in planning and control defined at Brunvoll AS?*

4.1 Flexibility planning and control at Brunvoll

This chapter will define how flexibility is at Brunvoll. Interviews and analysis of data will help define flexibility through Brunvoll´s supply chain. Looking at Vokurka and O'Leary-Kelly (2000) work on definitions of flexibility dimensions will help map down how Brunvoll manages flexibility today.

4.1.1 Current situation at Brunvoll

To understand how flexibility works at Brunvoll it is necessary to look at the whole value chain of their products, from the customer order decupling point to finished product.

The first step in Brunvoll`s value chain is sales; this is where the first contact with the customer takes place, also called the customer decupling point. As stated earlier in the thesis the production at Brunvoll is 80 percent make to order and 20 percent Engineer to order, these 20 percent effects the whole supply chain making it an ETO manufacturing environment. After the sale is made, the engineering phase takes place where they draw up the necessary drawing and programs needed to start production. The production planners and the floor managers are involved in this process as well. The reason for all these departments to communicate this process is to figure out how much they can produce in-house, and how much to outsource / purchase. Before the production plan is released, the planners plan the production in the M3 ERP system.

All the planned work orders and operations is scheduled in the work order schedule in the M3 ERP system. Figure 2 show the work order schedule for one machine. This work order can be viewed by both planners and the person working on the specific machine. This type of work order schedule is provided to all departments to inform them of the agenda of each work station from day to day operations. The workers on each workstation can choose what order to start on, by examining the work order schedule and chose from the priority of each component. As long as the component have the same priority and this is of highest priority they can start production based on their expertise.

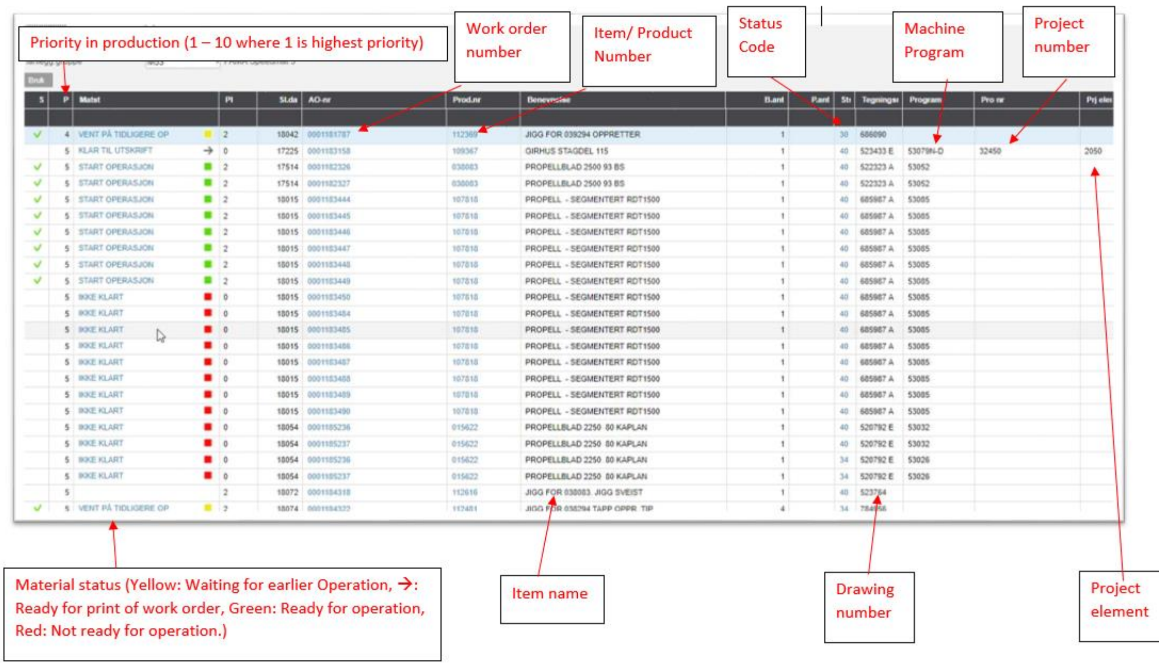

Figure 2 The Work Order Schedule in M3 ERP system

4.1.1.1 Machine flexibility

Brunvoll a highly modern machine park with specialized tools to handle specific production needs. Their machines have the ability to handle multiple products, which reflects their huge product mix. After acquiring information about flexibility at Brunvoll, it is clear that their machine park is quite flexible; the different machines have the flexibility to handle large variance of complex and unique products.

Table 7 Different types of machines at Brunvoll

Machine	Machine Type	Description
M50, M52 and M55	Palette machine	Medium sized with the ability to turn, rout and drill.
M53	Milling machine	The biggest machine
M59	Lathe Machine	Very big machine with the same abilities as M50, M52 and M55
M45, M47 and M51	Milling machine	Small machine
M49, M54, M56, M57, M58, M61	Lathe machine	Small machine
M60	Grinding machine	Machine that sands down metal material
M61	Milling machine but also a Pallet machine	

Information about the different machines at Brunvoll is listed in Table 7. The machines have different levels of flexibility.

The palette machine is capable of rigging up a certain amount of components that que up for production, and it consist of a vast variation of tools. This is a machine that is flexible in the manner that it can carry out many different operations without there incurring major setup time. These machines often work at night, making them able to increase or decrease capacity depending on the demand. The capability of being able to run these machines without any workers on spot is very beneficial when producing in a high cost nation.

The Lathe machines carries out similar tasks of the Palette Machines, but these machines require a worker to be there during production. This machine do not have the capability to que up articles like the Palette machine does. Every time a new component is put in a machine, a setup time occur. This is where a worker place the rig and the new component in the machine before the production starts.

The Milling machines are machines that handle components with the need of milling, this is the process of routing down parts of the components to make them fit the specific project products. These machines can easily handle changes without big changes, these are flexible machines when it comes to new products and change orders.

Grinding machine is where they grind down the cast iron for the propellers, this machine have not been doing so well and they are dependent on a worker grinding the propellers. This is something that Brunvoll is working to change since it is not an attractive profession.

4.1.1.2 Routing Flexibility

At Brunvoll, many articles have at least one alternative route, but bigger components that are more complex only have the standard route and no alternative. To further explain how the routing works at Brunvoll, a map was created based on data from the ERP M3 system, here three different components were picked out and mapped down to provide an overview of how the routing is planned at Brunvoll.

The routing of components is often decided on the floor by managers, if problems occur unplanned or they see the need for moving components from one machine to another their allowed to do so. As said in some interviews the process of routing production was not always entered into the M3 ERP system, but rather just done based on the knowledge of workers and phone communication. To best explain the routing of the three randomly picked components, three different models where created. In Table 8 three products with corresponding names are presented.

Table 8 Component ID and Name

Component ID	Name
112446	Aksel mellom Ø100 L1900
102060	Lagerforing Propellaksel 80
107295	Rotorpart 2 RDT 1000

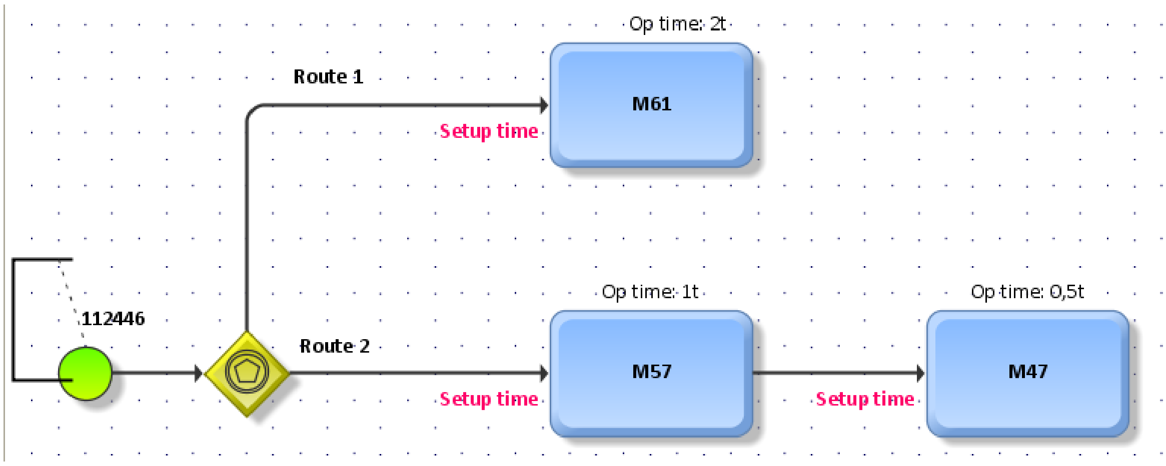

Figure 3 Routing component 1

Figure 3 show how "Aksel mellom" is routed in the system, it has two possible routs available. Route 1 is to M61 with an operating time of 2 hours for this component. Before the machine can start its process, a worker have to put the component into the rig and ready for the machine, this can be quite time consuming. This is referred to as setup time, is can take all from 20 minutes for more standard products up to 1 hour on more advanced products. If route one is not available then route 2 is the only existing alternative for this component. If a component have to go through route 2 it has to go through two machines. This will give less operation time, but the set up time will be doubled.

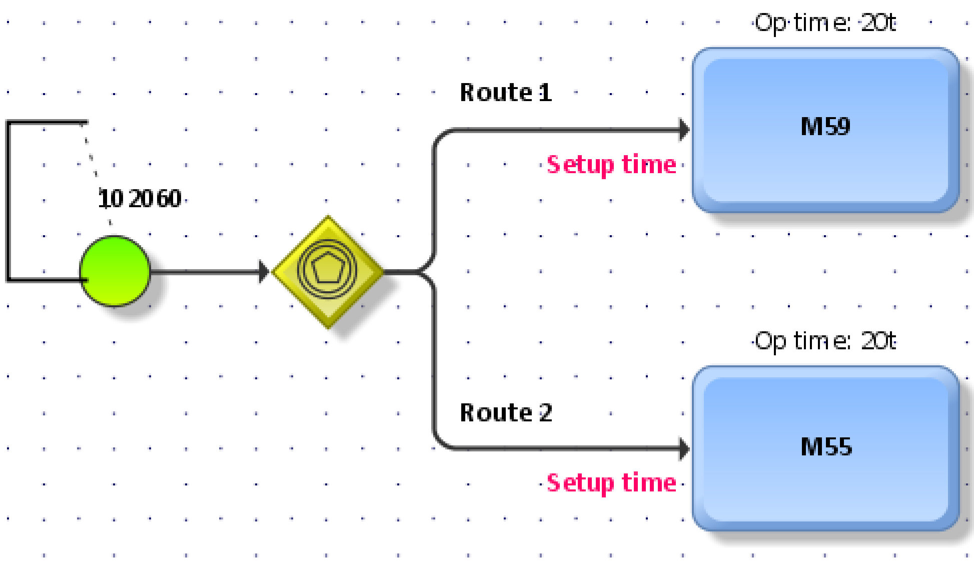

Figure 4 Routing component 2

Figure 4 show the routing for component "Lagerforing propellaksel 80", here, route 1 has an operation time for 20 hours and the same operation time is set for route 2. In this case there are no difference in time used in either routes, but the planners with the help of the M3 ERP systems figured out that it is best for the rest of production to run it through what is set as route 1, this might be because some other components in production can only be produced in M55.

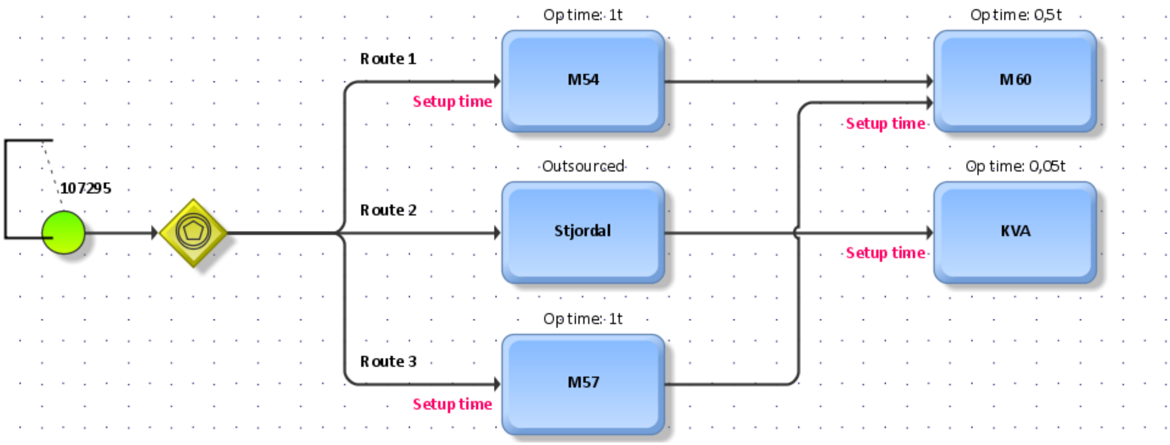

Figure 5 Routing component 3

The last Routing component shown in Figure 5 is quite different from the two others, this component have three different available routes. One of the routes is outsourcing, which is something Brunvoll tries to avoid, since they are so focused on quality. Route 1 is inhouse production with operation time of 1 hour in the first machine and operation time 0,5 hours in the second machine. Route 2 is outsourcing the production to "Stjordal". The interesting part of route 2 is when the complete component comes back to Brunvoll it has to go through a quality control phase before it is put back into the production, this again reflects that Brunvoll emphasize production inhouse.

These models provide an insight in how routing is handled at Brunvoll, but this is just a few products. As mentioned earlier bigger and more complex components does not necessarily have any alternative routes, duo to the size and complexity of the component. A few products have three alternative routes, but then one of the routes is outsourcing. According to planners they always try to have at least one alternative route. It becomes quite clear that Brunvoll lacks routing flexibility, because there is only one alternative route in most products. This means if there are any deviations making them change route this will affect the rest of the production on the agenda.

4.1.1.3 Workforce (labor) flexibility

The way Brunvoll is operating today, the demand for knowledge workers are high. Currently, the machining department is trying to increase the knowledge range of their workforce. The goal is to have at least three workers that can operate each machine, this is specific to the machining department. To this date, this is not the case; some machines still miss some operators to reach this goal. As seen in Figure 6, M40 and M61 only have one fully trained operator each, this is not up to standards when talking about flexibility. However, in interviews with the manager at the machining department at Brunvoll, it is clear that they were in the middle of trying to fix this problem since it caused them issues in earlier situations. One example here was that an operator that had the sole responsibility for one of the machines got sick; this caused a lot of problem in time-spent training a new operator, these kinds of issues can cause delays in finished product, and increased cost in training and production delays.

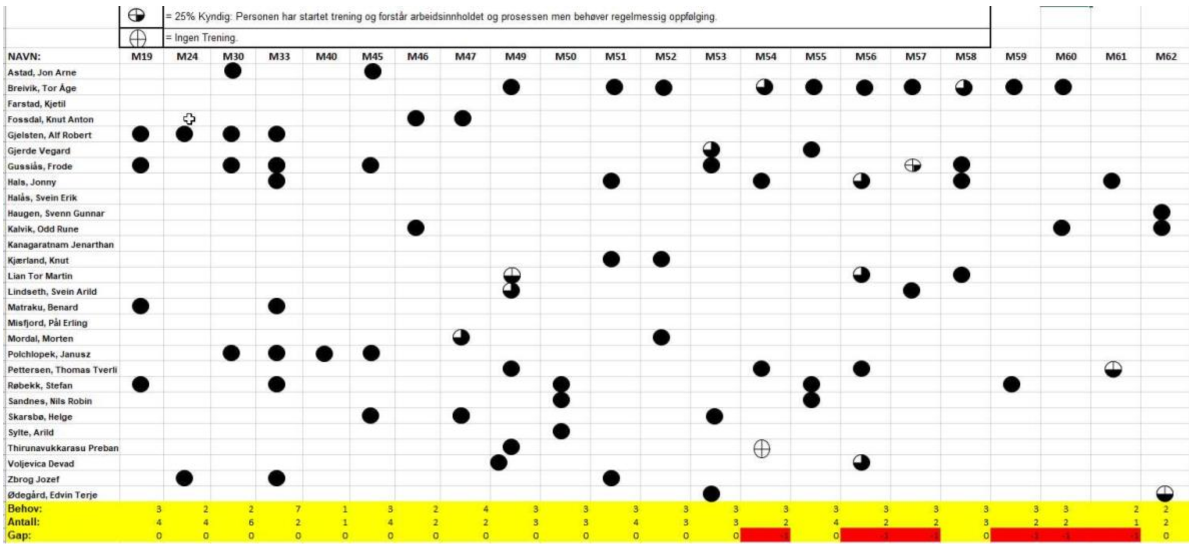

Figure 6 Workforce flexibility, competence labor

As the situation is at Brunvoll today, they are very dependent on their skilled and experienced workforce. The workforce flexibility is what keeps them flexible, it can still be improved. The workforce at Brunvoll seems to be proud of their jobs, and their knowledge in the area that Brunvoll operates in is good. After interviews we saw a clear pattern that to catch up lost time they put in a lot of overtime work and recently introduced shift work to handle the increase in production.

4.1.1.4 Material handling flexibility

Brunvoll have kept up with technologies and been able to change their way of producing according with the changes in the market. Back in the days production where more driven by workers rather than machines, they did not have automated machines to do the job, instead they had workers specialized on a specific job. Over time, technologies changes and made it easier to produce at a higher speed to reach new demanded lead-time requirements from customers. In the past years, Brunvoll have invested in large equipment such as big computerized robot machines that do the big jobs like machining, welding etc. to both increase quality and to be able to deliver to customer demand. They still depend on workforce to a high degree, but with increased automation they have increased capacity the need for a large workforce reduces. Therefore, over time, Brunvoll have increased material handling flexibility by investing in equipment that gives them the opportunity to follow the market demand by reducing lead-time. This give them the ability to handle more projects and still provide customers with high quality products.

4.1.1.5 Automation flexibility

As mentioned earlier, Brunvoll have machines and robot technologies that do several jobs regarding production, like handling steel, welding, machining and quality control, some of these machines requires workers to be there during operation, and some only need workers to set them up. The atomization of manufacturing technologies at Brunvoll provide them with the capability to increase efficiency in production. Their machines have provided them with the ability to handle complex components, and produce them at a high quality. However, the operations are not completely automated, they still need to monitor the machines while running. The automation of manufacturing technologies at Brunvoll brings a lot of their flexibility in that they have good capacity in their machines. But in handling changes and unexpected service orders the workforce play a big part.

4.1.1.6 Process flexibility

Brunvoll as an ETO-manufacturer have many standardized operations in production but can come over new types of products and components that do not exist in their system. The size and shape of an component can vary from standard tunnel thrusters to huge constructs like the retractable azimuth thrusters. The products that already exist in their system are efficient and they do not require major setup time, but when new products are introduced to the system the setup time are longer due to working with the unknown. The machines have the capability to be modified to handle changes in either existing products or when new products enter the system. Brunvoll`s machine park is specialized to handle the complex products that their customers require. This is a sign of a flexible machine park, but for new products, the reprogramming is a timely affair. Other examples of process flexibility at Brunvoll is if some new products require another set of tools in the machine, they have the ability to make new tools or order these to equip the machines with necessary tools to handle different operations. This is something that requires time, which again increases setup times. So for the MTO products Brunvoll is very process flexible, but new products require more setup time which also this will affect the MTO products in their production.

4.1.1.7 Product flexibility

Product flexibility at Brunvoll is mostly when new products or change orders occur. When new products enter the system this is a timely process, but once a workorder is released it goes through as a normal workorder. When introducing new parts into the system change orders occur much more often. It is obvious that when new parts enter the system things take more time. This is because it requires time for the workers to adopt to the new parts, but also the engineering and planning process becomes more advanced, in the way that they have to do everything from scratch. The fact that Brunvoll is creating their own rigs to set up their components in the machine is a sign that they are ready to handle new parts inhouse, and that they don't need to wait for suppliers to deliver custom made rigs. This a sign that Brunvoll are flexible when it comes to adding new part into the system.

At Brunvoll change orders often occur, in the M3 ERP system when they are working on completely new products the components are produced simultaneously as the changes are made. This is seen in the date where some components have been changed hundreds of times during its production time. Provided by Key personnel at Brunvoll was the dates of received change order from customer to the change order was handled, this is presented in the graph in Figure 7. It is visually shown the time spent handling of each change order, where change orders with 0 days spent means that change orders is handled within the same day. This dataset represents change orders between 19.02.2018 and 19.03.2018.

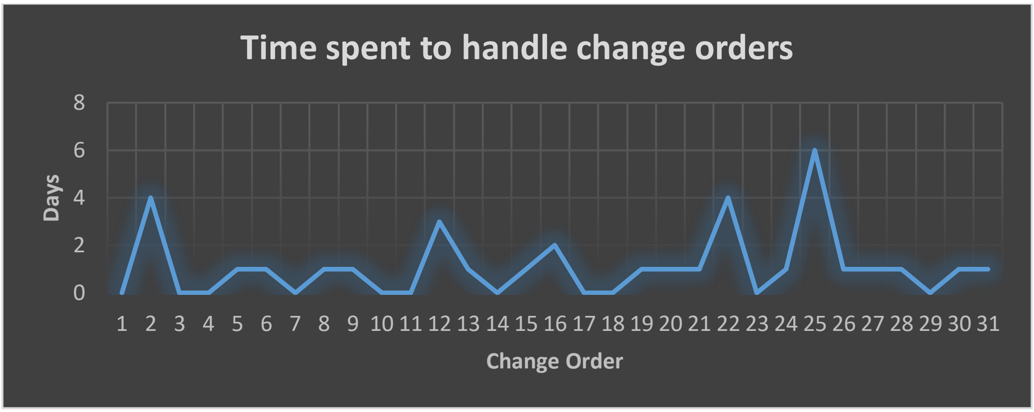

Figure 7 Change orders and corresponding days to handle change orders

Further Table 9 provide statistics considering change orders. These statistics show that they handle change orders within a day on average, which is really good. Looking at the different change orders some took up to 6 days to handle, based on information from the interviews they had a rule of thumb to handle change orders within 3 days.

Table 9 Descritpive statistics on responsiveness of change orders

Descriptive statistics on change orders	
Mean	1,096774194
Minimum	0
Maximum	6

4.1.1.8 New design flexibility

This has been briefly mentioned in “process flexibility” and “product flexibility” according to the manager from purchasing department, they usually have no problem adjusting to new design, if a customer want something new or modifications of products they already have in their system, they normally don’t have any problems adjusting to these. The process of new products entering the system takes longer then products that already exist. But These products are run as ongoing projects so that components are created while the design are made, from data provided by Brunvoll it is clear to see that new projects with new designs often get re-planned many times during its life cycle. Therefore, Brunvoll is flexible in new design. Also, they are always working on innovative and prototype products when they have capacity, this helps them stay competitive in the market.

Table 10 Statistics on times re-planed new products

Descriptive statistics on times re-planned new products	
Mean	5,863945578
Standard Error	1,324178255
Minimum	0
Maximum	280
Count	588

Table 10 shows statistics on times that new products have been re-planned. There are some components that have not been re-planned one single time and one that have been re-planned 280 times. After talking to the ERP consultant at Brunvoll there where a reason for this, as mentioned earlier, completely new products or research and development products are released into production and the engineering is a simultaneous process, which means that engineering changes will occur after the project is released into production.

4.1.1.9 Delivery flexibility

Customer service is a priority at Brunvoll, if the customer wants the delivery later than planned or if they need it before they do whatever they can to make this happen. Since the products that they make are large and complex, the way of transport can be difficult to change, also the scheduled time of shipment. However, Brunvoll will try to meet customers demand and deliver. But if customers want the production pushed forward, this is at the expense of the customer. Through interview with manager at surface treatment department, he could tell that in many cases the customer wants their product later than planned. This can create problems for Brunvoll in storage and other planned deliveries. As head of surface treatment department stated:

"the service we give our customer is very important so we need to be flexible to meet the customers demand and make them satisfied"

But the problem that is of most importance when it comes to changes in delivery is that this is not registered in the M3 ERP system. This makes it hard to create performance indicators in form of delivery flexibility. The planned delivery times put against the actual delivery date does not provide reliable data.

4.1.1.10 Volume flexibility

As an ETO- manufacturer Brunvoll deliver after customer demand and the output level strongly relate to the workforce flexibility. When the demand rises and the volume of production increases it is important to have enough workers since this is where Brunvoll's flexibility lies. Also the supplier relationships and agreements are a huge deal when talking about volume flexibility. If the suppliers are not able to deliver, Brunvoll can´t deliver. Volume flexibility is not were Brunvoll needs the most flexibility, there will be a limit in their production area to how much they can produce.

4.1.1.11 Expansion flexibility

Other than adding workforce or the fact that Brunvoll have a competent workforce, it is not much Brunvoll can do to add capacity to their system. This is also something that is hard to change in form of expansion of production site. The reason for this is that their production site is located so close to the airport that they are not allowed to make certain changes. However, they are in the process of expanding their production site a bit west. New technologies that make production easier and faster is something that is a hot topic at this moment. Brunvoll`s situation today is not reflecting that they have a ease to increase capacity in their existing system. But with future technologies they will have more possibilities to increase capacity, with the help of better control and planning.

4.1.1.12 Program flexibility

Brunvoll's machines have advanced programs with the tools to handle all their standard components. But the when new products enter the system they are required some times to add new tools, rigs and equipment to start production, most of the time their system have the required equipment to produce. When it comes to program flexibility Brunvoll is quite strong. As mentioned in machine flexibility, they have palette machines which can put components in queues and the machine will handle the changes; these machine can run at nighttime with no workers at the production site.

4.1.1.13 Production Flexibility

The machines they have are equipped with sets of different tools that do several different operations. They can make different components in the same machines, but an operator need to start the event (start the right program), take the finished component out and put in a new one, some machines have the ability to handle more components than others. However, in case of completely new products entering the production plan, it is possible to add tools to handle these products. Adding tools is something that will reflect on how long lead-time the production cycle of the product will have, ordering tools or making them in-house can take time. The flexibility is not in the range of products, but in the machine, that makes the products (machine flexibility). With that said, their production flexibility is quite strong in that they have a huge product mix that their system can handle as the situation is today.

4.1.1.14 Market flexibility

Brunvoll, is one of three manufacturer in their market segment; they have a strong position and a good reputation. For them to survive in the market they have to be able to follow the changes in the market. After interviewing several managers in different departments, they all stated that lead-time for delivering products had been reduced by half. This means that not only Brunvoll has to adapt to the changes but also their suppliers, this shows itself to be quite a challenge. The understanding after multiple interviews, inhouse production at Brunvoll have been able to meet this market change, but they are struggling some with the supplier side. The reason for this, reflects back to their core value to use local suppliers to the degree this is possible. Companies in the maritime industry have had huge cutdowns the last few years due to the low oil price. This issue is a hot topic at Brunvoll at this time. The suppliers are not able to meet the requirements from Brunvoll when it comes to lead-time issues. To handle these factors Brunvoll is making good deals with the suppliers, like for some products that Brunvoll know that they need they make deals with the suppliers that they make and store extra parts with a guarantee that Brunvoll will buy these parts. So, for Brunvoll it is important to make strong buyer-supplier relationships; especially for long lead-time and critical components.

4.1.2 The flexibility through Brunvoll´s supply chain

After going through (Vokurka and O'Leary-Kelly 2000) work on definitions of flexibility dimensions compared and put together with data collected at Brunvoll, there is something in every dimension worth mentioning, but some dimension stands out. To be able to clarify and identify flexibility at Brunvoll we will narrow it down to the flexibility dimensions that are most relevant for this thesis.

From analysis through data, gathered at Brunvoll, three dimensions fit Brunvoll the best, and reflect how they manage flexibility in their production planning and control. The dimensions that stands out is machine flexibility, labor (workforce) flexibility and delivery flexibility. All the different dimensions of flexibility impact each other in some way. The analysis clearly shows that these dimensions depend on each other. Brunvoll depends on a workforce that can operate the machines so they can deliver the right amount in the right condition at the right time to their customers. Data gathered from the SQL and M3 ERP system and additionally the interviews, show significant evidence that Brunvoll is most flexible in workforce. Their highly competent workers have the skills to work different stations within their own department, and also across departments. To try to identify flexibility, it is important to consider every department and view all aspect within production to see all resources interacting with each other. Brunvoll is a supplier of complex products and this requires a lot of competence in both employees and machines/equipment.

4.2 M3 ERP systems compatibility with ETO manufacturing

Working with data provided by Brunvoll and the interviews it seems like there is a mismatch with the manufacturing environment and the M3 ERP system.

4.2.1 The gap between ERP system and the ETO production

Key informant from production planning department described his average workday as:

"As production planner my job is to control and make sure that every operation in day to day business goes as planned. Around 80 percent of my day consists of running back and forth fixing information in the system with what is happening on the shop floor"

Through data provided by SQL and M3 ERP-system and analysis of this data there is a clear pattern that new products are almost, never completed according to plan. Still Brunvoll manages to deliver products on time to customers, stated by key personnel at Brunvoll. As mentioned earlier in ETO manufacturing, there are many uncertainties that can influence the production. Going through and compare findings from SQL and interviews, the time-gap showed in the SQL has several reasons for it delays in the planned schedule. It appears that there is not just internally deviations that makes delays in planned production but also externally deviations that make delays in production. Through looking at the M3 ERP data, it shows no direct system that register what type of deviation that makes the delay, at the same time some places there is registered finish and delivered products, but the product misses a part or material. This can be difficult for the next department on the floor or/and time consuming for the planners to further plan or to fix these errors.

After doing analyzing data from Brunvoll, it shows that there are variations like absence due to illness, service orders that gets priority, lack of tools, customers that re schedule their delivery date are some deviations that is not registered in the M3 ERP system. What is mentioned again and again is the fact that it is not registered in the M3 ERP system when a customer want to wait a week before control the products or if they just don’t need the product yet. This have a huge impact on data collected in the ERP system giving a lot of incorrect data.

Table 11 Data Problems at Brunvoll

Issue	Cause of problem	Results
Delivery Date	• Customers change their inspection date • Customers don’t want the product on planned delivery date	• Incorrect data about delivery date etc.
Real Time registration	• Manual registration on each workstation • Wrong registration of products put in stock	• Provide the system with wrong data about components completion dates. • Provide planners with wrong data, might result in overproduction or under production.

Table 11 presents some of the most common issues that occur at Brunvoll. According to the planners, a lot of the work of the production planner is to figure out if the registration of components in the ERP system is correct. Data in the ERP and SQL queries provided us with some information that between, 70-80 percent off all new components entering production is started late and finished late. Talking to the managers in the different departments, the understanding of why becomes clear. Every day they have meeting to decide which components on the work order schedule that is of most importance. In a perfect world this should have been decided by the planners and the ERP system, already here there are signs that there might be a mismatch between the ERP system and the ETO environment. Below some data from the M3 ERP system will be presented to provide some ground for further discussion on the potential misfit of the manufacturing environment and the M3 ERP system.

Figure 8 Project planned vs Acc. Finished

Figure 8 is a representation of data from the M3 ERP system showing that only 12 percent of projects are finished on time.

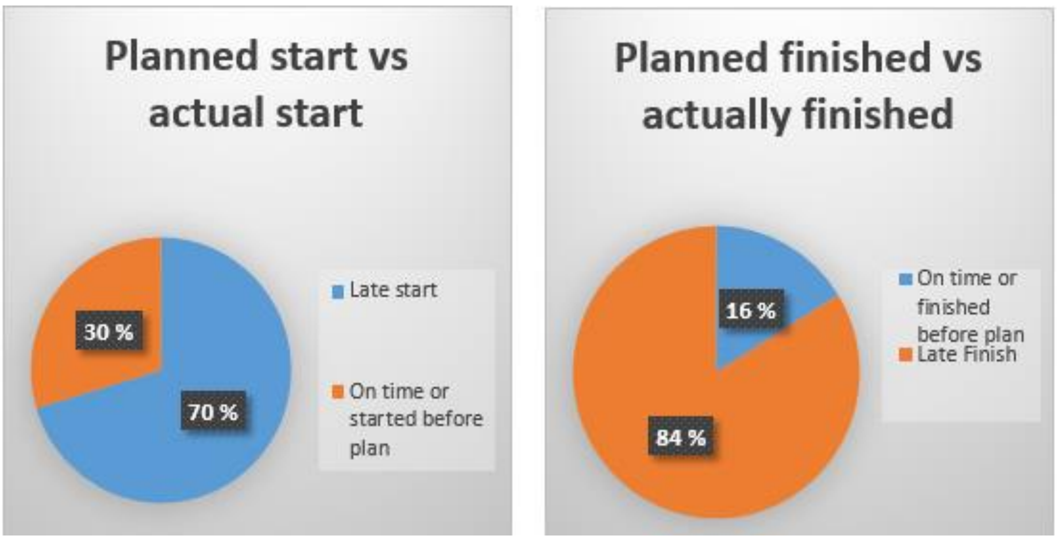

Figure 9 All new products

Figure 9 represent all new products in a time period from 1985 – today. The data shows the planned date vs actual date. As the figure show, 70 percent of all components are started late and 30 percent started on time or before plan. Also only 16 percent of components are finished on time.

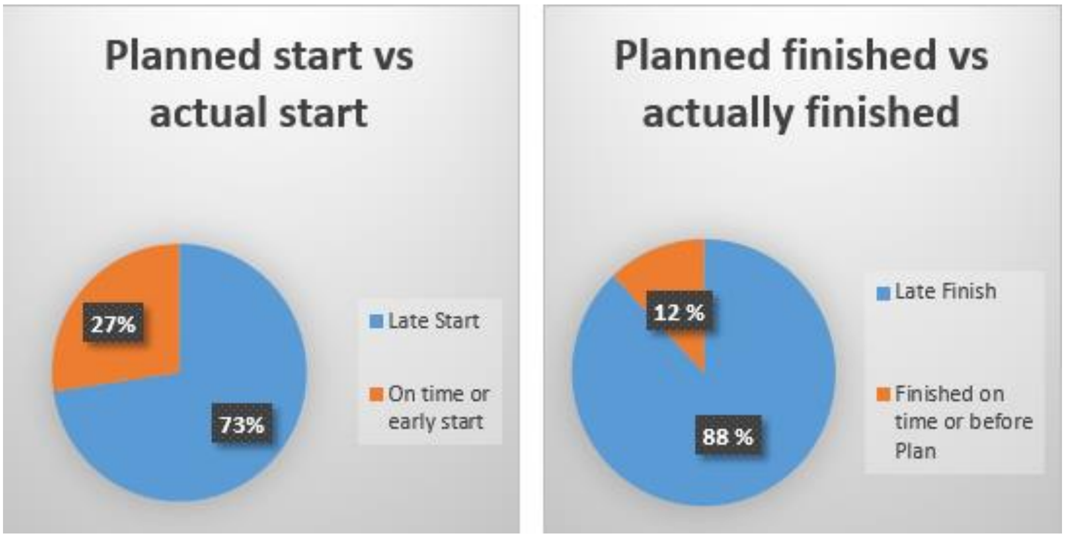

Figure 10 All new products re-planned

Figure 10 represents all new products in the same period, but as a sample where only re-planned components where selected. As seen, there is a 3 percent increase in how many components are started late in this sample. And 4 percent increase in components finished late.

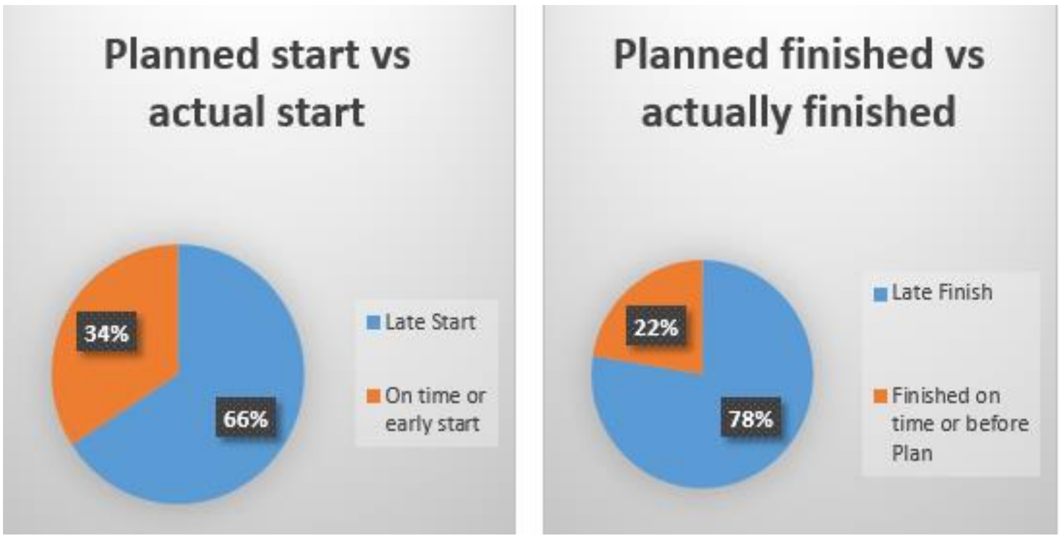

Figure 11 All new products not re-planned

Figure 11 represents all new products in the same period, but as a sample where only components that have not been re-planned is represented. Here we can see the opposite effect from the re-planned components, where it is a 4 percent decrease in late starts. And the late finishes have decreased by 6 percent.

The differentiation on the three different samples where as expected where there would be a little deviation between products being re-planned and the once that where not. But the fact that they are never done after the plan is something to look further into.

4.3 Measuring Flexibility at the case company Brunvoll

In this chapter, the topic of measuring flexibility at the case company will be presented based on the earlier work done by the PhD candidate Karolis Dugnas.

On the background of findings from RQ2, definition of flexibility at Brunvoll, this part of the study will be to investigate RQ3: How to measure flexibility, and how flexibility can be measured at the case company Brunvoll. This is a topic that has also been investigated by former PhD candidate Karolis Dugnas and the use of KPIs when measuring flexibility, or supply chain performance in ETO manufacturing companies.

4.3.1 Flexibility as a «KPI»

The working paper from Karolis Dugnas brings up the topic of measuring flexibility on an operational level, and he made some analysis of which performance indicators that potentially would work at Brunvoll with the systems they use today, and with what the future brings in the context of Industry 4.0.

Table 12 Key performance indicators for operational planning and control in the Industry 4.0 context (Dugnas 2017)

Emerging strategic requirements for operations and supply chains	Corresponding issues regarding planning / control at the operational level at the case firm. Qualitative interviews	Corresponding KPIs for operational planning and control. Qualitative interviews	Feasibility (in terms of automatic reports) tested by SQL queries
From capacity to capability: Flexibility	a) Rapid introduction of new products in the existing logistics setup b) > 1 alternative routes through the manufacturing resources c) Follow-up of new products after their release into production d) Operational responsiveness to deviations/disturbances	a) Setup time new products (Kaestle et al., 2017; Soldatos et al., 2016; Wang et al., 2016) b) N/A, acceptable utilization level achieved, large investments needed for further improvements c) Error rate new products (Kaestle et al., 2017; Soldatos et al., 2016; Wang et al., 2016) d) Time between deviation/disturbance and reconfiguration (Bauer et al., 2015; Kaestle et al., 2017)	a) Yes b) N/A c) Yes d) No

In Table 12 some potential flexibility measures at Brunvoll is presented. These measures where tested by Karolis Dugnas by access to the M3 ERP system, SQL queries and interviews at Brunvoll. Next the once feasible will be presented with corresponding descriptions in Table 13. These findings will be used to further explore the possibilities of measuring flexibility at Brunvoll especially in the dimension of machine flexibility.

Table 13 Description of key performance indicators proposed in the case study (Dugnas 2017)

Key-performance indicator	Description	Effect on improvement of planning and control, estimated by the author and based on the case study results
Setup time new products	Time it takes to set-up all the logistics parameters, associated drawings, tools, and machining programs for a new product in order to get it ready for release into production. The target value should be smaller than a lead-time for raw materials delivery from supplier.	Short set-up times can increase supply chain responsiveness and makes planning and control run faster and error-free in changing supply chain environment.
Error rate new products	Amount of new products in a given interval of time which are delayed and deviating from the planning schedule due to wrong set-up after their release for production	This indicator can evaluate the set-up quality of new products as well, as discover reasons for delay. Improvement of set-up before release, ensuring high degree of effective and efficient operations for new products.
Time between deviation/disturbance and reconfiguration	Mean time between deviation / disturbance of planned activities and reconfiguration of the system making it ready for re-execution	Short reconfiguration times can alleviate negative effect of changes in the system early and before accumulation of consequences to a unacceptable degree. Positive for supply chain responsiveness.

4.3.2 Measuring flexibility planning and control at Brunvoll

Based on interviews, walkthrough at Brunvoll and literature review, the chosen approach to figure out ways to measure flexibility at Brunvoll; have been to narrow it down to some areas which would help reduce lead-time without reducing the flexibility. The decided dimensions of flexibility that this section will try to make some estimated measures are: Machine flexibility where new design flexibility will play a key role, and its interaction with flexibility performance parameters. Next, workforce flexibility will be looked at, since this is important for Brunvoll’s complex production situation as it is today. This will be presented with the intention to increase workforce flexibility and by doing so reducing costs of workhours.

Measuring performance of a manufacturer can, according to the theory, be done in different ways, whether it is at a strategic level or at an operational level. In a real situation company, KPIs are indicator that are used to measure performance, but in this thesis, we have chosen to call them Flexibility Performance Indicators (FPIs), with the goal “what gets measured gets managed”.

4.3.2.1 Machine Flexibility

For Brunvoll, based on findings and interviews, it seems like machine flexibility is a dimensions worth looking into when measuring flexibility. When looking at machine flexibility there are several ways to measure. Considering previous literature and research, it is important to look the whole, not only the operation time of the machine. When it comes to lead-time reduction theory states that one of the most time consuming issues are queue times, this is also one of the pressing issues at Brunvoll now. However, there is no way of hiding the setup time. As discovered through interviews with key personnel and data from the M3 ERP system there is a clear pattern that around 80 percent of components are late finished and late started. This might be a sign of the machines not being flexible enough to handle unknown changes. Therefore, it would be beneficial to look at setup-time of new products. Which brings in the flexibility dimension new design, which means how fast a new product or new design can be introduced to the system. Based on earlier work from Karolis Dugnas and interviews with key personnel at Brunvoll, some FPIs for measuring machine flexibility are created:

- *Setup time new products*
- *Error rate new products*

These FPIs are the work of Dugnas Karolis, and are two measurements that are applicable at Brunvoll. The description and effects of these are presented in Table 13.

4.3.2.2 Delivery flexibility

In delivery flexibility it is about how the system responds and manages changes in delivery, this is all from changes in product specifications to changes in delivery date. As discovered through interviews at Brunvoll, planned delivery date vs actual delivery date in the system might not always be correct. This can relate to changes from customers in agreed upon delivery dates. As shown in the results from the M3 ERP data in Figure 8 that

83 percent of project are finished late. This data is not completely reliable since their ERP system does not have parameters for changes in delivery dates. Therefore, for the specific situation at Brunvoll, instead of formulating FPIs, the most beneficial thing to do is create parameters for their M3 ERP system. This will provide them with more reliable data, and by doing so it will be easier for planners to handle all the projects in production in day to day planning. To register in the M3 ERP system changes in delivery they should add parameters such as:

- *Change in planned delivery, with corresponding reason*

By doing so many benefits will help them with reducing storage costs of finished products, and open up room for changing production plans to get the more critical components through production. This will help reduce costs in form of overtime since projects that might be running late according to the planned date needs to be rushed, even if the delivery dates might have been changed outside the M3 ERP system.

4.3.2.3 Workforce Flexibility

Workforce flexibility is an important factor at Brunvoll, it became clear after the first meeting at Brunvoll that the knowledge of the workers are one of the main areas of flexibility. Since Brunvoll operates in a high wage country it is important to figure out ways to reduce workhours. At the machining department they started an initiative to increase the knowledge of each worker so that they had at least three workers that can operate each machine. This is something that Brunvoll can take further to every department and across departments. According to theory, to have a flexible workforce you should have at least three skilled workers per workstation. So, to measure this this thesis presents the following FPIs:

- *Percentage(proportion) of employees who can operate more than one workstation*
- *Percentage proportion) of employees who can operate workstations across departments*

The objective for these FPIs is to increase flexibility of employees. By doing so reducing the chance of stops in production in case of sick leave. Potentially reduce numbers of workers in each department, and reduce the number of required overtime hours used.

On the other hand measuring flexibility in case of deviations like machine breakdowns, it would be possible to look at factors like, how long it takes to fix the machine, and cost related to this brake down. How does this breakdown affect the rest of the production plan.

5 Discussion

This part of the thesis will answer RQ5 and RQ6, here will the evidence through data collection and analysis be aggregated in context of industry 4.0.

- *RQ 5: How can industry 4.0 be utilized to improve flexibility?*
- *RQ 6: How can industry 4.0 be utilized to improve flexibility at Brunvoll?*

The objectives through these research questions investigate how industry 4.0 can help improve the current situation by bringing the physical and digital world together, making decision making more reliable. How can modern and future technology contribute to better handling procedures as well as eliminate factors that put them back through high costs and time-consuming operations.

5.1 Flexibility planning and control in the context of industry 4.0

Through data collection and analysis, it is clear how operations at Brunvoll are today, and how flexibility creates value and provide with necessary benefits to handle the corresponding challenges in an ETO manufacturing environment, in a high cost nation. Brunvoll has an advanced production structure that requires precise planning and control, which emphasizing customer service. For a ETO manufacturer, the production does not start before the customer places an order. After customer specifics are settled then the engineering phase start, this stage in production are crucial when it comes to information handling, planning and control. At Brunvoll, there are several parties in different departments that are involved in the start of production or project. Findings indicate that there is a lack of integration between the physical environment and the digital environment. A lot of the information sharing is done by E-mails, phones calls and on the spot decisions directly with the relevant worker. This creates bias in information sharing through departments, especially between planners and floor workers, and the benefits that an ERP system can provide is not completely there, rather provide more work in adding information to the system. When the integration of the physical production area and the digital MPC platform not a good fit things become messy. This is where Industry 4.0 technologies come into play, further the use of IoT, CPS smart factory will be discussed.

5.1.1 M3 ERP compatibility with ETO manufacturing environment

The case study finding show that there is a mismatch between the physical manufacturing environment at Brunvoll and the M3 ERP system. It lacks visibility between the physical environment and the digital environment. This have a bad effect on both efficiency and flexibility. Therefore, it becomes more and more important to look at ways to connect the physical world to the digital. This can be as stated in section 4.3.2 that adding parameters to the M3 ERP system could provide a better match between the manufacturing environment and the M3 ERP system. But in the context of Industry 4.0. it is only natural to look at better integration between the physical world and the digital world, and create full visibility. This integration is in the core of IoT, which is one of the key concepts of Industry 4.0.

As found in data collection at Brunvoll, it looks like there is a mismatch between the shop-floor environment and the M3 ERP system. After looking into manufacturing execution systems this might be the missing link to close this gap. This type of system is not used at Brunvoll, but could potentially be the way to go to close many gaps in the findings of this case study. The lack of digital registration of real-time and more focus digital control over the shop-floor, this will increase the visibility of the production area, and ultimately make it easier for planners to get correct information at the right time. This will increase reaction time of unknown changes at the shop floor, thereby increasing flexibility. MES system will also open up new possibilities of measuring flexibility at the case company. With all these benefits of implementing a MES system it might not be the most beneficial solution regarding return of investment. It might be smarter to look at how Industry 4.0 solutions could improve flexibility planning and control.

5.1.2 IoT and CPS to increase flexibility

Tight integration between the physical and digital world is the key part of any cyber physical system. CPS is one of the key concepts of industry 4.0 with IoT as a key enabler, which is the integration between the digital virtual world with the use of embedded wireless technologies applied to the things of the physical world. This will not only provide visibility, but it is enabling interoperability and automation as things receive information and instructions. The fact that things and digital systems communicates is enabling both bottom-up and top-down planning, which is a requirement for dynamic planning. By improving dynamic planning, flexibility will be increased by making better plan-to-machine decisions. This opens up quicker response in the system for unknown changes. Looking at Figure 1 and one of its key component after-sale-service, this is prioritized at Brunvoll and can often impact the whole production plan. When a service order is placed this will be prioritized over all other workorders, ongoing projects and production is deprioritized. Brunvoll sets their customer service as one of the key competitive strategies. With technology like this, Brunvoll can achieve a more dynamic planning structure and be able to respond quicker in these situations, making it easier to handle uncertainties. IoT and CPS are two technologies that are dependent on each other. This basically means that the physical manufacturing environment should be as closely integrated with the digital environment as possible.

5.1.2.1 Flexibility gained by real-time registration and the use of industry 4.0 technologies

Another issue that is seen from output of data analysis, is real-time registration. This is because of complicated parts and processing of these parts. Real-time registration is something that is supposed to be done in today's operations at Brunvoll, but in some occasions it is not done or it is not done correctly. Reasons for this can be several, one department may just think that others will do this in the next department. In some occasions they might just forget to register it since it is done manually, and when it is not automatically done, human mistakes occur. To take the full use of IoT and CPS, Brunvoll should focus on creating automatic registrations instead of being dependent on human resources. Therefore, to further improve flexibility through industry 4.0 it is important to look at possible options to implement auto-id in their manufacturing environment.

Looking at Industry 4.0 it is necessary to first look at real-time registration in the company. If real-time registration is not implemented correctly it is hard to take advantage of the technologies that comes with Industry 4.0. Customers require more and more visibility throughout the products life cycle. In a perfect world, GS1 standards would be implemented from the start, by this meaning the first manufacturer to touch the part provide this part with a GS1 standard that follows the part throughout the whole lifecycle. This could open for many possibilities in the future, by always knowing where the part is in its life cycle to better plan when to start processing of the part. There are many different identification technologies that could be used, the most used is RFID. For Brunvoll with their big product mix it is necessary to look outside the box, and look at technologies like weight, camera recognition to auto register parts in the production system. This will provide less bias in the system and thereby provide better planning, control and response time to changes in the environment (flexibility).

As Auto-id and IoT gets more used at Brunvoll, they can start moving towards the Smart factory cyber-physical system, which integrates physical objects with information systems such as their M3 ERP system to move towards a more flexible and agile production. For a company like Brunvoll moving towards becoming a smart factory would potentially benefit them greatly. Moving towards smart factory with the help of Industry 4.0 technology will provide “maximum flexibility”, where there is a focus on operation flexibility. It will increase agility by using advanced embedded sensors technology, automatically recognize manufacturing demand fluctuation. Ultimately provide better supply chain agility. Predictability will be improved though analyzing big data to better understand and see patterns in the environment, this will increase supply chain predictability and efficiency. All of these benefits of smart factory are greatly integrated and all together will bring a more leaner process. It will help the manufacturer reduce order management, material handling and inventory cost.

5.1.3 Potential future technologies to increase flexibility

The manufacturing industry is in a period of big change. The future brings tools that can totally change how we operate today. Augmented reality, additive manufacturing and other Industry 4.0 technologies, looking at the benefits that augmented reality can bring to production are vast. The idea behind augmented reality have been around for some time now, but the technology is still in the starting face. Therefore, it might be a bit confusing and in manufacturing it might be better to look at it as a “mixed reality”.

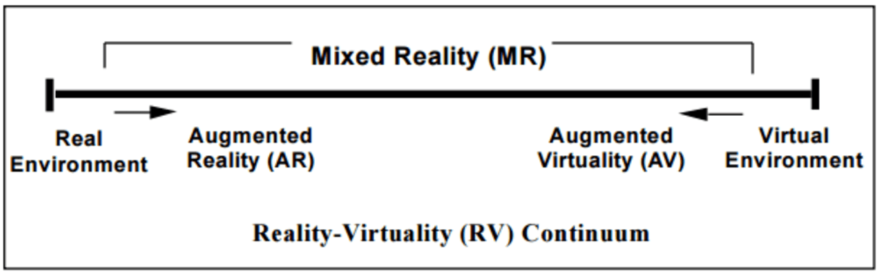

Figure 12 Mixed reality in manufacturing (Wright 2017)

As seen in Figure 12, mixed reality goes hand in hand with other industry 4.0 concepts like IoT and CPS. It is the connection between the real environment and the virtual environment, where the augmented reality and augmented virtually is a tool to better manufacturing. If Brunvoll was to use this technology it could potentially increase flexibility in many areas of production. Like mentioned earlier the way of registering parts into the system is done manually, by the use of virtual reality the camera recognition can be used. Components at Brunvoll are highly recognizable and can be identified with the use of cameras. If augmented reality was implemented in form of smart glasses with cameras this could make it easier to register the real-world things, and get them registered in the system in real-time. But this is just the start of the potential of virtual reality. Where information about assembly would be shown in the augmented reality making it easier for workers to assemble new and complex products. These technologies can be used in many areas like maintenance, expert support quality assurance and automation (Wright 2017).

For Brunvoll's case, where they have highly complex products and highly complex assembly, virtual reality could be used to make assembly more efficient. Especially when new products and new ways of assembly becomes the case.

Additive manufacturing or more known as 3D printing is a hot topic in manufacturing. It is still in the face of infancy, but it is already starting to show its potential to change how manufacturers operate today.

With 3D printing it would be much faster to introduce new designs into the system, at the time being 3D printing is mostly used for prototyping. But imagine if the products could be 3D printed, this would increase the flexibility drastically and reduce time and cost associated with production. It opens up a whole new world of possibilities when it comes to design. Additive manufacturing is something that could be worth researching further.

6 Conclusion

Conclusion to the research questions of this thesis will be presented.

- *RQ 1: How is flexibility defined within ETO-manufacturing planning and control?*
- *RQ 2: How is flexibility in planning and control defined at Brunvoll AS?*

To answer research question 1 a literature review was carried out. Here we found out that to understand how flexibility impact ETO manufacturing planning and control it is important to look at potential deviations that exist. According to theory the definitions all have in common that flexibility is the ability to adapt to changes in the manufacturing environment. To further explore flexibility in the case company the more appropriate approach was to look at flexibility derived into dimensions. This provided a framework to further map down and define flexibility in planning in control at Brunvoll.

To further answer RQ2, after interviews and looking at data analysis from M3 ERP system it became clear that Brunvoll is a flexible company. They showed a high degree of flexibility in areas like workforce, machine and delivery. Their machine park is highly automated, and flexible in the manner that they can handle many different operations, even when new products enter the system they have the ability to adapt by bringing in new tools and rigs. They are flexible in a lot of areas, but in most cases it seem like this is due to human resources. One important fact that was found during this process was that there is a mismatch between the physical environment and the M3 ERP system.

- *RQ 3: To what extent can flexibility in planning and control be measured?*
- *RQ 4: How can flexibility in planning and control be improved at Brunvoll with the help of performance measurements?*

Found in literature was frameworks for measuring flexibility. It is said that performance measurements trigger actions from management, and that it is important that the measurements are derived from a company's strategies. By looking at this together with a KPI philosophy where "what gets measured gets managed" over time will make workers change their way of working to reach flexibility goals. This put down a strategy for how we were to go about measuring flexibility at Brunvoll.

When we looked into how flexibility in planning and control could be improved at Brunvoll, we made some FPIs to potentially measure flexibility, to increase control in their manufacturing process. The dimensions that were chosen where the once we found most important for Brunvoll; Machine flexibility, delivery flexibility and workforce flexibility. For machine flexibility we made two FPIs to gain performance indicators that would help Brunvoll better flexibility performance long-term. For workforce flexibility two more FPIs were established with the goal of increasing workforce flexibility. If the focus on making the workforce as flexible as possible it could potentially long-term reduce costs related to workhours. Finally, we focused on delivery flexibility, which is an important factor at Brunvoll to stay competitive. Customers demand have increased and lead-times have been reduced. In trying to make performance indicators, it was clear that data in their M3 ERP system is not reliable enough. It was clear that customers changed delivery date and that this was not registered in the system, this provides a lot of unreliable data and therefore, we found it necessary to first introduce a new parameter in the M3 ERP system "change in planned delivery".

- *RQ 5: How can industry 4.0 be utilized to improve flexibility?*
- *RQ 6: How can industry 4.0 be utilized to improve flexibility at Brunvoll?*

Brunvoll's M3 ERP system is not a complete match with the environment they operate in. It is clear that in the ETO manufacturing environment, control becomes a more important part than the planning. Within industry 4.0 with IoT, CPS and smart factories bringing technologies like wireless sensors, controllers, 3D printing, digital twins, virtual reality, augmented reality and machine learning. These provide with better control throughout production with real-time registration as an important factor. The way we see it, Industry 4.0 brings better control and increased flexibility to ETO- environments. With the use of these technologies flexibility will be increased by better visibility, machines being able to adapt easier, and planning and control becomes more dynamic. In these environments where things change and plans are not met it becomes of so much more importance to carry out better control, by using Industry 4.0 technologies controlling becomes more automatic. To gain more control over the shop-floor a MES system could be helpful but, it is expensive to implement. Therefore, we recommend a long-term investment moving towards Industry 4.0 solutions where workstations/ machines are organized as independent nodes in a network.

7 Limitations and Further Research

The research of this thesis has been aimed at identifying the current situation and the challenge of production, planning and control at Brunvoll AS by looking at the definition of "flexibility." and what flexibility means for Brunvoll as an ETO manufacturer. These findings have then been reflected in the scope of Industry 4.0.

Given the time of this master thesis and availability of data and the time it takes to process this data, there have been limitations due to the investigation in this thesis. Based on the topic of this research there are many more angles and aspects that could be interesting to look into and by this maybe give more reliable data findings. After conducting this research paper, it is shown great potential in further research on this topic. Something that could be interesting for Brunvoll, is how to increase flexibility at less cost by using new and future technology. Other finding that could be interesting to further investigate is how the ERP-system Infor M3, operate and possibilities of improving the system for better dynamic planning and control. Another interesting study to look further into is augmented reality, how this can help increase flexibility and at the same time reduce use of resources as for example workforce flexibility with use of smart glasses. Other intelligent technology that can be further studied is 3D printing and how 3D printing can help production in an ETO-manufacturer as Brunvoll.

This study has provided the opportunity for valuable information and insight into how the day's situation is at Brunvoll and how their process and challenge in the market are linked to each other and interact with each other, and how industry 4.0 can contribute as a tool in such an environment.

Further studies:

- Augmented reality to help increase workforce flexibility with reduced use of resources. (With the help of smart glasses)
- Additive manufacturing (3D printing for more flexible manufacturing.

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