Master's degree thesis

LOG950 Logistics

IoT-enabled planning, control, and execution in ETO manufacturing: dynamics, requirements, and system architecture. A case study of Brunvoll AS

Erling Johan Wollen

Number of pages including this page:152

Molde, 25.05.2017

Molde University College
Specialized University in Logistics

Mandatory statement

Each student is responsible for complying with rules and regulations that relate to examinations and to academic work in general. The purpose of the mandatory statement is to make students aware of their responsibility and the consequences of cheating. Failure to complete the statement does not excuse students from their responsibility.

*Please complete the mandatory statement by placing a mark **in each box** for statements 1-6 below.*		
1.	**I/we hereby declare that my/our paper/assignment is my/our own work, and that I/we have not used other sources or received other help than mentioned in the paper/assignment.**	☒
2.	**I/we hereby declare that this paper** 1. Has not been used in any other exam at another department/university/university college 2. Is not referring to the work of others without acknowledgement 3. Is not referring to my/our previous work without acknowledgement 4. Has acknowledged all sources of literature in the text and in the list of references 5. Is not a copy, duplicate or transcript of other work	Mark each box: 1. ☒ 2. ☒ 3. ☒ 4. ☒ 5. ☒
3.	**I am/we are aware that any breach of the above will be considered as cheating, and may result in annulment of the examination and exclusion from all universities and university colleges in Norway for up to one year, according to the Act relating to Norwegian Universities and University Colleges, section 4-7 and 4-8 and Examination regulations** section 14 and 15.	☒
4.	**I am/we are aware that all papers/assignments may be checked for plagiarism by a software assisted plagiarism check**	☒
5.	**I am/we are aware that Molde University College will handle all cases of suspected cheating according to prevailing guidelines.**	☒
6.	**I/we are aware of the University College's rules and regulation for using sources**	☒

Publication agreement

ECTS credits: 30

Supervisor: Bjørn Jæger

Agreement on electronic publication of master thesis

Author(s) have copyright to the thesis, including the exclusive right to publish the document (The Copyright Act §2).

All theses fulfilling the requirements will be registered and published in Brage HiM, with the approval of the author(s).

Theses with a confidentiality agreement will not be published.

I/we hereby give Molde University College the right to, free of charge, make the thesis available for electronic publication: ☒**yes** ☐**no**

Is there an agreement of confidentiality? ☒**yes** ☐**no**

(A supplementary confidentiality agreement must be filled in)

- If yes: **Can the thesis be online published when the period of confidentiality is expired?** ☒**yes** ☐**no**

Date: 25.05.2017

Høgskolen i Molde

STANDARD AGREEMENT

This agreement is between

Erling Johan Wollen (Student(s)).

BJØRN JÆGER (Faculty Advisor at Molde University College),

BRUNVOLL AS (Company/Institution),

And Molde University College/MSc Logistics Program Coordinator, concerning the use of specifications and results reported in the Master's degree thesis in accordance with the study plan for the Master's degree program in Logistics at Molde University College.

1. The student will complete the work assigned for the Master's degree thesis in cooperation with the company/institution
(Optional):

The title of the thesis is: IoT-enabled Planning, control, and execution in ETO manufacturing: dynamics, requirements, and system Architecture. A case study of Brunvoll As.

2. The student has copyrights to the thesis. Those copies of the thesis submitted for evaluation along with descriptions and models, such as computer software that is included as part of or as an attachment to the thesis, belongs to Molde University College. The thesis and its attachments can be used by the College for teaching and research purposes without charge. The thesis and its attachments must not be used for other purposes.

3. The student has the right to publish the thesis, or parts of it, as an independent study or as part of a larger work, or in popularized form in any publication.

4. The company/institution has the right to receive a copy of the thesis with attachments, and the College's evaluation of it. The company/institution will have three (3) months from the time the thesis is submitted to the College for censoring to determine whether a patent is possible and to apply for a patent for all or part of the results in the thesis. The specifications and results in the thesis can be used by the company/institution in its own activities.

5. An additional confidentiality agreement may be entered into between the parties, if the company/institution sees this as necessary.

6. Each part of the agreement should have one copy of the agreement. The final signature should be from the Program Coordinator/Dean validating the agreement.

Place Molde

Date of final signature 18.5.2017

Erling Johan Wollen
Student(s)

Bjørn Jæger
Faculty Advisor

Halvard Bakken
Company/Institution
BRUNVOLL AS

Høgskolen i Molde

SUPPLEMENTARY AGREEMENT/CONFIDENTIALITY AGREEMENT

(Supplement to Point 5 of the Standard Agreement)

This agreement is between

Erling Johan Wollen .... (Student(s)),
BJØRN JÆGER (Faculty Advisor at Molde University College),
BRUNVOLL AS .... (Company/Institution),

and Molde University College/MSc logistics Program Coordinator. This is a supplement to the Standard Agreement, which defines the use of specifications and results reported in a Master's degree thesis in accordance with the study plan for the Master's degree program in Logistics at Molde University College.

1. As stated in Point 5 of the Standard Agreement the parties named above agree to limit access to the Master's degree thesis for 5 Year(s) from the date of this agreement. The limit should be 1 to 5 years, for longer confidentiality periods, contact the program coordinator for a special agreement.

2. The reason for keeping the thesis results confidential is so that the company/institution can avoid giving away information that would give others a competitive advantage.

3. The thesis must be submitted to Molde University College. It will be kept in a secure room in the main archive at the College during the period agreed upon. The thesis can be borrowed during this period if a written request is submitted and the company/institution gives permission. Academic staff members can access the thesis after signing a declaration of secrecy. After the period of confidentiality is ended the thesis will be placed in the library for general use.

4. Four copies of this agreement must be signed so that each party will have a copy. The agreement is valid when it has been approved and signed by the program coordinator or Dean at Molde University College.

5. The confidentiality agreement does not exclude members of the academic staff from being present at the final oral presentation of the thesis.

Place. Molde ....

Date of last signature. 18.5.2017........

Erling Johan Wollen
Student(s)

Bjørn Jæger
Faculty Advisor

BRUNVOLL AS
Company/Institution

Abstract

The Manufacturing Networks 4.0 project was initiated as a response to the need for new knowledge and methodologies for the Norwegian manufacturing industries within the scope of the fourth industrial revolution, often referred to as Industry 4.0. Furthermore, one of its main objective is to address critical challenges related to effective planning and control in dynamic, temporary, often project-based manufacturing networks. The traditional theoretical and systematic approach to Manufacturing Planning and Control (MPC) has been very much geared toward stable and forecast driven manufacturing environments such as for instance Make-To-Stock (MTS). As the findings suggest, some parts of this traditional approach lack some of capabilities required by the dynamic and varied nature of manufacturing environments such as Engineer-To-Order (ETO). Furthermore, the traditional approach to MPC lacks somewhat focus towards the execution aspect of the manufacturing operations that are planned and controlled, which in the scope of this thesis is argued be an highly and just as important aspect of MPC.

The aim of this master thesis has been investigate the theoretical, technological, and practical aspects of manufacturing planning, control, and execution (MPCE) in the context of ETO manufacturing at Brunvoll, in order to identify current challenges, underlying factors, and potential improvements within the scope of the Manufacturing Networks 4.0 project. First, the current situation, challenges, and underlying factors have been investigated and analyzed at the process level, which has been delimited to one node in the manufacturing process (a Machining center) and one component type (Gear housings) at Brunvoll. The findings shows that the challenges, focused towards process dynamics, manifests themselves in the fact that over 85% of all gear housing work orders processed during the last year and a half were reported as completed after their scheduled finishing date, which by the system requirements meant that the work orders was delayed. At the process level, this means that the intended processes, i.e. the planned operations and/or the process procedures, has been violated during the actual iteration of the process. These violations have been investigated further in order to identify which underlying factors cause or contribute to the occurrence of the violations and subsequent process dynamics. Findings support that such violations to the intended process are complex events that might consist of several underlying factors that contribute to their occurrence. First, several situational events where process dynamics would occur is identified along with their underlying factors through the use of qualitative interviews with key informants at Brunvoll, which could provide insight into such events

based on their personal experiences. Subsequently, historic transaction data from the M3 ERP system was extracted through using SQL queries, which provides quantitative data that supports the qualitative findings. Based on this, process dynamics was investigated through the four main situational events identified; business event reporting, production faults, subject availability, and work order re-scheduling. Furthermore, the underlying factors have been summarized as the following four main factors; the Human factor, the Process factor, the Integration factor, and the ETO factor. These factors represent important factors who's occurrence must either be handled, reduced, or eliminated in order to reduce the overall occurrence of process dynamics and increase the performance of MPCE at Brunvoll.

A central part of this case study analysis has been to investigate the occurrence of process dynamics and underlying factors at the process level in order to evaluate whether or not the current systematic approach to MPCE at Brunvoll is sufficient in light of this. However, as the findings suggest, the current systematic approach to MPCE is lacking several important capabilities identified through the situational events and underlying factors, such as for instance the ability to perform dynamic planning in the occurrence of process dynamics, which in turn is not handled very well by the M3 ERP system alone. All the findings mentioned so far forms what is defined as the As-Is situation at Brunvoll. The subsequent part the thesis therefore consisted of suggesting a To-Be systematic approach to MPCE based on the current challenges at Brunvoll, put in the scope of Industry 4.0. In order to achieve this, the factors identified were first translated into high-level requirement that represent key characteristics and capabilities that the To-Be conceptual model needs to possess. The developed To-Be system architecture represents a systematic approach to MPCE enabled by technologies such as the Internet-of-Things (IoT) and other Industry 4.0 related concepts and technologies. The final system architecture has been named the IoT-enabled MPCE because of the key enabling role that the IoT plays in the system. The final part of the thesis is devoted to discussing how such a system architecture could reduce the overall occurrence of process dynamics and improve the performance of the MPCE, as well as the potential implications on the value chain and strategic areas within ETO supply chains.

Acknowledgements

This Master thesis represent the final stage of the Master of Science degree in Logistics at Molde University College, Norway. This master thesis has been part of the research project Manufacturing Networks 4.0, and has been written during the spring semester of 2017.

First off, I would like to sincerely thank my supervisor, Associate Professor Bjørn Jæger, and co-supervisor Karolis Dugnas at Molde University College for their valuable guidance, suggestions and feedback during the case study and writing of this thesis. Secondly, I would like to thank Brunvoll AS and their representatives who agreed to spend time and share the information needed to conduct the case study.

Finally, I would like to thank my family and friends for their support during this thesis writing process.

Erling Johan Wollen

Author

Molde, Norway

May 2017

Table of content

List of figures and tables

Abbreviations

ATO - Assemble-To-Order
BOM - Bill Of Materials
BPM - Business Process Management
BPMN - Business Process Model and Notation
BRP - Business process Re-Engineering
BSE - Business Systems Engineering
BTO - Build-To-Order
CODP - Customer Order Decoupling Point
EPCIS - Electronic Product Code Information Systems
ERP - Enterprise Resource Planning
ETO - Engineer-To-Order
GDSN - Global Data Synchronization Network
ICT - Internet and Communication Technology
IOT - Internet of Things
IT - Information Technology
ITU - The International Telecommunication Union
MES - Manufacturing execution system
MPC - Manufacturing Planning and control
MPCE - Manufacturing planning, control, and execution
MRP - Material Requirements Planning
MTO - Make-To-Order
MTS - Make-To-Stock
OMG - Object Management Group
OPC UA - Open Platform Communications Unified Architecture
OPP - Order Penetration Point
PPC - Production planning and control
RFID - Radio Frequency Identification
SC - Supply Chain
SCM - Supply Chain Management
SCV - Supply Chain Visibility

1.0 Introduction

This chapter introduces the background for this thesis along with the scope, purpose and objectives of the case study and the case company Brunvoll AS. Finally, the structure of the thesis will be outlined.

1.1 Background

Today, technology has become an integrated part of modern business, industries and society, a trend that will continue to grow and develop in the future. Currently, there is a lot of buzz around the idea that the technological developments now have such disruptive properties that we now stand on the forefront of the fourth industrial revolution. The industrial revolutions have all had a huge impact on productivity, economies and societies. As history shows, the extensive changes brought forward by these shifts in the industrial base has led to the development and adaptation of new business models and manufacturing systems. As illustrated in figure 1, the evolution of manufacturing shows that the trend of mass customization continues to develop, meaning more product proliferation, increased complexity and more customer specific production, across global markets (FoF, 2016).

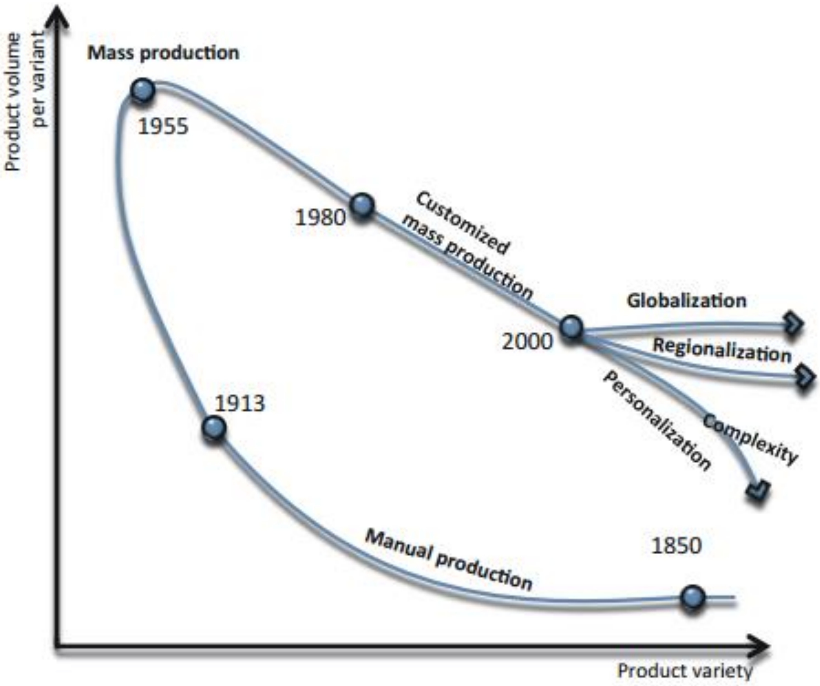


Figure 1. Evolution of manufacturing (FoF. 2016)

Not only has this evolution revolutionized manufacturing companies and their products, but it has also changed the competitive nature of the markets at which they operate and compete in. Here, the basic tenants of strategy theory still applies as either the ability to either deliver on a differentiation or a cost leadership strategy, or a combination of both. One of the key foundations for competitive advantage is operational effectiveness, where in the context of the fourth industrial revolution, the developments both provide the means of increasing operational effectiveness while at the same time putting pressure on companies to adapt to the development or risk losing their competitive edges (Porter and Heppelmann, 2014)

The Norwegian manufacturing sector has for a long time held a strong position within the manufacturing of complex and specialized manufacturing, especially within what is widely known as Norway's core competency, namely the offshore segment. However, as a result of the economic developments in Norway since the 1970's, the cost of production in Norway has increased substantially and is comparably higher than most other countries on a global perspective. Because of this, a central trend during the last couple of decades has been to outsource activities, such as for instance the labor-intensive ones, to lower-cost countries. From a strategic perspective, it has become difficult for Norwegian based companies to compete globally on a cost leadership strategy, which is why the remaining companies often follow a differentiation strategy through providing complex and specialized products. However, recent technological developments in manufacturing such as for instance the encompassing introduction of automated robotics means that factors such as labor cost becomes less of an important strategic factor. Furthermore, the global developments within manufacturing has shown a trend towards differentiated, complex and specialized production (Figure 1). This has two main effects, one is that the amount of activities outsources can be reduced or even back sourced, and the other is that the competitive nature of markets changes once more. What is meant by that is that it will become more challenging for companies to only compete on a differentiation or a cost leadership strategy basis. As a result of this, successful companies will have to leverage the two strategic approaches as a source of competitive advantage in markets (Porter and Heppelmann, 2014). After all, customers are becoming more and more demanding for products that are both customized and offered at a low cost. If Norwegian manufacturing companies wishes to remain competitive in the context of the industrial shift that is expected to occur, then they need to be aware of and adapt to the changes in customer demand, markets, competition, technological development and other developments that may influence the company's position in the marketplace.

As will be introduced later, several industrial research projects have been established to conduct research on the topic and scope of the fourth industrial revolution. One of these projects is the Norwegian Manufacturing Networks 4.0, which is a research collaboration between some Norwegian manufacturing companies, two business clusters, NTNU and Molde University College. The goal of this research project is to respond to the need for new knowledge and methodologies for the Norwegian manufacturing industries, which in turn will help the companies sustain their competitive advantages in the context of the technological developments and new competitive challenges occurring within the scope of the fourth industrial revolution (ManuNet 4.0).

1.2 Scope, Purpose, and Objectives of study

Since this thesis is a contribution to the Manufacturing network 4.0 project, its purpose and scope is somewhat balances between the scope and topics related to the fourth industrial revolution and the specific context of Brunvoll as the case company. The primary goal of the Manufacturing Networks 4.0 project is to respond to the need for new knowledge and methodologies for the Norwegian manufacturing industries within the scope of the fourth industrial revolution, often referred to as Industry 4.0. This thesis will be a contribution to Work package 4 in the project, which addresses the use of Internet-of-Things technologies for collaborative planning and control of manufacturing in supply chains. Its main objective is to address critical challenges related to effective planning and control in dynamic, temporary, often project-based manufacturing networks (ManuNet 4.0).

Based on the discussions with Brunvoll as the case company, it was concluded that the main area of interest concerning the unit of analysis was the planning, control, and execution of the internal manufacturing operations. The main objective from Brunvoll as the case company and as a member of Manufacturing Network 4.0 was therefore to analyze their current processes in order to gain insight into current challenges and areas for potential improvements, developments, technologies and concepts provided within the scope of Industry 4.0.

The purpose of this study is thus to identify and address critical challenges with regards to the planning, control, and execution of manufacturing operations at Brunvoll. This thesis will be based around the theoretical framework of Manufacturing Planning and Control

(MPC), where the systematic approach to MPC at Brunvoll will be evaluated and then put into the scope of Industry 4.0 by providing a revised systematic approach to MPC based on several Industry 4.0 related concepts and technologies. The main objective of the thesis is thus to provide insight in the current situation, challenges, and underlying factors that within the scope of Industry 4.0 might be improved. As will be discussed later, MPC is predominately focused on the planning and control aspects of manufacturing operations. Although the execution of such operations is considered a part of the concept, its importance within the scope of this thesis is equally as important as the other two. This is why MPC in the context of this thesis is referred to as MCPE, in order to highlight and include the importance of the "Execution" aspect. This is also true in the scope of Industry 4.0, where the importance of interoperable and automated manufacturing environments is central.

In order to achieve the purpose defined, several research questions has been formulated to steer the research process in the right direction. The purpose of the case study of Brunvoll can be broken down into four main objectives and subsequent research questions.

The first objective is to investigate and analyze the current As-Is situations for the manufacturing planning, control, and execution processes that forms the systematic approach to MPCE at Brunvoll. Since these processes have not been defined before, the first tasks of this investigation is to map the current processes on order to gain insight into how these processes are currently intended to be executed at Brunvoll, which is why the first research question is defined as the following:

RQ1: What is the As-Is situation for the intended manufacturing planning, control and execution processes at Brunvoll?

The word "Intended" here is key as it described how the processes and systematic approach to MPCE is supposed to look like. This inherently means that challenges and deviations can easily be identified and measures whenever the intended processes does not match the actual iteration of the processes, which has been defined as process dynamics. This forms the important distinction for the second objective of the research, which is to identify and analyze the underlying factors that cause or contribute to the occurrence of process dynamics. Based on this the second research question is defined as:

RQ2: What are the main underlying factors behind the occurrence of process dynamics in the manufacturing planning, control and execution processes at Brunvoll?

This research question is related to the challenges facing Brunvoll today within the scope of the processes and the systematic approach to MPCE. Since this study is mostly exploratory in nature, the aim is not to understand and explain all the underlying factors that cause process dynamics, which often are highly complex events, but to rather provide to initial insight into some of the key factors behind process dynamics and challenges for Brunvoll, which can be used as important considerations the subsequent objective.

The third objective is to put these challenges and factors into the scope of Industry 4.0 in order to propose ways of handling, reducing, or eliminating the occurrence of these underlying factors and subsequent process dynamics. The third research question is therefore the following:

RQ3: How can Industry 4.0 related concepts and technologies be used to improve MPCE at Brunvoll?

Again, the objective of this research question is not to provide extensive explanations on how these concepts and technologies can be implemented directly at Brunvoll, but rather as an initial high-level assessment of how certain concepts and technologies can be used within the scope of the underlying factors identified and Industry 4.0. Although this and the previous research question have been based around MPCE on the process level, this answer will presented more on the system level, which is not only relevant at the process level but is also more generalizable.

The outcome of the third research question is thus a revised systematic approach to MPCE based on the technological scope of Industry 4.0, which build on high-level requirements derived from the case study findings. A fourth objective and research question has thus been formulated to discuss some of the potential implications such a system might have on the value chain and some of the strategic areas within ETO manufacturing.

RQ4: What are the potential implications of an Industry 4.0 enriched MPCE system on the value chain and some of the strategic areas within ETO manufacturing?

1.3 The case Company Brunvoll AS

Brunvoll AS is a single source supplier of complete Thruster systems used in ships and vessels. They provide fully integrated thruster solutions with diesel or electric drive motors, hydraulic power units, controls, alarm and monitoring system tailored to the needs of the customer.

Brunvoll was originally named “Brødr. Brunvoll Motorfabrikk” when established in 1912 by the two brothers Andreas and Anders Brunvoll. In the early days, they produced low-pressure diesel engines and controllable pitch propellers for fishing vessels. In the 1960’s they developed their first tunnel thruster, which increased the safety and efficiency of fishing vessels. The company has since then become a global market leader in the supply of Thruster Systems, with over 8000 thrusters delivered to more than 5000 vessels. Their vision and slogan is “Trusted world wide”.

Today, Brunvoll have sales representatives in 26 countries with a strong market position as a supplier of the following types of advanced vessels:

- Offshore support vessels.
- Shuttle tankers.
- Seismic vessels.
- Advanced fishing vessels.
- Live fish carriers.
- Cruise ships.
- Mega yachts.
- Naval vessels.

Brunvoll’s business concept involves the phases design, manufacturing, sales, and service of complete Thruster Systems for maneuvering and propulsion of advanced vessels. A thruster system might consist of anywhere between a few hundred component to a few thousand depending on the type and size. In addition, Brunvoll provide the capabilities of manufacturing specialized thruster system based on specific requirements from customers, which further emphasizes the complexity of the product and the value chain.

Brunvoll’s value chain consists of two main business areas; new sales/project management and the after-sales service (Figure 2). As will be explained later, the main unit of analysis for this thesis case study mainly fall within the component production activities, which is part of the surface treatment processes.

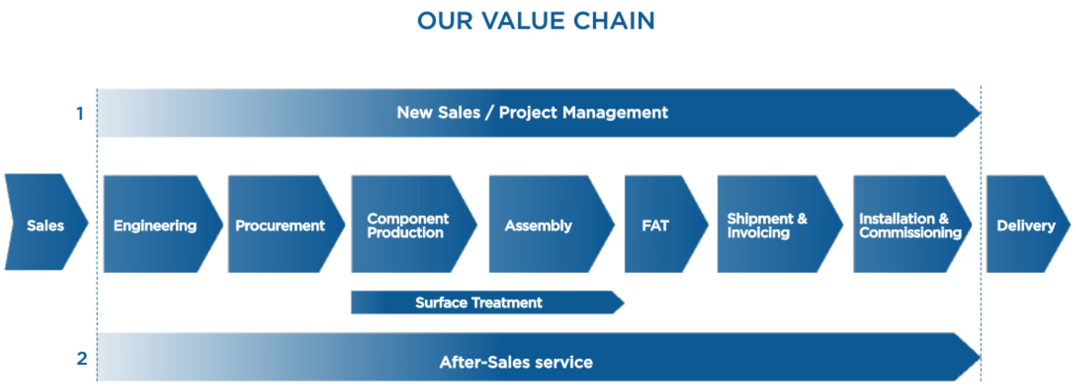


Figure 2. Brunvoll's Value Chain (Brunvoll, 2015)

As will be discussed later, Brunvoll is considered an Engineer-To-Order Manufacturer, a characteristic shown in Brunvoll's value chain, where the first activity performed after sales activity is the Engineering phase.

Besides the human resources, MPC at Brunvoll is mainly supported by the Infor M3 ERP system, which is marketed by Infor as a highly adaptable and flexible ERP system with Industry-specific suites (Infor). The capabilities of this ERP system will be investigated during the case study analysis.

1.4 The thesis structure

Besides the Introduction chapter already presented, the subsequent chapters consists of the following:

The second chapter consist of the literature review on the theoretical foundation that support the overall scope, purpose and objectives of this thesis. The relevant literature has been divided into two main streams. First, the theoretical and technological foundation for the fourth industrial revolution will be presented. This includes the technological concepts, technologies, and global standards that forms the visionary scope of Industry 4.0. The second stream of literature deals with the theoretical foundation for manufacturing, logistics and SCM. More specifically, this involves theoretical concepts such as the value chain, ETO manufacturing, manufacturing planning and control, and the role of technology and information within these. The third chapter is concerned with providing insight into the methodological approach taken to answering the research questions and performing the case study data collection and analysis. In the fourth chapter, the case study analysis and findings will be presented, which is related to answering the first two research question. The fifth chapter consist of a discussion as to how Industry 4.0 related concepts and technologies can be used to improve manufacturing planning, control, and execution processes at Brunvoll based on the findings from the case study analysis put in the scope of Industry 4.0. This consists of developing a conceptual system architecture for an IoT/Industry 4.0 enabled manufacturing planning, control and execution (MPCE) system. In addition, potential implications if such a developed system is discussed across several strategic areas. The sixth chapter consist of summarizing all the findings from the thesis into a conclusion. Finally, the seventh chapter involves discussing the limitations of the thesis and suggest potential further studies.

2.0 Literature review

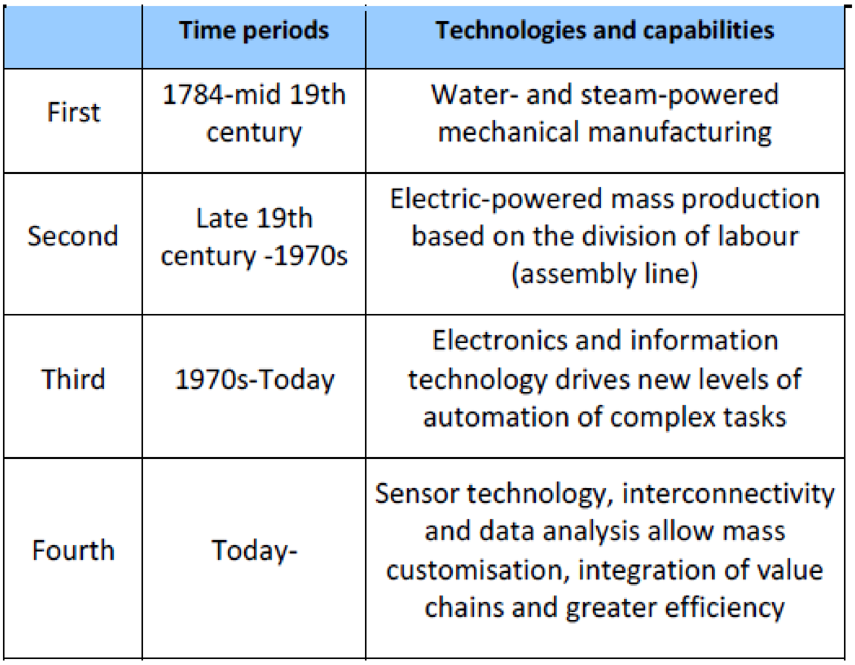
This chapter provides an extensive literature review on what represents the theoretical and technological foundation for this thesis.

2.1 Technological developments and revolutions

This section provides the literature review on the topics, technologies, and concepts related to the fourth industrial revolution.

2.1.1 The fourth industrial revolution

The 1st industrial revolution was sparked by the move from manual to mechanized production and the introduction of steam power. The 2nd revolution was supported by innovations such as steel, chemicals and electricity, that supported the shift towards mass production of goods and products. The 3rd revolution was sparked by the introduction electronics and information technologies. Now, there is a lot of buzz around industries about the full integration between the digital and physical world that will spark the next industrial revolution.



	Time periods	Technologies and capabilities
First	1784-mid 19th century	Water- and steam-powered mechanical manufacturing
Second	Late 19th century -1970s	Electric-powered mass production based on the division of labour (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 customisation, integration of value chains and greater efficiency

Figure 3. The industrial revolutions (EPRS, 2015)

As illustrated in figure 3, the previous industrial revolutions all had revolutionizing impact on productivity and economies, which emphasizes the importance of adapting to next revolutionary shift. This anticipated revolution has sparked a number of major industrial research projects, including the Manufacturing Network 4.0 project that this thesis is a part of. Other initiatives include the German Industrie 4.0, while General Electric use the term “Industrial Internet” for where they think their business is heading. The scope and definition of each concepts varies, but what they all have in common is the use of digital technologies to drive industrial developments. The term Industry 4.0 has been widely adopted as the term for the technological movement towards the fourth industrial revolution, which is why the term will be used when referring to the fourth industrial revolution in this thesis. Furthermore, the terms Industry 4.0, Internet of Things, and Industrial Internet are often used interchangeably and generally as referring to the same industrial and technological developments, but with different origins and somewhat different scopes (De Bernardini, 2015). As will be explained later, the concept of the Internet-of-Things in this thesis is considered a key component of Industry 4.0, where the latter represent more of a conceptualization of a revolution.

In 2015, The European Parliament released their own research report that summarized the technological developments that forms the basis of Industry 4.0 as the following (EPRS, 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.*
- *"Network communications including wireless and internet technologies that serve to link machines, work products, systems and people, both within the manufacturing plant, and with suppliers and distributors.*
- *"Simulation, modelling and virtualization in the design of products and the 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."*

As can be understood from the core technological developments described above, Industry 4.0 is a relatively wide concept encompassing many different technological developments and capabilities. However, these technological developments and capabilities do not really provide much insight into the specific technologies and concepts that are going to provide industries with these set of capabilities, which is why more specific technologies and concepts will be introduced later.

2.1.2 Technological trends within Logistics

Figure 4 shows the Logistics Trends Radar, where key social, business, and technology trends within logistics are listed along with their relevance based on research conducted by global logistics provider DHL (DHL, 2016). As can be seen, technologies such as the Internet-of-Things, Big Data, Robotics and Automation are relatively high on the trend radar and within a 5-year scope, thus supporting their current relevance within Industry 4.0.

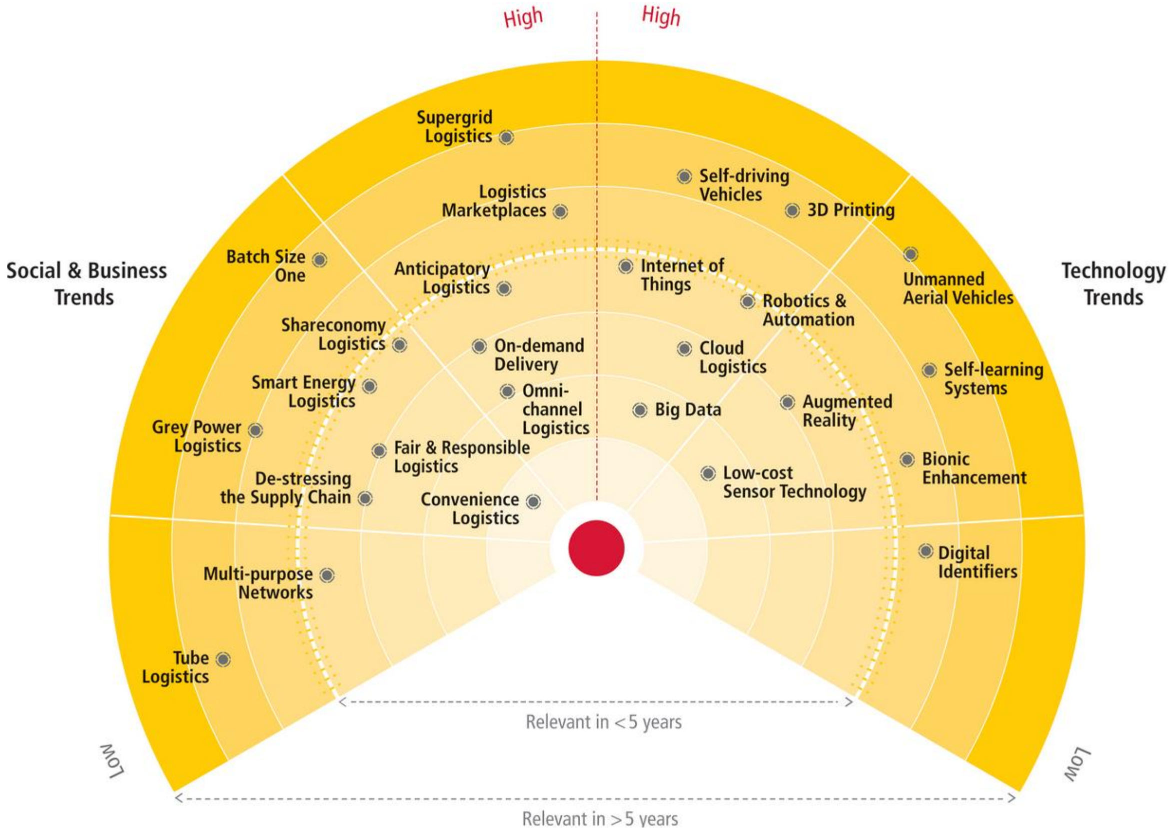


Figure 4. The Logistics Trend Radar (DHL, 2016)

All these trends can be considered as relevant in the context of Industry 4.0. However, due to the limitations of a master thesis, it is not possible to cover all these topics in detail. This meant that the technological concepts selected had to be of relevance the scope and objectives of this thesis. Based on this, the following technologies and concepts have been selected as the most relevant in the context of the research scope, purpose, and objectives.

2.1.3 The Internet-of-Things (IoT)

The concept of the Internet-of-Things was first coined by Kevin Ashton back in 1999. Ashton, a pioneer within RFID technology and one of the founders of the MIT Auto-ID Center, saw the potential of the vast amounts of data that could be collected by using Auto-ID technologies from objects besides the traditional data input units such as keyboard and barcode scanners (Gabbai, 2015). Sundmaeker et al. (2010) describes Auto-ID technologies as:

"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 considered the IoT as a mere extension of RFID technologies with the added vision that machines not only have the capability to do and learn, but also to sense and respond (Sundmaeker et.al. 2010). The idea behind the IOT is quite simple when just contemplating the meaning of its name. You have the "Internet" part, and then you have the "Things" part. The thing is defined as any object of the physical or digital world that is able to be identified and integrated into communication networks (ITU-T Y.2060, 2012). The essence of IoT can thus be explained as connecting things through the internet, which essential is a synonym for wireless connectivity. As one starts to uncover the potential use and benefits of these seemingly simple concepts, it becomes clear that they have disruptive potential in them.

It is clear that the visions of the IoT has developed a lot over the recent years, where the concept now play a central role across all the Industry 4.0 visions. Gartner defines IoT as the:

*"Network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment (*Gartner*)".*

The McKinsey research institute (2013) defines IoT as referring to the:

"Use of sensors, actuators, and data communications technology built into physical objects that enable those objects to be tracked, coordinated, or controlled across a data network or the Internet."

The International Telecommunication Unions Standardization Sector (ITU-T) extends this understanding of IoT by including some of the relevant technologies that are integrated in IOT and Industry 4.0:

*"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" (*ITU-T Y.2060, 2012*).*

What can be summarized from the definitions is that the IoT is the connection of physical objects in a network by the use of embedded and wireless technologies. In the context of Industry 4.0, the IoT is therefore considered as the key enabler for establishing connectivity between the physical and digital world, and by doing so connects and unites all the other technologies and concepts that together will deliver on the visions and capabilities of Industry 4.0. Based on the understanding from the definitions it is clear that the IoT is not any specific technology, but is rather a systematic approach of how to use technologies to connect objects in a network as to serve a certain purpose. Which objects to be connected and which technologies to be used is thus determined by the systematic requirements of the context in which the system operates or is intended to operate.

2.1.3.1 IoT characteristics

According to the International Telecommunication Union's Standardization Sector (ITU-T Y.2060, 2012), the following are the key fundamental characteristics of the IoT:

<u>Interconnectivity</u>: all physical things have the ability to be interconnected with the use of embedded and wireless communication technologies.

<u>Things-related services</u>: IOT is capable of delivering services to things within the constraints of things, including privacy protection and semantic consistency between physical and virtual things.

<u>Heterogeneity</u>: embedded devices are heterogeneous and based on different hardware platforms and networks. They can however interact with other devices and service platforms through different networks.

<u>Dynamic</u>: The state, quantity, quality and location of things changes dynamically.

<u>Enormous scale</u>: The number of connected objects will be significantly greater than before. Most of the data generated by will come from device-triggered communication, that will open up new possibilities and challenges as to analyzing and making decision and actions based on this information.

2.1.3.2 The role of the IoT in ICT

The objective of ICT is to provide connectivity and communication, any time, any place. When adding the "Thing" dimension, we extend the connectivity from the typical devices such as phones or computers to the entire physical word. Figure 5 shows how the IoT is able to create a new dimensions in the scope of ICT. This figure also show that the two preexisting dimensions of ICT are critical enablers of the IoT (ITU-T Y.2060, 2012).

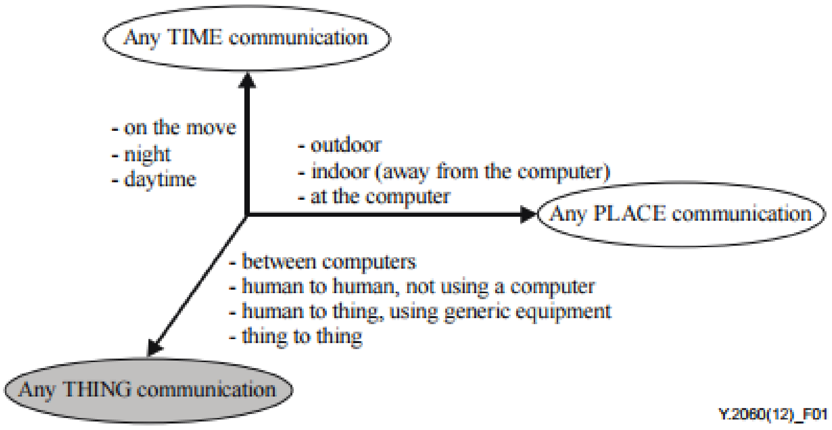


Figure 5. The new dimension introduced in the IoT [ITU-T Y.2060, 2012]

The result of adding a new dimension to ICT capabilities means that the amount of data being generated is likely grow exponential in the years to come, which in turn will need to be managed. This topic will be furthered discussed in the section on Big Data.

2.1.3.3 The IoT components

Figure 6 shows the technical overview of the IOT developed by the Telecommunication Standardization Sector (ITU-T Y.2060, 2012).

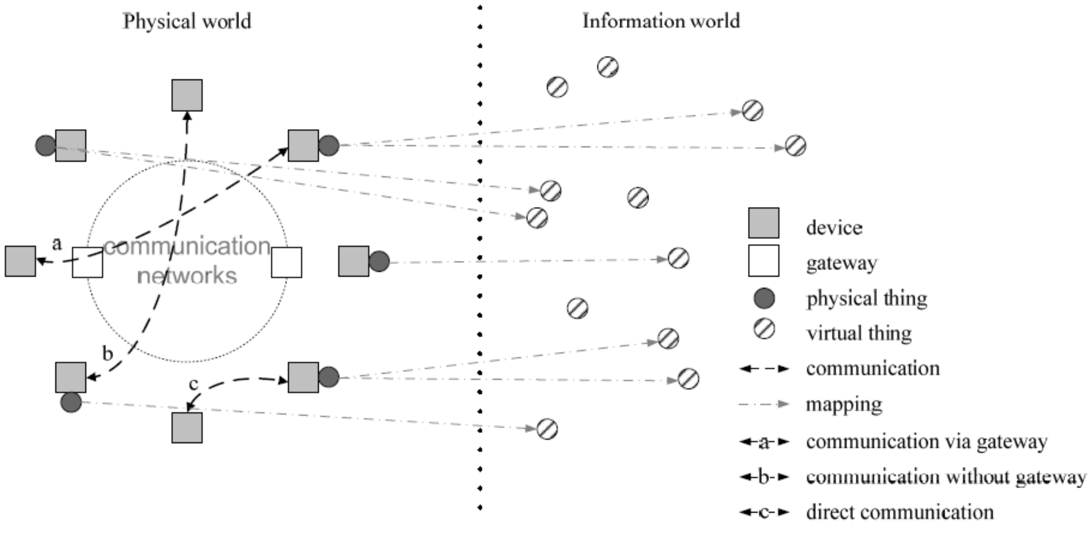


Figure 6. Technical overview of the IoT (ITU-T Y.2060, 2012):

The following list is a description of the core components of the technical overview (ITU-T Y.2060, 2012).

Things: are objects that are capable of being identified and integrated into communication networks. In the context of IOT, a thing usually contain either static or dynamic information that can provide some value in its context. A Thing is furthered separated into:

Physical thing: is an object that exists in the physical world and that is capable of being sensed, actuated and connected.

Virtual thing: is an object that exist in the information/virtual world and that is capable of being stored, processed and accessed.

Device: is a piece of equipment that at least has the capabilities of communication, and has the optional capabilities for sensing, actuation, data capture, data storage and data processing. The main objective of a device is to collect and share information from the physical world, included the use of embedded sensors on physical things. In addition, some devices may have the ability to execute operations based on information received through information and communication networks. Figure 7 shows the different types of devices and the relationship between devices and physical things, used in ITU-T's framework for the IOT:

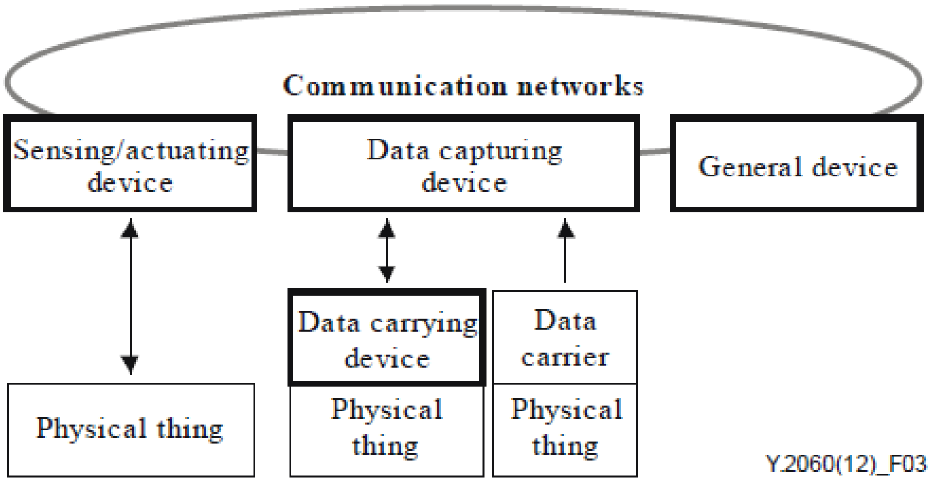


Figure 7. Devices and their relationship with physical things (ITU-T Y.2060, 2012).

Communication: In the IOT, devices have the ability to communicate with each other either through a communication network with or without using a gateway, or directly to each other. The goal of the communication network is to enable reliable and efficient data transfer, so that data and instructions can be collected and shared between the physical and virtual world, in other words between the devices and the applications. The communication network infrastructure can be based on one of the many available communication protocols, for instance such as the conventional TCP/IP-based network.

2.1.3.4 IoT impact on logistics

The IoT is believed to have a revolutionizing impact on decision-making and performance within companies. The benefits are expected to reach across the entire value chain, adding value to areas such as operational efficiency, safety and security, customer experience, and the development of new business models. As shown in figure 8, the capabilities enabled by the IoT has a huge potential impact on the operational performance of companies (DHL, 2015).

Figure 8. IoT-enabled Capabilities in logistics (DHL, 2015)

These capabilities includes the ability to (DHL, 2015):

- Monitor all things in real-time. This includes tracking products, people, and assets across the entire value chain.
- Measure the current state and performance of products, systems, people and asses.
- Control what “things” are doing now and dictate what they will do in the future.
- Automate business processes and eliminate manual tasks in order to improve efficiency, quality and predictability at a lower cost.
- Optimize how people, systems, and assets work together by analyzing information and coordinate their activities.
- Learn from analyzing data collected from things across the entire value chain in order to identify wider improvement opportunities and best practices.

Although the logistics industry has been one of the early adopters of IoT related technologies such as RFID, sensor technology, microprocessors, and wireless connectivity, the industry is still considered as only being at the tip of the iceberg in terms of realizing and exploiting the true potential of the IoT (DHL, 2015). The potential of IoT lies everywhere, from the manufacturing value chain to the entire supply chain. According to McKinsey and industry experts, IoT has the potential to trigger a paradigm shift in manufacturing, where production control become far more automated and decentralized. In addition, manufacturing environments and supply chains will become substantial more networked and interlinked as a result of the connectivity provided by the IoT (Löffler and Tschiesner, 2013). However, this will also make them grow more complicated, which can be an indicator that the ability to adopt the IoT may become a competitive factor.

2.1.3.5 IoT maturity at Brunvoll

Previous research within the Manufacturing Network 4.0 project include a master thesis by Bø and Wiig (2016) who developed an IoT Technological Maturity Model and used it to assess the technology status of companies in the context of the IoT, Industry 4.0. The developed maturity model (Figure 9) includes eight different subsequent levels from level 1 characterized by organizations that are just starting to embrace the IoT concepts, to level 8 characterized by organizations reaching the visionary stage of Industry 4.0.

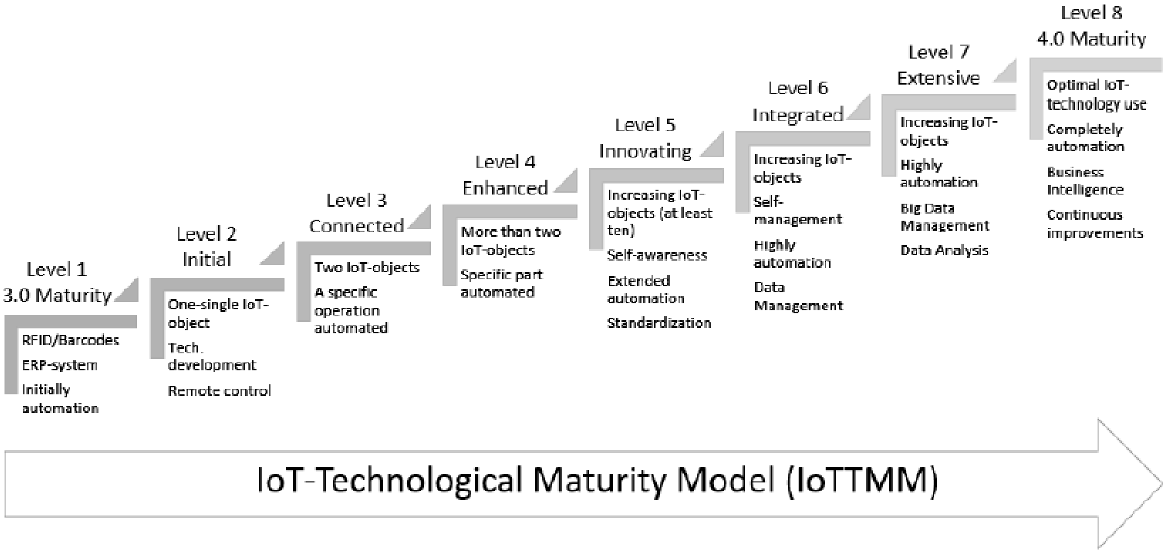


Figure 9. IOTTMM (Bø & Wiig, 2016)

Bø and Wiig’s (2016) assessment of Brunvoll concluded that Brunvoll has a high degree of technological competence, especially within the business functions responsible for managing business systems and other information and communication technologies. In addition, there is a high degree of strategic focus on investing in more automation with the use of robots and automated processing in the manufacturing process, as well as more automated and paper free administrative processes. When it came to Brunvoll’s manufacturing process and the maturity level assessment, finding showed that current operations are mainly supported by the ERP-system, and that the manufacturing process is characterized by a mix of manually and automated operations. None of the robots or machines in the manufacturing process had the capability to be accessed or controlled externally from the control systems, nor was there any robots or machines with the ability to communicate horizontally.

Their conclusion was that the maturity level of Brunvoll at the time was at level three, which includes the capabilities of the previous levels including the use of:

- Barcodes
- ERP-system
- At least two IoT-objects (welding robot and CNC-machine), with the ability for machines and robots to communication vertically with the control system.
- The automation of specific operations

The IOT-maturity assessment of Brunvoll and the other companies in ManuNet 4.0 is shown in figure 10, which gives a slight indication of the long and challenging road towards the scope of Industry 4.0 when considering that the companies are already considered as technologically advanced and competitive.

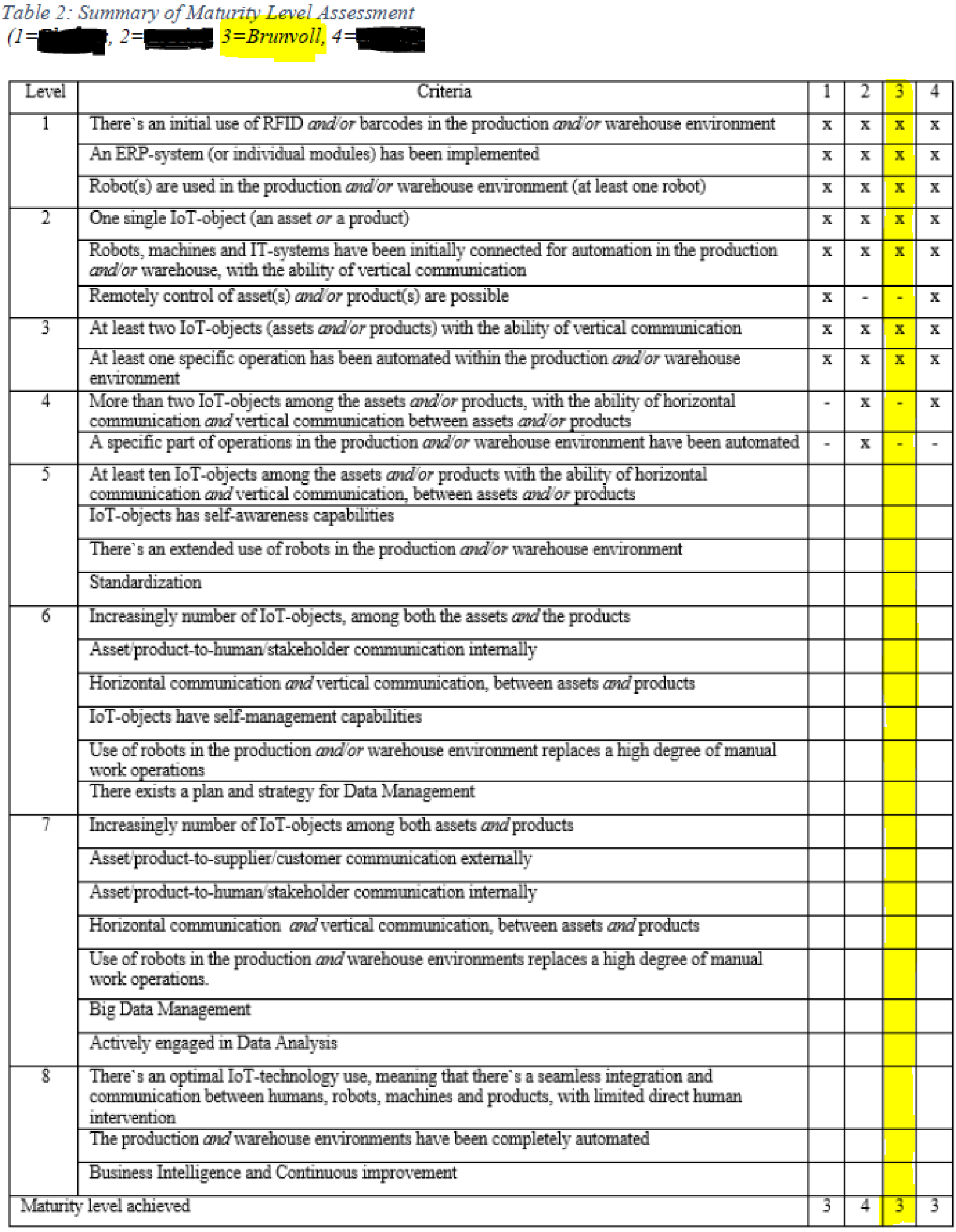


Table 2: Summary of Maturity Level Assessment
(1=[redacted], 2=[redacted] 3=Brunvoll, 4=[redacted]

Level	Criteria	1	2	3	4
1	There`s an initial use of RFID *and/or* barcodes in the production *and/or* warehouse environment	x	x	x	x
	An ERP-system (or individual modules) has been implemented	x	x	x	x
	Robot(s) are used in the production *and/or* warehouse environment (at least one robot)	x	x	x	x
2	One single IoT-object (an asset *or* a product)	x	x	x	x
	Robots, machines and IT-systems have been initially connected for automation in the production *and/or* warehouse, with the ability of vertical communication	x	x	x	x
	Remotely control of asset(s) *and/or* product(s) are possible	x	-	-	x
3	At least two IoT-objects (assets *and/or* products) with the ability of vertical communication	x	x	x	x
	At least one specific operation has been automated within the production *and/or* warehouse environment	x	x	x	x
4	More than two IoT-objects among the assets *and/or* products, with the ability of horizontal communication *and* vertical communication between assets *and/or* products	-	x	-	x
	A specific part of operations in the production *and/or* warehouse environment have been automated	-	x	-	-
5	At least ten IoT-objects among the assets *and/or* products with the ability of horizontal communication *and* vertical communication, between assets *and/or* products				
	IoT-objects has self-awareness capabilities				
	There`s an extended use of robots in the production *and/or* warehouse environment				
	Standardization				
6	Increasingly number of IoT-objects, among both the assets *and* the products				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	IoT-objects have self-management capabilities				
	Use of robots in the production *and/or* warehouse environment replaces a high degree of manual work operations				
	There exists a plan and strategy for Data Management				
7	Increasingly number of IoT-objects among both assets *and* products				
	Asset/product-to-supplier/customer communication externally				
	Asset/product-to-human/stakeholder communication internally				
	Horizontal communication *and* vertical communication, between assets *and* products				
	Use of robots in the production *and* warehouse environments replaces a high degree of manual work operations.				
	Big Data Management				
	Actively engaged in Data Analysis				
8	There`s an optimal IoT-technology use, meaning that there`s a seamless integration and communication between humans, robots, machines and products, with limited direct human intervention				
	The production *and* warehouse environments have been completely automated				
	Business Intelligence and Continuous improvement				
Maturity level achieved		3	4	3	3

Figure 10. IoT maturity assessment (Bø & Wiig, 2016)

2.1.4 Other Industry 4.0 related concepts and technologies

2.1.4.1 Cyber physical systems (CPS)

Another key concept in Industry 4.0 is Cyber Physical Systems (CPS), which is defined by German Trade and Invest as:

"Cyber-physical systems (CPS) are enabling technologies which bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other."(GTAI, 2014).

From todays embedded systems, CPS represents the next generation embedded intelligent ICT systems that will perform more efficiently, collaboratively and resiliently, while transforming industries towards the fourth industrial revolution. (Sintef, Lee et.al. 2014). Based on the definitions of IoT and CPS it is clear that the concepts are highly related to each other, where it is clear that the IoT is one of the key enabling technologies for CPS as it enables the connectivity of the physical and digital world and the ability for object to communicate and interact with each other. In that sense, CPS can be viewed as the systems that manages and coordinates the flow of information collected through the IoT. Thus, the two concepts becomes mutually dependent on each other. A CPS cannot be achieved without the IoT, and the benefits of IoT cannot be realized without the CPS.

2.1.4.2 Robotics

The use of robotics in manufacturing has grown formidable during the last couple of decades. Today, robots and machines play an important role in most manufacturing environment as their efficiency in many areas far exceeds human capabilities. They also might alleviate those tasks that are too difficult, dangerous, or impractical for humans. Technological developments such as sensor technology and artificial technology will likely result in more advanced robotics used in various applications (McKinsey, 2013). Since robots and machines operate in the physical world, they too will require integration and connectivity in the context of CPS and IOT.

2.1.4.3 Big Data

The amount of data being generated around the world today is staggering and far beyond the human comprehension of quantity. Data is being generated across a wide range of sources such as internet transactions, enterprise systems, phones, cars, and sensors to mention a few.

This leads to the collection of vast amounts of data that is extremely varied and unstructured. In addition, it is expected that the amount of data generated will double every two years (Gantz and Reinsel 2013). The collection of data at a high velocity, with high variety, and in high volume are the three V's that traditionally have been used as characteristics of the concept Big Data. Companies that are able to harness the power of Big Data are expected become data-driven businesses, capable of transforming big amounts of unstructured and varied data into information in a high velocity, which manifests itself in some form of increased value and competitive advantage. The value added by Big Data analytics is highly varied and is determined by the information need of the decision makers in question (DHL, 2013). From a value perspective, Big Data can be divided into three value dimension (DHL, 2013):

1. Operational efficiency is based on the ability to make better decisions with the use of data to increase the level of transparency in operations, optimize the utilization of resources, and improve process quality and performance.
2. Customer experience is based on the ability exploit data to understand the behavior of customers and to optimize the service provided towards customers.
3. New Business models is based on the ability to capitalize on data by expanding and creating revenue streams from existing and new products.

There has been a lot of buzz around Big Data in recent years and the perceived benefits are often highly optimistic. On the one hand, the potential benefits are significantly great, while on the other hand the complexity of achieving this and risk of failure is also present. The role of Big Data will still be relevant and important in the context of Industry 4.0 as the amount of data collected from IOT and CPS will continue to grow in the future. This further emphasizes the role of Big Data analytics as a core component of such systems and an important contributor to operational efficiency and the other value adding dimensions.

2.1.4.4 Artificial Intelligence

One of the core visions of Industry 4.0 is to have systems that are able to make intelligent and autonomous decisions based on the information collected from the physical and digital world. This involves the capability of objects to intelligently communicate and interact with each other without needing the support of humans (GTAI, 2014).

One of the most anticipated and discussed development within the field of computer science is Artificial Intelligence (AI), which aims at creating intelligent machines that work and react as humans in order to be able to learn, decide, and solve complex problems autonomously (Techopedia). Combining the data processing powers of machines with the learning and decision making capabilities of humans is one of the key enablers of increased efficiency and automated manufacturing environments within the scope of Industry 4.0, where planning and control system will have the capability to make sound decisions based on the ability to process vast amounts of data in an intelligent manner.

2.1.5 Global Standards

The world as we know it is increasingly becoming more and more globalized as a result of the developments within technology and trade that has connected countries, markets and people. The use of global standards have played an important role in developing the interconnected technological infrastructure needed to establishing efficient global trade. One of the biggest organizations working to develop and maintain international standards is ISO, short for International Organization for Standardization. ISO has over 21000 standards in total that provide value, safety and quality for consumers, businesses and governments (ISO). The importance of international standards is defined by ISO as:

"International Standards are the backbone of our society, ensuring the safety and quality of products and services, facilitating international trade and improving the environment in which we live in (*ISO)."*

ISO is just one of many organizations offering global standards for technology, manufacturing and trade. There are numerus of providers for global standards across different business functions, markets and sectors. Within the scope of logistics and SCM, the ability to communicate and share information effortlessly and efficiently with trading partners both in the upstream and down stream supply chain is extensively covered in the SCM literature as an important success factor. The main challenge to accomplish this goal is that many supply chains are not well integrated in terms of processes, systems, and standards. This means that even sharing simple information can become time-consuming and potentially error-prone. The use of global standards is an effective way of reducing the challenges related to ensuring efficient flow of information through the supply chain. When everyone is using the same standards, or in other words speak the same language, less time and resources is wasted on activities that does not add value to the companies and the final customer.

In the scope of this thesis, three important types of global standards is relevant and considered as important considerations. The first type of standards deals with the way physical objects are identified and captured as they flow through the value chain, and subsequently through the supply chain. The second type deals with the integration between the physical assets in the manufacturing environment, while the thirds type deals with the integration between the different system- and management-levels in the manufacturing environment. The following is an introduction to some of the global standards that are considered important elements for the conceptual MPCE system that will be developed later.

2.1.5.1 GS1 Standards

Unless supply chains are completely vertically integrated, they usually consist of different companies that use different methods and standards towards how they identifying products, and how they structure and share information. The global non-profit organization GS1 develop, maintain and offer global standards used in logistics and supply chain management to ensure the efficient flow of goods and related information. The main service offered is defined by GS1 as *"a common language to identify, capture and share supply chain data– ensuring important information is accessible, accurate and easy to understand (GS1)."*

The logic behind the GS1 standards is therefore divided into four main dimensions according to their role in supporting information needs related to real world business processes. The following is an introduction to the four dimensions; Identify, Capture, Share, and Use.

2.1.5.1.1 Identify

The GS1 identification standards provide methods and tools needed to enable the identification of real world entities, so that electronic information about them can be stored and communicated.

The GS1 standards use ID keys to uniquely identify, products, documents, businesses and physical locations. The uniqueness of the ID keys enable them to be shared among trading partners across the supply chain, increasing visibility and traceability. Currently, there are 11 different types of GS1 ID keys that can be used to identify a wide range of object classes. Table 1 shows the current set of ID keys developed and maintained by GS1.

Table 1 GS1 Identification keys (GS1)

GS1 ID Key	**Used to Identify**
Global Trade Item Number (GTIN)	Products and services
Global Location Number (GLN)	Parties and locations
Serial Shipping Container Code (SSCC)	Logistics units
Global Returnable Asset Identifier (GRAI)	Returnable assets
Global Individual Asset Identifier (GIAI)	Assets
Global Service Relation Number (GSRN)	Service provider and recipient relationships
Global Document Type Identifier (GDTI)	Documents
Global Identification Number for Consignment (GINC)	Consignments
Global Shipment Identification Number (GSIN)	Shipments
Global Coupon Number (GCN)	Coupons
Component/Part Identifier (CPID)	Components and parts

Within the scope of IoT, the GS1 standards provide solution for the unique identification of all "Things" related to the flow of goods. The rapid growth of the IoT will require a persistent set of identifiers for everything that needs to be accessed and monitored in the physical world, which according to GS1, is well suited for their identification system that has been designed in a generic way that makes it applicable for any IoT application (*GS1*).

2.1.5.1.2 Capture

The capture dimension of the GS1 regards the tools, technologies and methods that enables the automatic capture of data carried by physical objects.

When goods move through the supply chain, the associated information should flow even faster. When a product is completed at one business event, the next event should be aware of the incoming flow before the physical flow arrives. In addition, customers are demanding more and more dynamic, accurate and detailed product information, meaning that information becomes a potential source of competitive advantage. This mean that the associated information flow must flow faster than the physical movement of goods, which is a characteristic enabled by the development of ICT that has enabled real-time connectivity across the whole world. In order to improve control and visibility in the supply chain, trading companies want to capture as much relevant information as possible in order to make better managerial and operational decisions, with the objective of providing better products and services to their customers.

GS1 use a standard called Electronic Product Code Information System (EPCIS) to capture and share information about the physical movement of products through the supply chain. The main goal of EPCIS is to increase supply chain visibility through the sharing of event data, both within and between trading partners. In order to achieve increased visibility and control, certain data needs to be collected at each business event. The EPCIS is intended to be used together with the GS1 Core Business Vocabulary (CBV) standard, which further standardizes the way data structures and definitions are used in a supply chain business context. These data requirements are articulated into four questions that needs to be answered at each data capture event:

- What is captured? When using GS1 standards, one of the 11 types of ID key category is used to uniquely identify an object. The ID key itself will not provide any valuable information about the object, but the ID key will usually be linked to the product in a centralized data storage such as an ERP system. This is related to the concept of a digital twin, where the physical product contain only the minimum amount of information needed, i.e. ID key on barcode or RFID tag, while complete information about the product is stored digitally and separated from the physical product.
- Where is it captured? It is also important to know where the capturing of the business event took place. This could be a physical location such as exact geographic coordinates, or it could be a business location like for instance inbound warehouse.
- When was it captured? Is a timestamp in a standardized format at which the capturing event took place.
- Why was is captured? This question is concerned with explaining why the information was captured trough the three previous questions. The right answer should be that the capture point denotes the beginning or end of a business event, at

which valuable information from the event can be extracted and used to achieve better control and visibility.

Within the scope of the IoT and Industry 4.0, the ability to capture business event information will continue to evolve as the integration of the physical and digital world continues through the use embedded identification and sensor technologies. This translates to the ability to not only capture more detailed and complete information from each business event, but also on the ability to capture more business events. If one consider the possibilities provided by an IoT-enabled Cyber Physical Systems, which has said to provide a complete integration between the physical and digital world, then this in theory would mean that we could capture all events in the cyber physical space, which in other words would be all the real world events.

2.1.5.1.3 Share

The share dimension consists of the technologies and standards that provide the means for sharing information between trading partners, as well as internally. This includes data standards for handling and sharing master data, business transaction data, and visibility event data used for tracking objects in the supply chain. In addition, data communication standards and protocols enable the sharing of information between physical objects, applications, and trading partners (GS1).

The IoT gives rise to vast amounts of data that needs to be captured and shared internally and across the supply chain. The use of embedded technologies entails the use of wireless communication and networks to transfer the information from the physical to the digital world. Technological concepts such as cloud computing enable decentralized storage of data where data can be easily shared and accessed by stakeholders and trading partners. The growing set of IoT applications will further increase demand for accessing and sharing data ubiquitously and in real-time (*GS1*).

2.1.5.1.4 Use

Unlike the previous dimensions, the use dimension is far less based on standards and more situational depended. Traditionally, the main usage of the information captured in the GS1 has been to increase visibility and traceability of flow objects across the supply chain.

Within the scope of Industry 4.0 and the IoT, the use dimension will play an important role in transforming the huge amount of data that is captured, not only from the flow objects in the supply chains, but also from a wide range of physical things. Technology concepts such as Big Data will play an important role in managing and analyzing vast amounts of data in order to streamline business processes and to support optimal decision-making or event making them autonomously. This means that operations supported by Industry 4.0 concepts and technologies such as the IoT, Big-Data, and machine-to-machine communication will enable smart manufacturing environments where things and systems are connected and integrated in order to make intelligent and autonomous decisions and execution of tasks (GTAI, 2014).

2.1.5.1.5 GS1 4.0

According to GS1, the standards provided by GS1 connects the physical and digital world, enabling the connectivity and interoperability required by the IoT. The ever-increasing interconnectivity between objects, people and their environment will require a new set of capabilities within the IoT represented as the following services at which the GS1 standards are ideally positioned to serve (*GS1*):

- Identification schemes management, which is concerned with uniquely identifying objects/things.
- Authentication services, which ensures the authentication of objects identified.
- Master data about classes of things, serialized items, and legal entities.
- Resolution services, which provides the directions to the digital representations of physical things, i.e. digital twin.

The GS1 standards have traditionally been used to gain increased visibility through identifying, capturing, sharing, and using information collected from the flow of physical objects through the supply chain. The logic behind the GS1 standard is based around capturing major business events in order to gain visibility and transparency into the supply chain flow. In other words, the GS1 standards is centered on the ability to track and trace the location and/or status of physical trade objects in the supply chain. Although this thesis is centered on the internal flow of subjects and information, or in other words on the internal value/supply chain, the same logic applies as to the overall supply chain. The only difference is that for the internal supply chain, the amount of information captured can be significantly higher and more detailed as the potential use of the information is much wider and without privacy concerns. This means that not only do companies want to capture information about major business events, but also more intermediate information such as real time monitoring of all things and processes. In addition, it could be beneficial for companies to align the internal business language and identification schemes with the external supply chain actors as described by the GS1.

2.1.5.2 OPC UA Standards

The OPC foundation is responsible for the development and maintenance of global interoperability standards that enable secure and reliable exchange of data within the industrial automation space (OPC).

Most manufacturing environments are characterized by being heterogeneous in terms of having systems and machines from different vendors that may not use the same standards in terms of communication protocols and data formats. This poses a great challenge when trying to connect systems, machines and other physical “Things” in the creation of cyber physical systems.

OPC Unified Architecture (UA) is a communication standard that ensures secure and reliable exchange of data in the industrial automation space and in machine-to-machine communication. The standard works independently among devices from multiple vendors to ensure the seamless flow of information (OPC). The advantages of OPC AU are the following:

- Independent of hardware and software platforms.
- Secure transfer of data by using encrypted communication protocols.
- Scalable and extensible by having backwards and forwards compatibility for existing and new technologies and products (OPC).

2.1.5.3 ISA-95 Standards

The International Society of Automation (ISA) is a nonprofit professional association that develops and maintains standards aimed at improving the management, safety and cybersecurity of modern automation and control systems (ISA)

The concept of automation in manufacturing has focused a lot on the automation of tasks on the manufacturing process level. Automation does however not end with equipment control, but also include the higher levels of control regarding the management of materials, people and assets across production areas, where the true efficiency of the manufacturing company should be measured. The ISA-95 standard defines five levels of activities in a manufacturing environment (OPC, 2013):

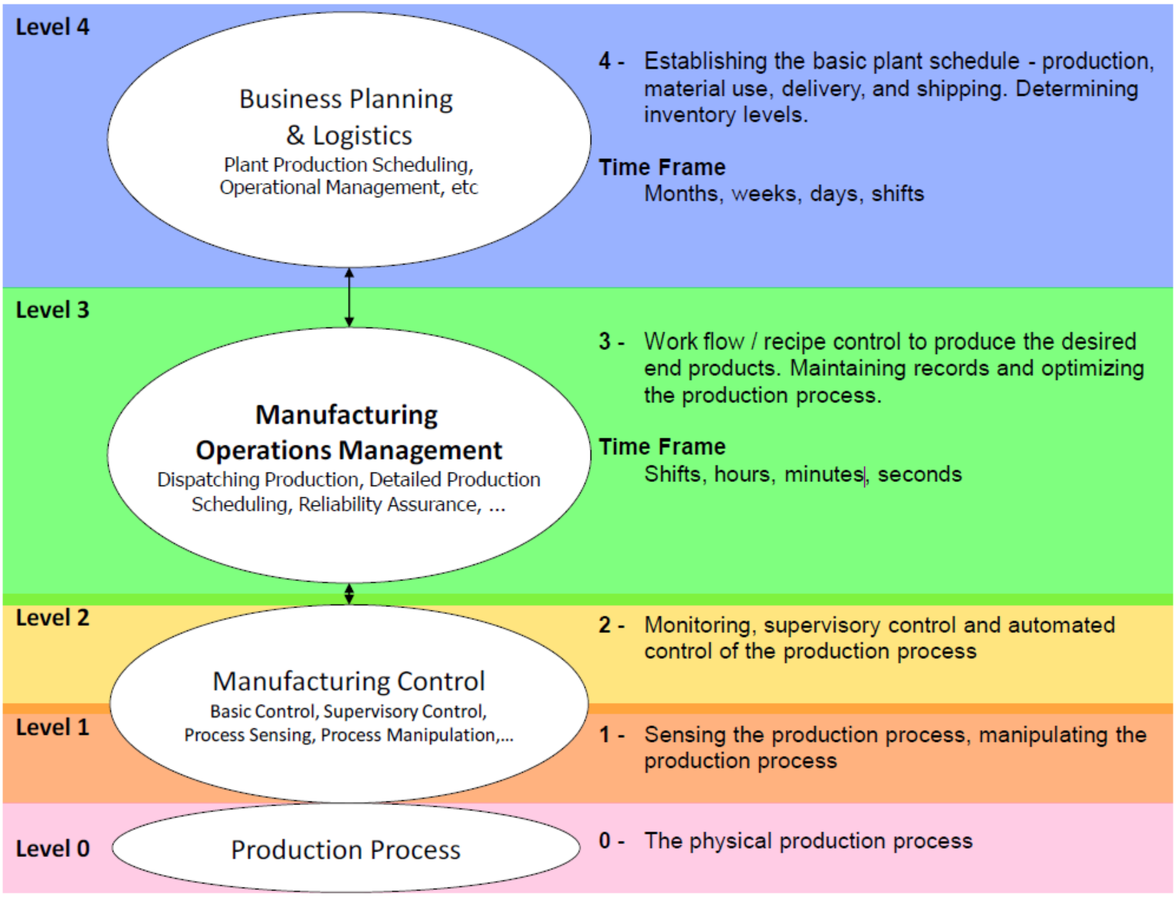


Figure 11. Five Activity Levels in Business (OPC)

As illustrated in figure 11, level 1 and 2 is generally supported by the use of various technologies to automate tasks and processes that lead to the increased efficiency of the manufacturing process. Level 3 is concerned with the coordination and control of all the resources consumed by the manufacturing process in real time, as the processes is running. Manufacturing operations management usually collects information from multiple processes and information systems such as Manufacturing Execution Systems (MES) and Warehouse Management Systems (WMS). Level 4 is typically supported by an ERP-system that enable the manufacturing company to schedule its manufacturing activities and required resources. The ISA-95 standard was developed to enable the efficient sharing and coordination of information across the different levels. This is achieved by using standards that uniquely describe the exchanged information, including the interrelationships between the different types of information. The information collected from the different levels consists of four primary types of information that are frequently exchanged (OPC, 2013):

- *"Information about material and the properties of materials,*
- *Information about equipment as it pertains to the operations being performed,*
- *Information about the physical assets that make up the equipment,*
- *Information about personnel and their roles and qualifications."*

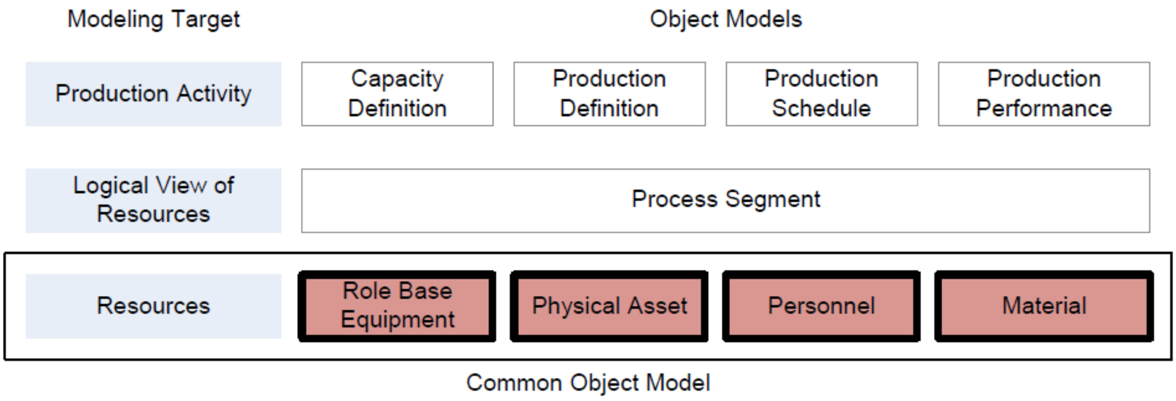


Figure 12. ISA-95 Overview (OPC)

Figure 12 shows the overview of the ISA-95 standard. It shows the necessary sources of information that needs to be collected, shared and coordinated in order to achieve high levels of efficiency across the entire manufacturing environment. This includes not only the information collected from the different types of resources and the efficient sharing of this information, but also on the knowledge and integration with manufacturing resources such as the production capacity, processes, schedule and performance.

Standards such as the OPC UA and ISA-95 can be considered to be core enablers of Industry 4.0 related concept such as the IoT and CPS, as they enable horizontal and vertical communication, integration and interoperability across different levels in its environment (Zumbach). An example of this is illustrated in Figure 13, where the automation pyramid represents the different levels that must be integrated to achieve Interoperability and Integration Requirements for Industry 4.0 that when fully integrated, the structure of the system will resemble a network rather than a pyramid. This implicitly involves the integration between the different levels, systems, resources and activities into an integrated and interoperable manufacturing network, which to a large degree can be supported by the use of the UPC-UA and ISA-95 standards.

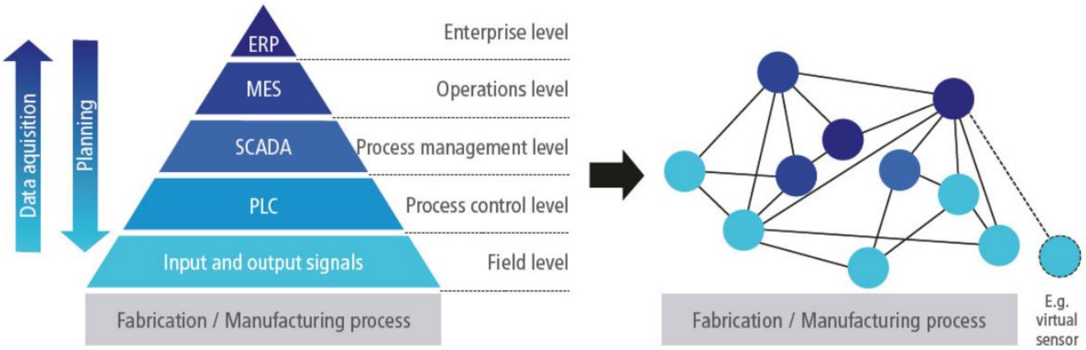


Figure 13. Automation pyramid (Zumbach)

Figure 13 also illustrates the more traditional approach to manufacturing planning and control where planning related information flows from the top-down to the manufacturing process, and event related information flows from the bottom-up to the ERP system within the control aspect. This the theory behind this topic will be presented in more detail in a later section.

2.2 Manufacturing, Logistics and Supply Chain Management

This section provides the literature review that forms the theoretical foundation for manufacturing, logistics, and SCM.

2.2.1 Definitions of Logistics and SCM

Within the academic field of Logistics and Supply Chain Management there is a whole range of different definitions and boundaries used to describe the concepts. As will be defined later, the two concept share an important commonality in terms managing the supply chain, which is defined by Harrison and Van Hoek as the:

"A supply chain is a network of partners who collectively convert a basic commodity (upstream) into a finished product (downstream) that is valued by end-customers, and who manage returns at each stage (Harrison and Van Hoek, 2011:7) *."*

Each partner in the supply chain thus represent one or more processes that that adds value to the final product in the eyes of the customer. The objective of the overall supply chain process is to transform materials and information into output in the form of the finished products or service (Harrison and Van Hoek, 2011).

In recent years, the globalization trend supported by the developments in ICT have greatly changes the landscapes of supply chains. Many supply chains have grown to reach across continents, which has increased the complexity of managing the chains and created highly competitive markets. This means that companies can no longer attribute their success and performance to their own internal performance, but rather on the capability of the management to integrate the intricate network of business relationships (Lambert et.al. 1998), i.e. the supply chain. The management of the supply chain is known as Supply Chain Management and is defined by the Council of Supply Chain Management Professionals as:

*"Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies (*Cscmp*)."*

As can be understood from this definition, SCM is mostly concerned with planning and controlling all inter-organizational relationships and flows by achieving linkage and coordination between the supply chain members and major business processes. Furthermore, this definition defines logistics as a part of SCM. Whereas SCM is more focused on interlinkage and coordination between supply chain partners, logistics is more focused on the two critical flows within supply chains, namely the material and associated information flow. The Council of Supply Chain Management Professionals defines logistics management as the:

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

These definitions place a lot of emphasis on inter-company coordination and flow of goods and information across the whole supply chain. However, the internal processes within each supply chain member is also an important part of logistics and supply chain management, where coordination and management of the internal supply chain should be aligned with the external supply chain. In the context of this thesis case study, the main emphasis is placed on analyzing a specific node within the internal manufacturing process at Brunvoll. In that sense, the case study will mainly follow the logistical perspective of product and information flow internally.

2.2.2 The Value Chain

Another way of viewing the internal supply chain is through the concept of the value chain, where the focus is on the creation of value within each process. Michael Porter first coined the concept Value Chain back in 1985 in his book "Competitive Advantage: creating and sustaining superior performance". Porter stated that competitive advantage could not be understood by just looking at a company as a whole, but rather disaggregate the company into strategically relevant activities. When companies analyze their value chain, they are more able to identify which strategic activities represent the core competencies and competitive advantage for the company. Furthermore, the value chain enables companies to understand the behavior of costs and the sources of differentiating capabilities. This means that the ability to understand the value chain and make decisions based on it is what will deliver value to companies in terms of increased margins and competitive advantage (Porter 1985, Christopher 2011).

Porter's value chain categorizes the activities of traditional manufacturing companies into primary and secondary activities. Primary activities are the core functions used for making and selling the product to the customer. The secondary activities are support functions that cuts across the primary activities in order to give the required support. The profitability and competiveness of companies will be determined by analyzing each activity in the value chain by looking at what value the activity adds to the total picture, which in Porter's model is known as the margin (Figure 14). Even though the primary activities usually deliver the most value to the company, it is still important to not to neglect the secondary activities. This is because the secondary activates has the potential either adding or reducing value across one or more primary activities. The trend during the last couple of decades has been to outsource the activities that does not add value to companies. The effects of outsourcing is that the value chain extends beyond the boundaries of the company and thus becomes the supply chain (Christopher, 2011).

Figure 14. The value chain (Porter, 1985)

In the scope of this thesis, the focus of the case study will be within the primary activity operation, which includes the different manufacturing processes. Furthermore, support activity technology development will also play an important role, as the revised To-Be system incorporates serval technological concepts that could potentially support several of the primary activities.

2.2.3 Product Delivery Strategy

Product proliferation is a term used to describe the how production and customer requirements has changed during the last couple of decades, as consumers have become more demanding in search of personalized and customized products that suits their exact requirements. Globalization and developments in ICT technologies has fueled this trend even further by making the world a global marketplace for products and services with almost countless possibilities and offerings. Which manufacturing and supply chain strategy a company will use will largely depend on the nature of the product and the requirements of the customer. Olhager (2003) classifies four different product delivery strategies based on where the customer order decupling point/order penetration point (CODP or OPP) occur in the value chain, illustrated in figure 15.

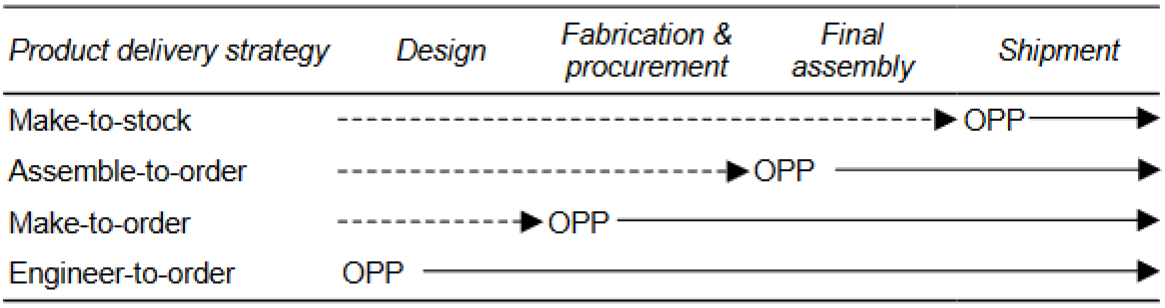


Figure 15. Product delivery strategy (Olhager, 2003)

Make-To-Stock (MTS) products are usually standardized products that are produced to stock on a forecast basis, i.e. before the customer orders it. Here, the customer has little or no influence as to the design and specification of the products. Typical MTS products are consumables and other shelf products. Assemble-to-Order (ATO) are products that have a predefined modular design with standardized components that are assembled to the requirements of the customer. Examples of ATO products could be modular products like computers and bicycles where the manufacturer allows the customer to make decisions as to the configuration of certain components. The Make-To-Order (MTO) manufacturing process is characterized by having the customer order decupling before any product is produced. This might include products that are both standardized or have some degree of customization. An example of an MTO product can be products where demand is highly volatile and hard to predict, at which production only occur after the customer places an order. Another example of an MTO product could be tailor made suits where the design of the suit is predefined, but the fitment process is tailored to the measurements of the customer. Engineer-To-Order (ETO) takes the MTO strategy one step further by allowing the customer to influence his or her requirements in the product engineering/design phase. This means that none of the main manufacturing activities in figure 15 are performed before the customer places an order and thus initiates the production of a unique product. As can be understood from figure 15, the product delivery strategy will greatly influence the amount of interaction with the customer and the lead-times from order placement to fulfillment. Gosling and Naim (2009) find that despite the trend that markets are moving more and more towards the two latter strategies, research into the ETO sector has been neglected within the field of operation and supply chain management.

2.2.4 Engineer-To-Order manufacturing

In this section, the theoretical foundation for ETO manufactured will be outlined. As mentioned in section 1.3, Brunvoll's capabilities and value chain help classify them as an ETO Manufacturer, which is also supported by the case study findings. However, the case study findings also shows that for the specific component under analysis, most of the components have been produced before and are thus considered as standardized. This means that certain parts of the manufacturing process and certain components and products at Brunvoll fall within both the MTO and ETO production strategy paradigm. The reasoning behind classifying Brunvoll as an ETO company is that the value chain and manufacturing processes is designed with the ability to handle ETO requirement. This inherently means that an ETO value chain and manufacturing processes can handle both MTO and ETO production strategy, while a pure MTO value chain/process would not be able to handle ETO requirements due to the lack of the customization/engineering capabilities.

Through an extensive literature review on ETO supply chain management, Gosling and Naim (2009) find that there is a lack of clarity as to the terminology and definition used to describe the Engineer-To-Order' supply chain type among different studies. The different ETO frameworks all agree to on the fact that an ETO supply chain is driven by the customer order and that orders penetrate the supply chain before the design or engineering phase, but some disagreements can be found as to the extent and role of the customer involvement in the design phase. This will obviously depend and vary on the requirements of the customer and the capabilities of the process, like for instance if the customer require the exact same product that has been made before, which in such a case might imply that the company follows an MTO strategy for that specific customer order. This means that many companies and their product delivery strategy can be classified as both ETO and MTO manufacturers depending on the uniqueness of each customer order. ETO manufacturing is associated with a wide variety of terminology synonyms used to describe the operating environments in which customer specific manufacturing occur, such as Project-based, craft, one-of-a-kind, and design-to-order manufacturing (Gosling and Naim, 2009).

Based on the summary of the literature review on ETO manufacturing, Gosling and Naim (2009) provide a comprehensive classification of the ETO supply chain as:

"The commonalities are that the ETO supply chain operates in a project environment and that each product is different to the last. Production dimensions of the supply chain are

completely customized and the decoupling point is located at the design stage. The differences are that existing designs maybe modified to order or completely new designs are developed to order. There may also be sector specific differences. For example, each construction project has to be completed on a new site, whereas shipbuilding may take place at a fixed location (Gosling and Naim, 2009).*"*

An important distinction is that a company or product group as a whole does not necessarily belong to just one of the product delivery strategies. An example of this could be a manufacturer that makes both standardized products, as well as customized variants within the same product group and manufacturing process. Will be discussed later, the classification of a company at the process level lies more in the design and capabilities of the process rather than the product and the CODP/OPP at the value chain level.

2.2.4.1 Strategic areas within ETO

As mentioned, the trend of mass customization combined with the visions of Industry 4.0 means that products and manufacturing will continue to develop into more complex product and process configurations. More companies will shift supply chain structure from producing standardized products to become ATO, MTO, and ETO manufacturers, which also highlights the importance of conducting more research within the field of ETO SCM. Choosing the right product delivery strategy/supply chain structure is one of many strategic considerations companies must make as part of their strategic response to increased competition and changes in customer behavior. In their literature review article, Gosling and Naim (2009) find several different strategic areas, where different strategies are used to improve performance within ETO supply chains. The following is an introduction to some of the strategic areas, concepts and paradigms identified by Gosling and Naim (2009) that are considered to be relevant in the scope of this thesis.

2.2.4.1.1 Information management

The developments in ICT has enabled companies to collect, store and share large amounts of information created across processes in the supply chain. The rapid sharing of demand and supply data enable companies to capture more value in the eyes of the customer by creating a demand chain, which transforms the demand of the customer into value adding activities (Harrison and Van Hoek, 2011). Donselaar et al. (2001) find that even incomplete or imperfect advanced demand information could be highly useful as a source of reducing demand uncertainty in a project-based supply chain. More literature on information management will be presented later.

According to Karkkainen et al. (2003), international project based supply chains represent some of the most formidable challenges within logistics. They discuss the potential effects of creating a more effective project delivery chain by using advanced web technologies and product identification technologies, enabling what they call intelligent products. They suggest a new control system based on distributed programming and wireless identification technologies, where information is collected and shared in an open network with all supply chain members. A key characteristic of project based chains is that products needs to be planned and controlled at the individual product level as a result of the products uniqueness. The traditional transaction based control only focus on what the companies and processes need to do in order to deliver the products as scheduled. However, this type of control is considered to be highly inefficient when disruptions occur. The new identity based control system simplifies the tasks of controlling individual products across the supply chain. Furthermore, another key benefit of the developed control system is that it increases traceability across the supply chain, which increases the flexibility of the system, which in turn enables companies to make rapid responses to dynamics changes and disruptions (Karkkainen et al. 2003).

2.2.4.1.2 Supply chain integration

Hicks et al. (2000) find that the level of vertical integration in the ETO sector vary a lot from company to company. Some ETO manufactures may have the entire manufacturing process of components and assemblies in-house, while other companies may only perform design and contracting activates in-house. When considering the right level of vertical integration, companies must consider factors such as:

- *"Reconciling customer delivery times with available capacity.*
- *Reducing costs.*
- *The availability of capital for investment in equipment.*
- *Potential utilization of plant.*
- *Internal and external capabilities and flexibility (*Hicks et al. 2000*)."*

These factors will in turn decide which level of integration to be present in the supply chain. In addition, Hicks et al. (2000) also find that there has been a trend among ETO companies to move towards more vertical disintegration partly driven by the financial pressure and the need to reduce cost.

This could also be considered relevant for Brunvoll and the Norwegian offshore industry where financing and cost reduction are currently central issues due to the low oil price.

2.2.4.1.3 Business systems/process re-engineering

Gosling and Naim (2009) find that Business systems engineering (BSE) and business process re-engineering (BPR) are two popular strategies for improving performance in the ETO sector. Since ETO companies are particular exposed to changes in customer requirements demand, the ability to adapt to these changes in a responsive manner is of high importance in today's competitive markets. This implicitly means that process design is not some onetime event, but rather a continuous process, where the objective is to conform the process requirements at all times. Business systems engineering is concerned with designing and implementing business processes within companies or across supply chains. Systems engineering is defined as the:

"Systematic efforts to (1) translate an operational need into system performance and configuration specifications, (2) incorporate all physical and functional requirements to achieve an optimal design, and (3) integrate factors such as maintainability, reliability, safety, and security to meet cost, performance, and schedule objectives" (Businessdictionary).

This inherently means that if the operational needs of a process changes, then the system engineering process should be repeated. Another important aspect system engineering is that the integration of factors that might influence the process ability to meet the cost, performance and schedule objectives must be taken into consideration by either handling these factors, or that efforts are made to reduce the bad ones. This topic will be analyzed and discussed extensively during the case study section.

Business process re-engineering (BPR) is a method based on radically changing business processes. The core fundamentals of BRP is to rethink and redesign a business process, its structures and associated management systems, in order to deliver significant improvements in performance. BRP is a method widely used within total quality management (TQM), where the goal is to align all processes and activities with the requirements of the customer, and to manage these with the intent to create value in the eyes of the customer. BRP initiatives are often triggered by disruptions such as rapid changes in customer requirements and emerging technologies. The development in information technology has been a driver for BRP initiatives during the last couple of decades. It has enabled the automation of business processes, changed customer behavior, as well as creating new products and markets. Often, the rapid change in technology will give companies the opportunity to create a breakthrough in performance. However, if the business processes of the company is not adapted to handle the disruptive requirements of the change, then the incremental improvements approach of TQM may not have the power needed to change the process in the required rate. Since responding to disruptions in technology and customer requirements is a source of competitive advantage, the ability to utilize the BRP approach could prove to be an important strategic tool for companies (Oakland, 2003).

Gosling and Naim (2009) find several case studies where BSE and BRP initiatives yielded substantial improvements in performance in the ETO sector. Finding from Childerhouse et al. (2003) showed improvements in reduced cycle-times, delivery frequencies, stock turns, profit margin and annual volume. The case study was conducted across four different areas in a construction supply chain: Just-In time manufacturing, reducing lead times, Supplier Integration, and Customer Integration. However, according to Cameron and Braiden (2004), the application of BRP principles become much more complex when functional boundaries and supply units are crossed.

2.2.4.1.4 Flexibility

The role of flexibility in ETO related processes and supply chains are shared among many researchers as an important competitive factor (Gosling et al. 2013, Gosling and Naim 2009).

According to Gerwin (1993), flexibility within supply chains is perceived as the adaptive response to environmental uncertainty. Most of the research on SC flexibility is focused on the internal flexibility of the manufacturing processes within flexibility dimensions such as machines, material handling, operations, automation, labor, process, routing, product, market, volume, expansion, program, production, resources, and coordination (Vokurka and Lummus, 2003). More recent research has extended the view of flexibility from the manufacturing environment to the whole supply chain. Gosling et.al. (2010) propose two internal flexibility types for supply chain flexibility; namely vendor and sourcing flexibility. Vendor flexibility is related to the manufacturing process, warehousing and logistics, while sourcing flexibility in related to the ability to adapt, response, and reconfigure the supply chain meet the customer requirements, and to achieve supplier responsiveness, coordination and integration across the supply chain. The ability to be flexible both internally and externally thus becomes an important strategy for ETO companies. Salvador et al. (2007) find that for companies using a Build-To-Order (BTO) strategy, the supply chain requires both volume and mix flexibility. Volume flexibility is the ability to change the gross output of a supply chain while maintaining cost efficiency. This is especially important in markets with cyclical demand patterns such as the offshore industry where much of the investment and activity is highly correlated with factors such as oil and gas prices. Mix flexibility is the ability to change the mix of items and products being delivered to the market, while also remaining cost-effective. This involves the ability to respond quickly to changes in customer requirements or changes in the marketplace such as new product development by competitors, which requires both flexibility in the manufacturing and supply chain processes, as well as flexibility in the product configuration/engineering phases. Balancing volume and mix flexibility is a challenging objective, and trade-offs between the two may occur, i.e. increasing mix flexibility may reduce the ability to be volume flexible. However, Salvador et al. (2007) also find that there are potential important synergies between volume and mix flexibility. They highlight as an example that mix flexibility has the potential to also improve volume flexibility. By increasing mix flexibility, a manufacturer may increase his ability to reduce changeover times between products, and thus increase the ability to increase the output, or in other words, volume flexibility. The exact strategic approach taken by companies towards the flexibility dimensions ultimately vary based on the requirements and characteristics of the individual company, as well as its markets and customer. Taking into account the trade-offs, synergies and dimensions, companies need to have a dynamic and flexible approach to this important strategic area.

According to Christopher (2000), flexibility is a key characteristic of an agile organization. An agile supply chain is a supply chain that is responsive to turbulent and volatile market conditions, including the typical market conditions found within the ETO sector. The strength of the agile supply chain lies in the ability to rapidly respond to changes in demand in terms of both volume and variety.

2.2.4.1.5 Time compression

According to Gosling and Naim (2009), the application of time compression principles and strategies are widely proposed to improve performance in the ETO sector. According to Towill (2003), the total cycle time (TCT) paradigm is widely considered as a source of attaining international competitiveness. Towill (2003) defines the TCT paradigm as *"the* *principle of reducing the time taken to execute a business process from the perception of customer need to the satisfying of that need".* This paradigm is closely related to BPR as it involves disruptive changes of systems or processes, but the focus or goal of the initiatives is to reduce the time factor of the process. The basic re-engineering principles used within the TCT paradigm are summarized across four main principles (Towill, 2003):

1. Elimination of all unnecessary work/tasks.
2. Compress and/or streamline Non-Value-Added/Value Added time within work processes.
3. Integration of interfaces between work processes to streamline material and information flow.
4. Concurrency by developing ways of executing parallel work processes.

Success factors for achieving a successful TCT compression include an extensive and accurate analysis of the process requirements, innovations at the process design stage, along with the right subsequent planning, execution and monitoring phases. The case study findings suggests that by re-engineering the relevant business processes, total cycle time (TCT) could be reduced by as much as 40% with a 25% reduction in cost without compromising any safety or quality (Towill, 2003).

As mentioned, reducing the time factor in manufacturing and supply chains are often associated with reducing or eliminating non-value added activities, which is closely related to the objective of the LEAN paradigm and the elimination of waste. The LEAN paradigm is all about doing more with *"less human effort, less equipment,* ***less time*** *and less space-while coming closer and closer to providing customers with exactly what they want*" (Womack and Jones 2003). Time and waste are closely related as reducing waste might have a positive effect on reducing lead- and cycle-times, especially related to waste-types such as waiting, unnecessary motion, transportation and over-processing.

2.2.4.1.6 New product development/process improvement

According to Rahman et al. (2003), companies should have a continuous approach towards developing new products to satisfy the requirements of the customers and to remain competitive. New product development (NDP) is identified as a key to becoming a market leader and as a core competence. By emphasizing quality in the design phase of new products, later engineering changes, quality problems, production time and overall cost could potentially be reduced. The need for high quality in the design process is especially important for pure ETO manufacturing, where each product design is engineered/designed to a specific set of customer requirements. Other measures used to achieve business objectives more effectively is related to the information flow in the supply chain. The ability to communicate the right information from the customer in a dynamic manner, through the design and manufacturing process is essential to the success of ETO companies. In addition, the ability to predict customer demand and requirements may provide an additional competitive edge with potential reductions in cycle times.

2.2.5 Manufacturing Planning and Control

Planning and controlling manufacturing operations is a central aspect of manufacturing and operation management, where successful companies are able to build effective manufacturing planning and control (MPC) systems that integrate different functions and aspects of manufacturing. This includes the management of material and components, scheduling activities, machines and people, while coordinating suppliers and key customers. The planning part or phase of the system is concerned with planning and scheduling the activities and resources needed to fulfill the demand of the customers, while the control part or phase is concerned with measuring, controlling and flowing up on the actual outcome of the planned activities. The objective of MPC systems is thus to increase manufacturing efficiency by responding to customer demand in the most optimal way. Information from key processes are collected, which the system then coordinates so that material and information can flow efficiently and effectively across the supply chain, which ensures and support that the utilization of material, people and equipment is managed in response to the customer demand. (Vollmann et.al. 2005, Arica and Powell 2014, Harrison & Van Hoek 2011).

2.2.5.1 Enterprise resource planning

ERP systems might be the most known and adapted enterprise information system used in businesses today. Davenport et al. (2004) defines ERP systems as a:

‘‘packaged software application that connects and manages information flows within and across a complex organization, allowing managers to make decisions based on information that truly reflects the current state of their business’’.

In the scope of MPC, ERP systems are used across all the phases of planning and control, which is illustrated in figure 16. Besides providing the needed support within the important planning and control phases, a correctly implemented ERP system can yield substantial benefits such as increased automation of tasks, real-time data availability and improved visibility (Aslan et.al 2012), which inherently means that the ERP system can aid directly in the execution of the manufacturing process as well.

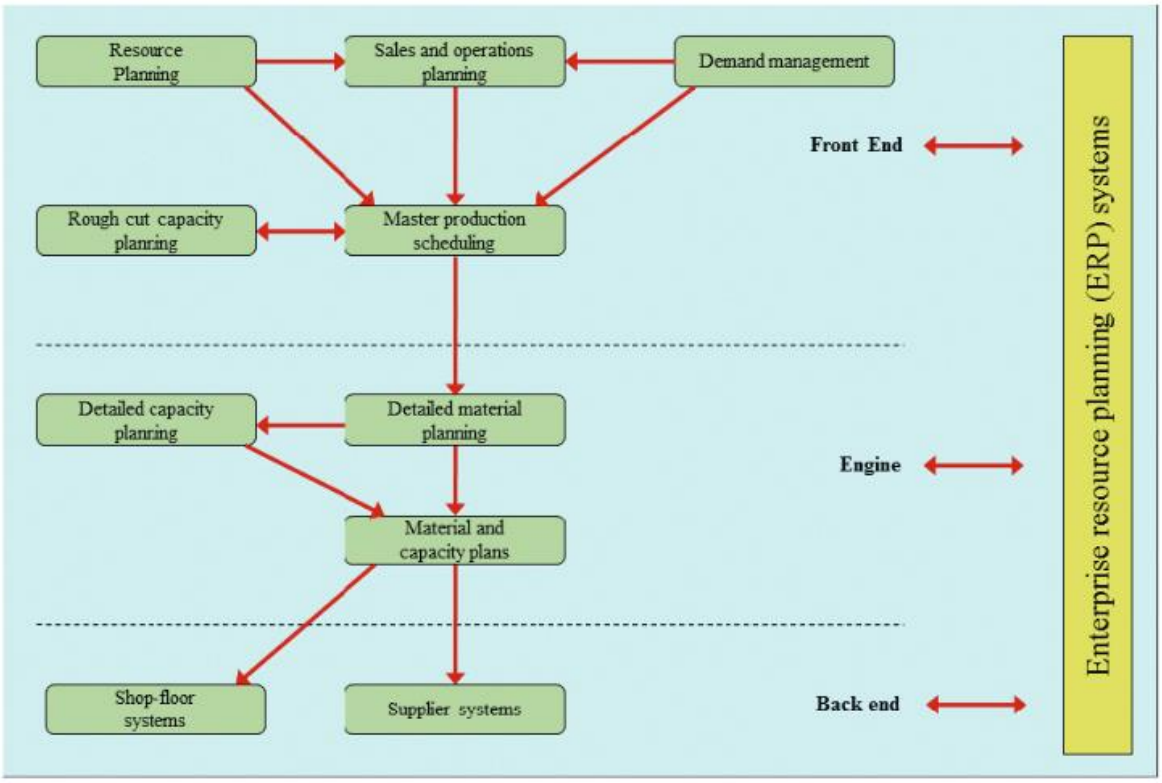


Figure 16.Traditional MPC system (Vollmann et al. 2005.)

The Front End phase of the MPC system (figure 16) is concerned with matching customer demand and supply capabilities thought the sales and operations planning that yield the Master Production Schedule (MPS). The MPS is the disaggregated high-level production schedule that at the highest level controls what is planned and what is happening (Harrison & Van Hoek 2011). The Engine phase consist of the detailed planning between capacity and materials. One of the core logical components within this phase and in ERP systems is Material Requirements Planning (MRP), which determine the purchasing and production requirements based on the structure of the product (BOM) and its demand derived from the MPS (Aslan et.al 2012). The Back End Phase consist of transforming the planned activities into actual orders and execution of tasks both internally within the manufacturing process and externally to suppliers. This is also knows as the control phase of MPC, where the actual execution of planned activities at the shop floor needs to be measured against the planned schedule (Harrison & Van Hoek 2011).

As can be seen in Figure 16, the traditional ERP/MRP based approach to MPC follows a top-down planning-to-control/execution structure, explained by the nature of the arrows only pointing downwards through the 3 phases. However, what if there is a deviation between the planned activities and the actual execution of these activities? For instance caused by an unexpected event. This is where most of the critique against the limitations of ERP system lies, as such events leads to situations where planners constantly needs to adjust plans and schedules, which requires time and resources, and might put pressure on the company and its employees to conform to the promised terms of delivery. Furthermore, it is also argued that although ERP systems provide the necessary information needed for the planning and execution of manufacturing operations, there still lack some functionality in the areas of intelligent and dynamic planning, decision support, and detailed workflow visibility. In addition, current ERP practices involve a lot of human interaction that cause problems related to quality and accuracy of data input (Arica and Powell, 2014). On the other hand, finding by Tenhiälä and Helkiö (2015) suggest that some functionalities of ERP system can actually support manufacturing planning and control in dynamic market environments thanks to the information-processing capabilities of ERP systems, which can support process reengineering and hence become flexible to changing requirements. Aslan et.al 2012 identified five critical planning and control stages for the order processing cycle in MTO/ETO companies as the:

1. Customer enquiry stage

2. Design and engineering stage

3. Job entry stage

4. Job release stage

5. Shop floor dispatching stage

They then assessed these five stages to find any fit or misalignment between ERP functionality and MTO production strategy. In the context of this thesis, the relevant stages and their fit with ERP will be the latter three stages. The job entry stage consist of activities such as purchasing, MRP-planning, and shop floor routing. At this stage, it is argued that the MRP driven replenishment strategy is somewhat unsuitable for MTO production. One of the arguments for this is that it is very difficult to derive or estimate correct lead-times when products are heterogeneous and/or unique. In addition, since the production process can include dynamic elements, such as different routing for different products, it can require a very tedious task of maintaining the correct master data that yield realistic MRP-planning. The job release stage is a decupling phase, where the transition from production planning to production control occur as the planned production is released onto the shop floor. At this stage, findings suggest that earlier ERP systems had the functionality of load-oriented manufacturing control, but that this function is not part of the contemporary ERP systems in the market. The dispatching phase is considered to be the least important stage in the planning and control hierarchy. The reasoning being that if sufficient control is achieved on the higher levels/stages, the dispatching activities can be decentralized. Due to the typical supply chain positioning of MTO companies, short-notice requests such as rush orders are quite common. This require having a responsive supply chain, which entails flexibility in the planning and control of manufacturing (Aslan et.al 2012).

As can be seen from literature and research on the fit between ERP and MTO production strategy, there exist some disagreements to the as to the applicability, strengths and weaknesses of ERP systems. It is important not to neglect the magnitude of ERP systems and their integration with most core business processes. As we have seen, the strength or weakness of ERP systems will vary based on a wide range of variables such as processing cycle stage, market conditions, product structure, manufacturing strategy, system architecture, and information quality. It is however clear, that the functionality of ERP systems lack some the capabilities needed to support all aspects of MTO manufacturing, especially in the context of ETO manufacturing and Industry 4.0, which will be investigated and discussed in detail later in this thesis.

2.2.5.2 Real-time Production Planning and Control (PPC)

According to Arica and Powell (2014), the shortcomings of ERP systems require some additional functions or systems in order to achieve complete and real-time planning and control within production systems. They believe the future of manufacturing will be based around intelligent and automated planning system that are closely integrated with real-time information systems across the supply chain that will enable manufacturers do deliver customized products while being highly responsive, reconfigurable and time efficient. They presents a conceptual framework (Figure 17) for ICT-enabled real-time production planning and control based on the integration of contemporary and emerging ICTs. As this framework is of high relevance for the scope and topic this thesis, the components of the framework will be described in more detail. This framework will be furthered revised and developed in the context of IoT and other Industry 4.0 related technologies in the discussion part of this thesis. The ERP system component have already been covered.

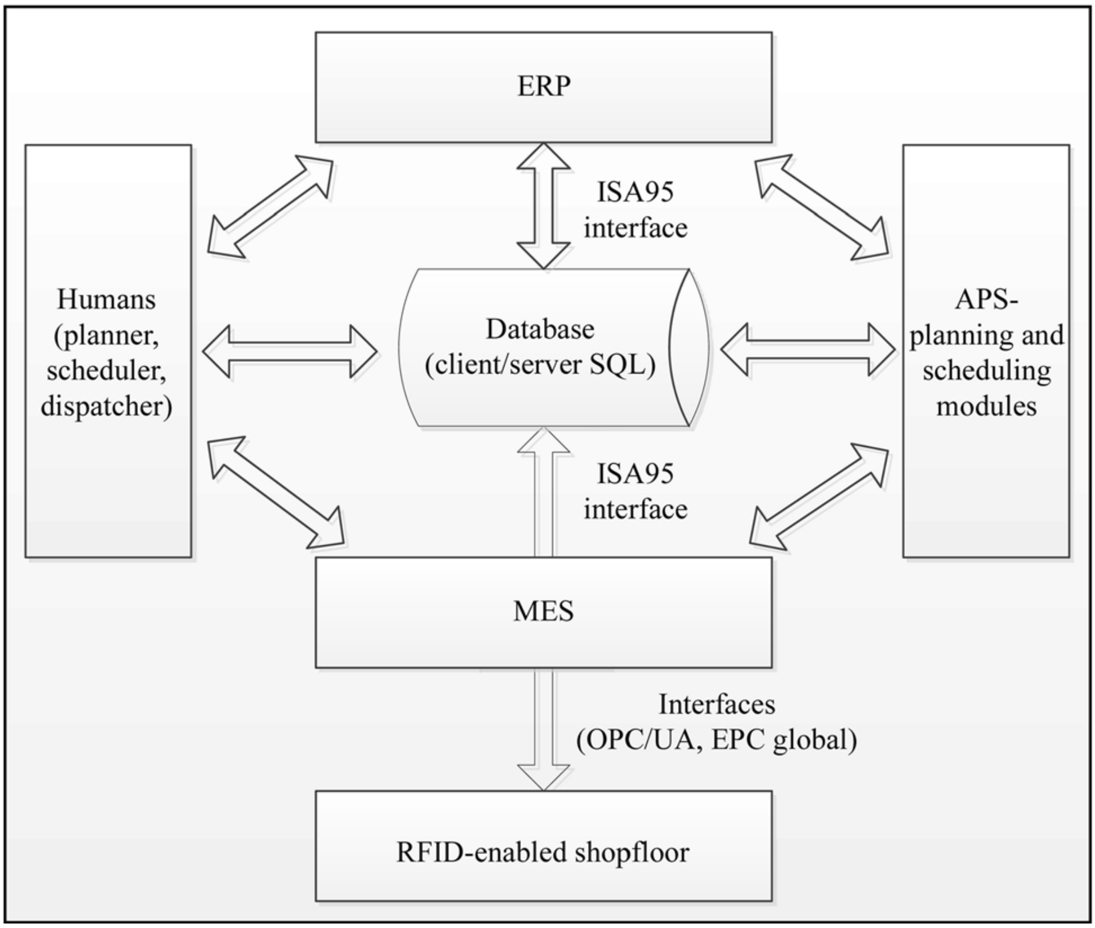


Figure 17. Real-time PPC (Arica and Powell, 2014)

2.2.5.2.1 Advanced Planning and Scheduling (APS) systems

The lack of intelligent planning and decision support functions in ERP systems has led to the development of supplementary systems such as Advanced Planning and Scheduling (APS) systems that work to reduce some of the weaknesses of ERP-systems in dynamic manufacturing environments such as can typically be found within ETO and MTO supply chains. The objective of the APS systems is to support complex planning as a supplementary system to the ERP system. When used together, the ERP system capabilities is considered as the rough planning, while the APS system is considered as detailed and dynamic planning. This means that in addition to the transaction-orientated nature of ERP systems, APS bring the additional capabilities of leveraging real time data from the shop floor with the data in the ERP system and from other sources in order to provide decision support for both demand and production planning in a dynamic manner (Arica and Powell, 2014).

2.2.5.2.2 Manufacturing Execution Systems (MES)

Manufacturing Execution Systems was developed with the purpose of aiding the execution and monitoring of the manufacturing process and shop floor activities, mainly in response to the lacking capabilities of ERP-systems in these areas. An MES is responsible for executing and monitoring the manufacturing process at an operational level that transform production plans and schedules derived from the ERP and APS systems into actual process output (Arica and Powell 2014). As can be seen from both figure 17 and 18, the MES and its functionalities lies between the shop floor processes and other components such as the ERP-system to aid in the quality quantity of information gathered to support better decision making, planning and control.

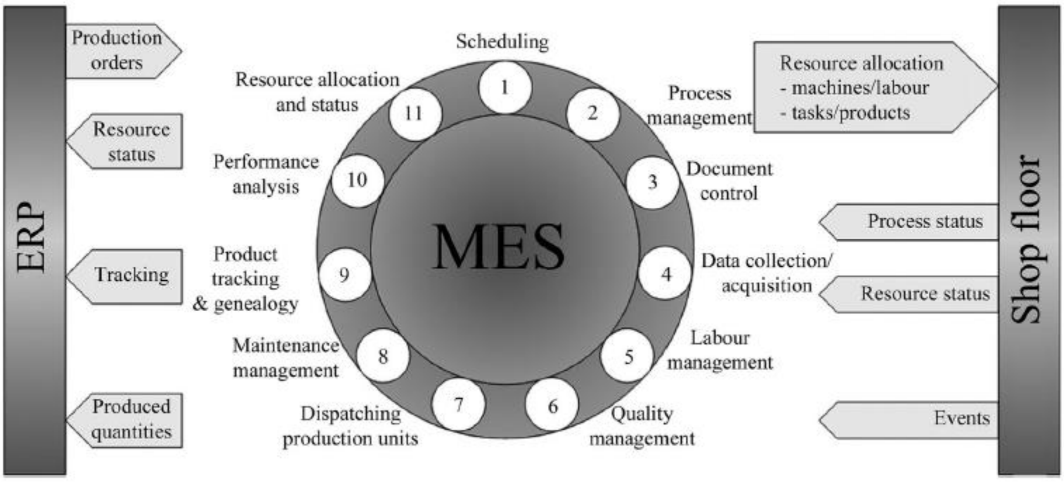


Figure 18. MES functionality (De Ugarte et.al 2009, cited in Arica and Powell 2014)

In many cases, the data capturing capabilities of an MES system lie far beyond the ERP systems, which is mostly based on capturing transaction data from the planned activities and predefined business events. An MES system can for instance be used to monitor the state of processes, available resources, and unexpected events, which is vital information in a manufacturing control and dynamic planning perspective. This support the important role of MES systems within dynamic manufacturing environments, where the relevant information needs to be captured and leveraged between the ERP and APS systems. This supports the logic behind the ICT-enabled real-time PPC framework by Arica and Powell (2012), where dynamic information from the shop floor is captured in real-time and shared with the higher level APS and ERP planning systems, which then leverage this information to make optimal decisions, as well as increasing the overall process and supply chain visibility. The benefit of this type of framework is that it can follow both the top-down and bottom-up aspects of planning. This means that normally, the overall system follows the traditional top-down approach of ERP planning. However, in the occurrence deviations at the shop floor level that should have an impact on the scheduled activities, then the system is able to adjust this from the bottom-up, which is enabled by the real time data capturing technologies, MES, APS, and ERP system working together.

2.2.5.2.3 Real Time Data Capture at the shop floor

In order for the real-time PPC system to be operational and efficient, it needs to be able to rely on the information collected from the manufacturing processes at the shop floor level. If manufacturing planning and control is based on inaccurate, untimely and uncontrolled information then the performance of the MPC/PPC will likely suffer. The conceptual framework for real-time PPC (Arica and Powell, 2014) is based on the assumption and prerequisite that information of high quality is collected from the physical shop floor processes in real-time. In the framework, the main technology used to identify and capture information relating to the physical flow of goods is RFID technology, which earlier have been considered one of the early technologies within the IoT.

2.2.6 The Role and value of Information

This section provides insight into the role and value of information in the context of manufacturing, logistics, and SCM.

2.2.6.1 Information

The traditional DIKW hierarchy (figure 19) is widely used for understanding how data is transformed from a raw state into something meaningful and value adding. The first stage in the hierarchy is data, which is collected by observing and sensing the properties of objects, events, and their environment. When data is processed in the context of a decision-making process, the purpose is usually to answer interrogative questions such as “What”, “Who” or “Why”. When we are able to extract data that support answering these questions, the data becomes information that gives it a purpose and meaning. Knowledge is the merging of information and experience so that decisions become rooted with the support of both information and experience. Wisdom is the final step in the hierarchy and depicts the ability to add value and increase efficiency based by using knowledge to make the right decisions (Ackoff 1989).

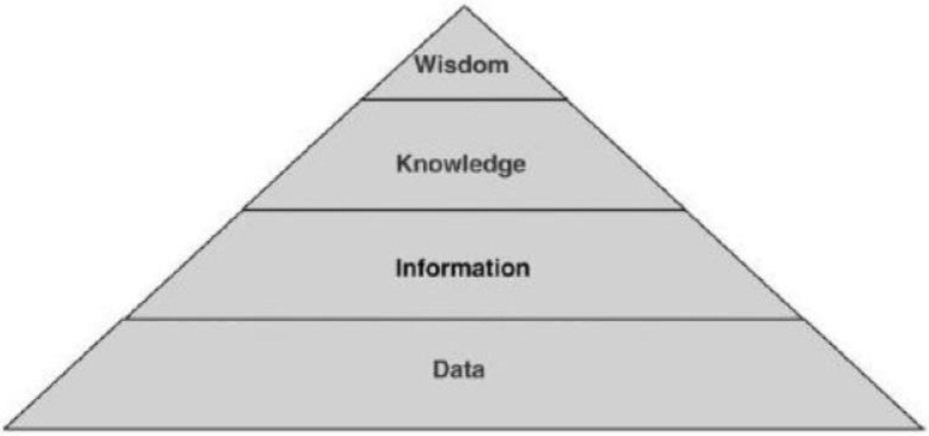


Figure 19. DIKW hierarchy

2.2.6.2 Information systems

All organizations have information systems. An information system is a system that provides processes and information that is useful for the members and clients of an organization, which in addition help organization to operate more effectively. The purpose and structure of an information system is highly dependent on the environmental context at which it operates, which in today's world is characterized by ever increasing complexity and dynamics. This means that information systems are under constant pressure to always conform to the requirements of all the stakeholders within its environmental context. Information systems are usually divided into sub-systems, which represent a set of interacting components that works in conjunction to conform to the overall objective of the information system (Avison & Fitzgerald, 2006). Examples of typical sub-systems components with information systems are:

- People
- Objects
- Procedures

Within the scope of advanced information systems such as CPS, all relevant components needs to be integrated and leveraged for the whole information system to delivers its overall capabilities. Just like with a supply chain, the overall strength of the system may easily be affected negatively by a weak link or component.

2.2.6.3 Information Quality

As described above, the term information is used as a rather general term for all data transformed for the purpose of answering inquiring questions. However, it does not take into account the important consideration of information quality as most data can be transformed into information, but not all information can be turned into wisdom that is truly wise. A more detailed definition of information is provided by the Businessdictionary as:

*"Information is data that is (1) accurate and timely, (2) specific and organized for a purpose, (3) presented within a context that gives it meaning and relevance, and (4) can lead to an increase in understanding and decrease in uncertainty (*Businessdictionary*)."*

Still, the validity of the informant is a missing aspect of the definition. Bad information exists everywhere and there is a fine line between what could potentially be turned into good information and what could end up as bad information. Bad information does not necessarily need to be caused by inaccurate or bad data, but factors such as human interpretation can in many cases lead to a misalignment between the data and the information.

McGowan (1998, cited in Zhou and Benton 2007) lists nine aspects of information quality as:

- *Accuracy*
- *Availability*
- *Timeliness*
- *Internal connectivity*
- *External connectivity*
- *Completeness*
- *Relevance*
- *Accessibility*
- *Frequently updated information*

These information quality aspects represent important factors for consideration within information management and can be used to measure the quality of information. The weight and relevance of each aspects will vary depending on the situations and the information needs of the company.

2.2.6.4 Information flow in SC

As mentioned, the flow of information is one of key flows in logistics and SCM besides the flow of goods and services. Managing and coordinating the information flow can be very challenging and complex, especially when coordinated across companies in the supply chain. In order to achieve the goal of fulfilling the customer demand at the right quality, quantity, place and time in the most efficient and responsive way, the flow of information must be coordinated across the entire supply chain effectively (Mangan et.al. 2011). This is especially important for demand driven supply chains that is fundamentally build on responding to the demand of the customer.

2.2.6.5 Information sharing in SC

It is widely accepted that effective information sharing across the supply chain enhances supply chain performance and practices (Sahin and Powell 2005, Zhou and Benton 2007). Developments in ICT has enabled companies to share information more effortlessly and in higher velocity than ever before. Information sharing practices involve the use of information technologies and global standards covered in other sections of this thesis.

Zhou and Benton (2007) developed and tested a conceptual model (Figure 20) showing the interaction between SC dynamism, information sharing and SC practices. The background of the study was the belief that supply chain dynamism will increasingly require more effective and efficient information sharing and supply chain practices and thus drive companies to improve them. SC dynamism is defined as the unpredictable changes in markets, products, technologies, and demand. Findings from the study suggest that 1. effective information sharing enhances effective supply chain practice, 2. supply chain dynamism has significant positive influence on information sharing, and that 3. supply chain dynamism has significant positive influence on supply chain practice, although not as much as for information sharing.

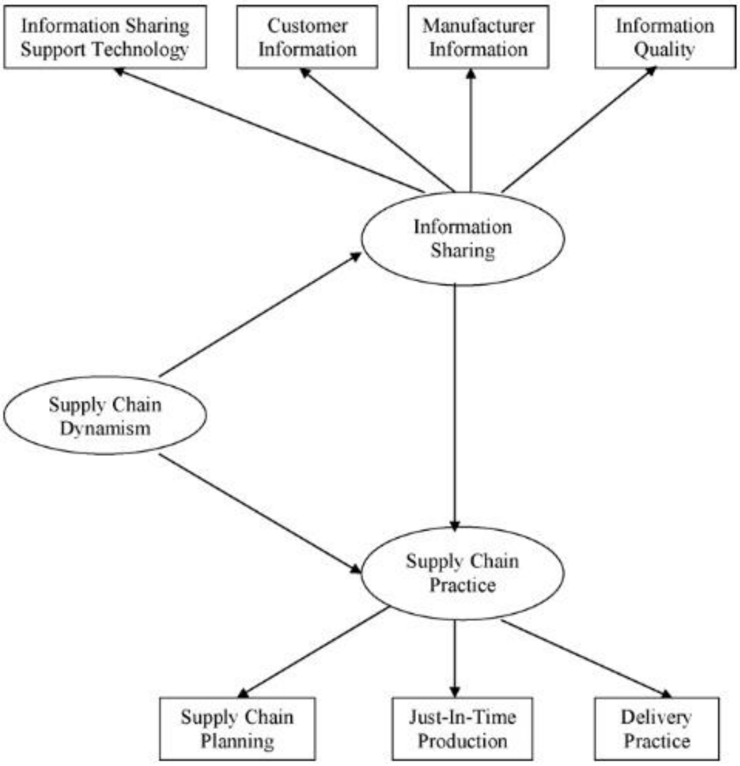


Figure 20. Supply chain practice, information sharing, and supply chain dynamism (Zhou and Benton, 2007).

2.2.6.6 Information Management.

All people and organizations need to make decisions from time to time, and information plays a central role in all decision-making processes. The developments in ICT has dramatically changed the tools and quantities of information that can be collected and used to make better decisions. Even back in 1985, Porter and Millar (1985) saw the potential disruptive effects of what they called the information revolution, which would affect competition in three vital ways:

- *"It changes industry structure and, in so doing, alters the rules of competition."*
- *"It creates competitive advantage by giving companies new ways to outperform their rivals."*
- *"It spawns whole new businesses, often from within a company's existing operations (*Porter and Millar, 1985*)."*

It is clear that the management of information is of both high importance and it serves as a potential source of competitive advantage. Choo (1995) defines information management as:

"Information management is the management of the processes and systems that create, acquire, organize, store, distribute, and use information. The goal of information management is to help people and organizations access, process and use information efficiently and effectively."

Choo (1995) also identified six core information management processes within the information management concept as:

- *"Identification of information needs;*
- *Acquisition and creation of information;*
- *Analysis and interpretation of information;*
- *Organization and storage of information;*
- *Information access and dissemination;*
- *Information use."*

In the context of MPC and ERP systems, information quality and management are two very important factors that will determine the performance of the system and its ability to plan, control, execute manufacturing activities, as well as the ability to capture quality information. As have been discussed, applying and utilizing technologies within scope of information management is one of the key elements in the scope of the IoT and Industry 4.0.

2.2.6.7 Supply Chain Visibility

The topic Supply Chain Visibility (SCV) has received a lot of attention in research and industry in recent years. SCV play a central role in SCM because of the importance of having the right information available at the right time, which is one of key factors for achieving good supply chain coordination. The market and technology trends that drives industries towards Industry 4.0 also increases the complexity and difficulty of managing the supply chain. Companies and supply chains that adapt to these factors through increased SCV are able to gain benefits such as increased performance, e.g. cost, time, flexibility, quality, and better decision making. These benefits can serve as important competitive advantages over competitors that do not utilize the potential of SCV. However, the factors also increase the difficulty of achieving the kind of visibility needed to increase performance, so while the potential benefits are huge, so are the challenges (Aberdeen Group 2013, Caridi et al. 2014, Francis 2008). In their survey of 149 companies, most of them with global supply chains, the Aberdeen Group found some interesting insight into the role of SCV in industries. The survey showed that 63% of companies think that SCV has a high priority in SCM, and that it is a critical strategy for achieving reduced costs and improved operational performance. Figure 21 shows which factors the respondents believed to increase pressure to increase SCV.

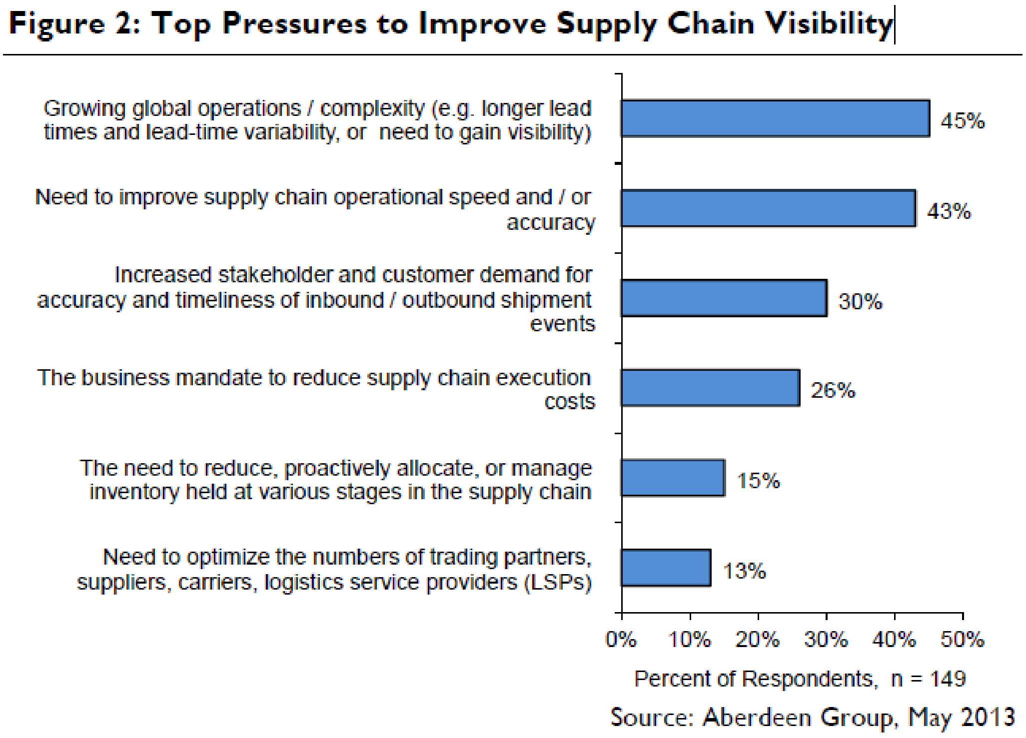


Figure 21. SCV top pressures (Aberdeen Group, 2013)

Francis (2008) finds many different definitions, characteristics and applications of SCV in the literature. Based on this, a definition that captures and unifies the most important characteristics is proposed as:

*"Supply chain visibility is the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events (*Francis, 2008*)."*

The above definition of SCV is centered around the information flow related to the physical flow of materials, components and products in the supply chain represented as entities. This definition also takes into consideration the important aspect of capturing events that also includes measuring the timeliness of the actual flow compared to the planned flow.

Goh et al. (2009) collect definitions on visibility and SCV then analyses this in the context of supply chain professional's task of optimal decision-making in order to propose a comprehensive definition of SCV:

*"SCV is the capability of a supply chain player to have access to or to provide the required timely information/knowledge about the entities involved in the supply chain form/to relevant supply chain partners for better decision support (*Goh et al. 2009*)."*

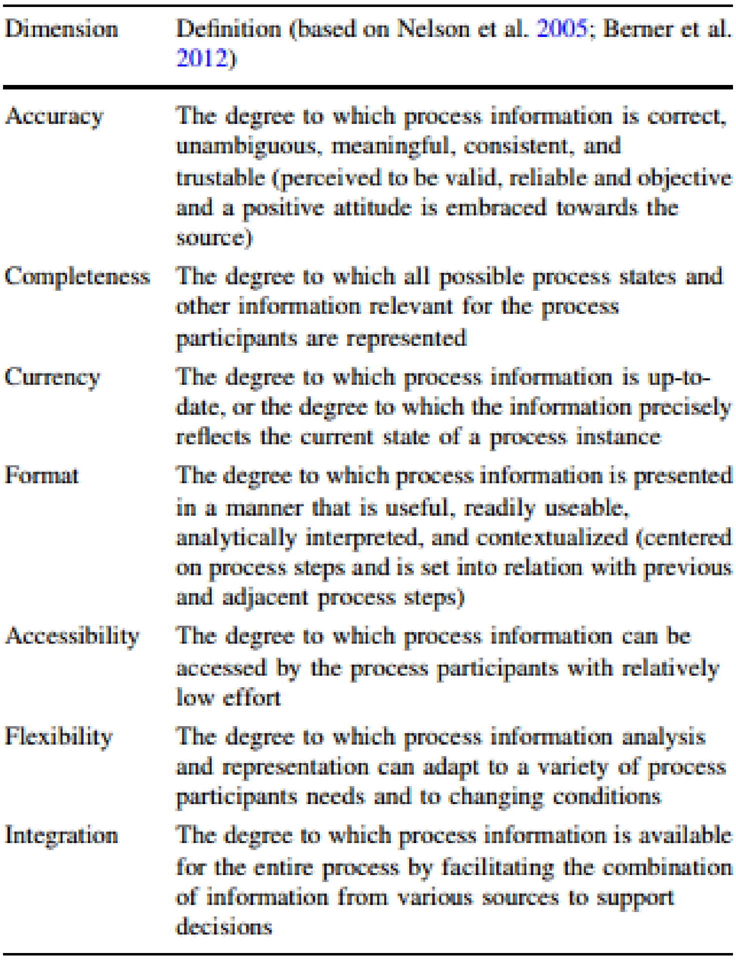
The above definition is quite similar to the first definition, but this also takes into consideration the importance of sharing this information across the supply chain the right decision-makers. It is clear from both definitions that supply chain visibility is closely related to information management, in terms of both information quality, flow, and sharing.

The 3 V's of Supply Chain is a well known framework within the SCM literature that depict the use of the three V's; visibility, variability and velocity as drivers for increased supply chain performance and profitability. The three V's are not only important independently, but they are also interconnected to each other. Poor visibility will in many cases lead to supply chains that respond slowly to customer demand and where lacking predictability leads to increased variability and the need for buffer capacities. Increasing the supply chain visibility can increase the velocity of the supply chain due to being able to respond and coordinate faster in response to the customer demand. It can also support decision making and make the supply chain more predictable, which in turn makes the supply more responsive and efficient when faced with variability (Wilhjelm, 2013).

2.2.6.7.1 Process Visibility

Most literature on visibility within the field of logistics focus on the aspect of visibility across the supply chain and especially between the different supply chain actors. However, the same logic behind SCV can also be used for the internal supply chain within the supply chain actors. Just like goods and information flow between supply chain actors, so does it internally between processes. In the context of this thesis, the most important aspect of visibility lies within the manufacturing process at Brunvoll.

Within SCV, the focus in mainly on capturing and sharing information between supply chain actors. This means that actors are willing to share specific and relevant informant that is of mutual benefit (Barrat & Oke, 2007). Implicitly, this also means that actors will only share what information is necessary and relevant in any given situation. The level of information sharing will also be determined by factors such as the sensitivity of the information and the level of integration between the actors. Within manufacturing visibility, the focus is more towards monitoring processes in real-time, which is essential for managing business-critical processes. Process visibility is directly associated with process performance, in terms of both operating and improving the process (Berner et.al 2016). Figure 22 shows the dimensions of process visibility derived from putting information quality dimensions in a process perspective.



Dimension	Definition (based on Nelson et al. 2005; Berner et al. 2012)
Accuracy	The degree to which process information is correct, unambiguous, meaningful, consistent, and trustable (perceived to be valid, reliable and objective and a positive attitude is embraced towards the source)
Completeness	The degree to which all possible process states and other information relevant for the process participants are represented
Currency	The degree to which process information is up-to-date, or the degree to which the information precisely reflects the current state of a process instance
Format	The degree to which process information is presented in a manner that is useful, readily useable, analytically interpreted, and contextualized (centered on process steps and is set into relation with previous and adjacent process steps)
Accessibility	The degree to which process information can be accessed by the process participants with relatively low effort
Flexibility	The degree to which process information analysis and representation can adapt to a variety of process participants needs and to changing conditions
Integration	The degree to which process information is available for the entire process by facilitating the combination of information from various sources to support decisions

Figure 22. Dimensions of process visibility (Berner et.al, 2016)

Although some of the dimensions are named slightly different as opposed to the information quality dimensions by McGowan (1998, cited in Zhou and Benton 2007) presented before, the logic behind the information quality and process visibility dimensions is quite alike, where information quality plays a central role in the ability to monitor and gain visibility in processes. Management guru Peter Drucker’s statement; “If you can't measure it, you can't manage it” implied that in order to truly manage a business processes, you need to able to measure it. In order to measure it, you would need true visibility within the process, which in turn is enabled by monitoring the process. However, without high information quality, you’re not really measuring and achieving visibility into the true state of the process.

3.0 Methodology

This chapter presents the methodological approach used for this case study research. Firstly, the case study research method will be described. Secondly, the research design used in for the case study will be outlined. Lastly, the assessment of the validity and reliability of the research will be discussed.

3.1 Choice of research method

A master thesis in logistics is defined by the Molde university college as a supervised research project where students are able to apply their acquired knowledge and skills within new areas of research (Himolde). This entails that the research has some characteristics that adds value to the overall research area for which the topic of the thesis belongs too. The Merriam-Webster dictionary defines research as the:

*“Investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws (*Merriam-Webster*)”.*

In the context of academia and science, research is about adding value to the knowledge of established or not yet established truths. Most research projects and initiatives builds on the identification of a problem statement that generates one or several research questions to be answered.

First off, given the background, scope and objectives of this thesis, it was quite evident that the choice of research method would be the single case study research method. This was first and foremost determined by the fact that the number of firms that would be investigated would just be one. Secondly, the case study research approach was also supported by the nature of the research, which is supported by the following theory on research methods.

In the scope of this thesis and its objectives, the first and second research questions are exploratory in nature denoted by the research questions starting with "What" questions. The objective of the first research question/s is to explore a little known phenomena within the case company Brunvoll. However, the second research question is both exploratory and explanatory in nature as it aims to investigate an unknown phenomena, while at the same time tries to explain the relationship between some of the underlying variables.

According to Yin (2009), exploratory "What" questions can be served by any of the main research methods, such as for instance case studies, experiments, surveys, etc. The third research question is partly explanatory in nature, as it seeks to extend the findings from the first exploratory research question/s by explaining "How" the phenomena discovered can be handled in the context of Industry 4.0.

According to Yin (2009:8), there are three main conditions that will help researcher determine the most suitable research method:

- *"The type of research questions posed.*
- *The extent of control an investigator has over actual behavioral events.*
- *The degree of focus on contemporary as opposed to historical events."*

The type of research question has already shown that the case study research method is one of the potential research methods that can be used within the scope of this thesis. The second and third condition also support the case study method as the method is great for investigating both contemporary and historical events.

As a result of this, the research method for this thesis can be defined as an exploratory-explanatory/qualitative-quantitative single case study. However, it can be considered that the case study is primarily exploratory-qualitative; as the case study is an initial investigation towards this topic at Brunvoll and that the analysis centered on the qualitative findings, and that the quantitative findings are aimed at supporting the qualitative findings.

3.2 Case study research

Yin (2009) defines the scope of a case study as the:

"*Empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomena and context are not clearly evident".* (Yin, 2009, 18)

The demand for case study research usually arises when we need to and desire to understand complex social phenomena. In-depth and real-life context are here the key words that direct researchers towards the case study research method. The strength of case studies lies in its ability to study an phenomena in depth by investigating evidence from a wide variety of sources like documents, direct observation of events, and interviews of different people involved in the event.

The choice of research method will usually depend on the nature of the research questions. If the research questions seek to explain “How” or “Why” some phenomena is working, then a case study method is suitable because it provides insight and depth into an often unknown phenomena (Yin, 2009). Still, many researchers believe that the case study approach is only suitable for the exploratory phase of research, which is research into a phenomenon that is relatively new and unknown. Both Yin (2009) and Ellram (1996) provide good evidence to support the use of the case study method in both the exploratory, descriptive and explanatory phases of research, including both qualitative and quantitative methods.

According to Yin (2009), the case study research method is considered as one of the most challenging of methods within social science, and any researcher conducting studies using the case study approach should be fully aware of both the strengths and limitations of the method in order to produce reliable and valid research results. One concern has been the lack of rigor of the case study research method. This means that the researcher has not followed a sufficient systematic procedure in order to ensure a strong chain of evidence and unbiased views. Another concern of the case study research has been the lack of generalizability, especially within single firm case study, where generalized statements based on the evidence found from a single firm requires a rigid research design. An important consideration is that the goal of case studies, like experiments, is to expand and generalize theories, and not to quantify frequencies.

3.3 BPMN

Basically, the first research question is concerned with gaining insight and understanding into the current business processes related to the planning, control, and execution of manufacturing operations at Brunvoll. More specifically, a business process is defined as:

“A defined set of business activities that represent the steps required to achieve a business objective. It includes the flow and use of information and resources (OMG).”

The management of business process is a central part of operation management and all major logistics and SCM paradigms such as for instance LEAN manufacturing, SIX Sigma, BPR, and TQM. In fact, the management of business processes is even classified as its own paradigm, knows as Business Process Management (BPM), which is defined as the:

*"Services and tools that support process management (for example, process analysis, definition, processing, monitoring and administration), including support for human and application-level interaction. BPM tools can eliminate manual processes and automate the routing of requests between departments and applications (*OMG*)."*

One popular tools within BPM is the Business Process Model and Notation 2.0 (BPMN) and other process modeling tools. The objective of using BPMN or any method for that matter is to create a graphical model notation that is easily understandable by all business users. BPMN models can yield the following benefits and opportunities:

- Having a graphical representation of processes increases the business users and managers understanding the process.
- It enables companies to analyze and provide detailed as-is models of the current business processes, including the sequence of tasks and flow of information.
- It supports process improvement by enabling easy comparison and understanding between as-is and suggested to-be models.
- When combined with software solutions, it supports simulating and testing the efficiency and syntax of business process models.

In the context of this case study, BPMN 2.0 will be used to create process models of the various business processes that will be investigated during the case study analysis. This is done to provide insight and understanding through creating a visual representation of the processes. In addition, the process models can be used during the analysis phase by assessing the syntax of the process design. The models will be developed by using a free BPM tool called Adonis Community edition (Adonis:CE).

3.4 Research design

The research design refers to the strategic approach that the researcher take in order to solve research problems and questions as logically and as unambiguously as possible (UCS Library Research guide)

Yin (2009) defines research design as:

"*In the most elementary sense, the design is the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions (*Yin 2009:26*)."*

However, research design is more than just planning the logical sequence of research tasks. It is also concerned with ensuring that the researcher/s collect the right evidence to answer the right research questions. This means that the design of the research must to be robust in such a way that the research activities does not deviate from the initial purpose of the research, which is grounded in the research questions. Thus, the research question/s and problem statement determines the design of the research. In that sense, the research design deals more with the logical problem rather than the logistical problem (Yin, 2009).

3.3.1 Unit of analysis

According to Yin (2009), one of the fundamental problems in case study research is to clearly define what a “case” is. Defining a case is very much rooted in the ability to set the boundaries of the case in the context of the study. This inherently means that without clearly defined research questions, the researcher’s ability to know how to analyze the case and which information that is to be extracted from the case is likely to be lacking.

The first task in the research design process is to select a unit of analysis that fits well to the overall topic, scope and objective of the thesis. The topic and scope for the thesis was determined by several factors that were subject to an extensive discussion among the representative parties. The first factor was the scientific interest for me as the author of this master thesis. The second factor was the topic and scope of the research project Manufacturing Networks 4.0, and the third factor was the practical interest from Brunvoll as the case study company. Based on the discussion and assessment of these factors, it was determined that the unit of analysis would be on the internal manufacturing processes at Brunvoll within the scope of manufacturing planning, control, and execution. Since this thesis is considered mostly exploratory, as little research has been conducted within the manufacturing environment at Brunvoll in the scope of this thesis, it was determined to limit the unit of analysis to one node in the Manufacturing process. The concept of a manufacturing node is basically the same as an manufacturing processes at the level were a set of inputs are transformed to a set of outputs within an defined schedule, purpose and objective. Brunvoll’s manufacturing environment consist of many such nodes, which in many cases represent functional objects such as machining centers, work stations, or even departments. After discussing the choice of node with the management at Brunvoll, it was decided that machining center M53 would be of high interest as a result of its critical role in the overall manufacturing process. In addition, the node was also relevant in relation to the recent acquisition of Scana Propulsion AS, where ideas around coordinated manufacturing were under discussion. Since the case study analysis also consisted of quantitative data collection, the unit of analysis was further limited to one specific type of component (subject) processed within the node. This was done to simplify the quantitative data collection process and analysis in the scope and limitations of a master thesis.

The machining center node M53 and the Gear Housing subject will be described in more detail in the case study findings section.

3.3.2 Data Collection

Data collection is the process of collecting the empirical evidence needed to analyze and answer the research questions. The following section will outline the sources of information to be collected during this case study.

3.3.2.1 Sources of data

Data is usually classified as either being qualitative or quantitative data based on the how one would describe the nature of the data. Qualitative data are usually data that is can only be described by using words, and quantitative data is best described with numbers. In a research setting, data can be further classified as primary and secondary data sources. Here, primary data sources represent the empirical evidence collected directly from the source with the specific aim of the specific research endeavor, while secondary sources represent all the sources of empirical evidence that already exists but is of value for the specific research endeavor.

Table 2 shows the primary and secondary data sources from where qualitative and quantitative data will be collected as evidence in order to answer the research questions. The sources of data denotes where the data is collected from internal sources at Brunvoll or from some other external sources.

Table 2. Data sources.

Data collection	Sources of data	
	Internal	External
Primary	• Interviews with key informants at Brunvoll • Observation	

	• Information from M3 ERP system	
Secondary	• Annual reports • Consultancy reports • Strategic documents	• Research reports • Journal articles • Master- and PhD-dissertations • Industry reports/white papers • Websites • Textbooks

The most important part of the data collection is the primary data collection within Brunvoll consisting from interviews with key informants, observations, and information collected from the M3 ERP system.

3.3.2.2 Key Informants

The primary source of qualitative data in this thesis comes from the interviews with the key information's at Brunvoll. The selection of informants was highly directed by the unit of analysis, which dictated that the informants would possess key roles within the different processes within the unit of analysis. The following table is a summary of the key informants, their role at Brunvoll, and the main objective of using them as key informants.

Table 3. Key Informants at Brunvoll.

Key Informant - Role	Data collection Objectives
1. Process planner	Provide the information needed to Map the process planning process. Provide information about process dynamics and process dynamics factors.
2. Production planner	Provide the information needed to Map the production planning process. Provide information about process dynamics and process dynamics factors.
3. M53 Operator	Provide the information needed to Map the machining process. Provide information about process dynamics and process dynamics factors.
4. ERP-consultant	Receive insight into the role of M3 and help developing quantitative data collection methods.

5. *Former Project planner at Brunvoll, now PhD student at Molde University College and co-supervisor for this thesis.*	*Receive insight, advice, and feedback to the findings (validation) and help developing the data collection methods.*

The three first key informants has an central role in the data collection process as the information they provided contributed directly to answering of the first two research questions. These interviews can be classified as semi-structured interviews as the informants were asked similarly type of questions, but with different content based on the specific role. The nature of the research questions also dictated that when applicable, the interview would further expand within certain areas depending on the informant's response.

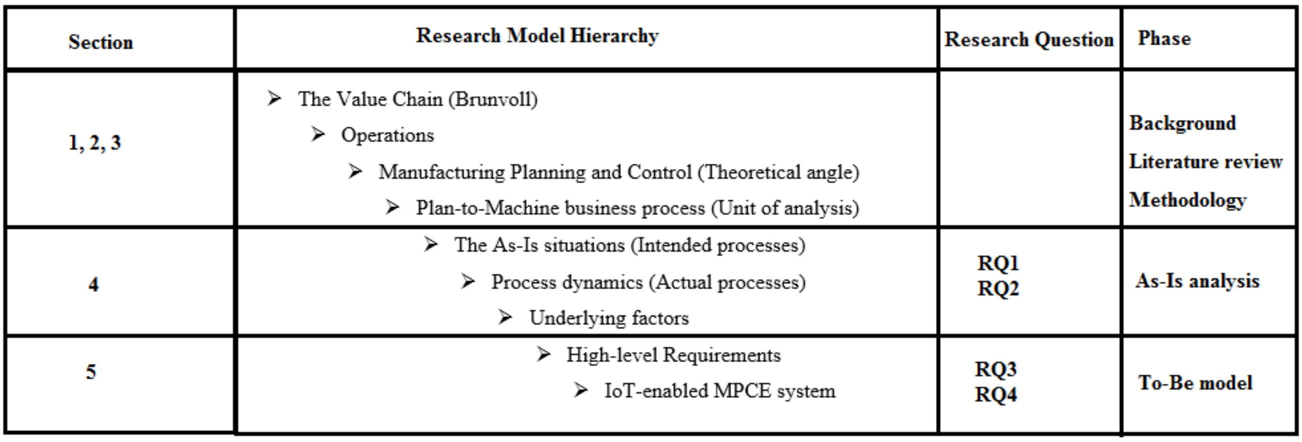
3.3.3 Research Model

The following table consist of three main research steps that summarizes the design for the case study data collection along with the type and source data collected to support the step/task. This represent the research approach towards answering the first two research questions.

Table 4. Data collection model.

Steps	Data collection
1. Map current processes using BPMN 2.0 modelling methodology.	Qualitative: • Interviews • Observation
2. Investigate process dynamics within the processes mapped in step 1.	Qualitative: • Interviews • Observation
3. Collect data that support and quantifies the finding in step 2.	Quantitative: • SQL extracted information from the M3 ERP system.

It is first when these questions are answered that the third research question can be discussed. Here, the findings from the first research questions will be used to define high-level requirements that within the scope of Industry 4.0 will be used to developed a To-Be MPCE system. Figure 23 shows the overall research model hierarchy for this thesis. As can be seen, the thesis follows an top-down approach to from the value chain to a specific process, which is then analyzed to find the underlying process dynamics factors, which than again provide much of the foundation for the discussion phase.



Section	Research Model Hierarchy	Research Question	Phase
1, 2, 3	➢ The Value Chain (Brunvoll) ➢ Operations ➢ Manufacturing Planning and Control (Theoretical angle) ➢ Plan-to-Machine business process (Unit of analysis)		Background Literature review Methodology
4	➢ The As-Is situations (Intended processes) ➢ Process dynamics (Actual processes) ➢ Underlying factors	RQ1 RQ2	As-Is analysis
5	➢ High-level Requirements ➢ IoT-enabled MPCE system	RQ3 RQ4	To-Be model

Figure 23. Research Model Hierarchy.

This also underlines that the two first research questions is concerned with investigating the As-Is situation at Brunvoll, which along with the scope of Industry 4.0 forms the basis for developing a To-Be approach to MPCE within the scope of answering the third and fourth research questions.

3.3.4 Validity and reliability of study

As mentioned, research design deals more with the logical problem rather than the logistical problem, which implies that one could evaluate the quality of research designs according to certain logical tests (Yin, 2009). Within the qualitative research paradigm, the two most common tests of research design quality is reliability and validity (Golafshani, 2003). Any research endeavor, either qualitative or quantitative, requires good external validity, reliability, construct validity, and internal validity to be considered as a good research design (Ellram, 1996)

<u>External validity</u> is conserved with whether a studies findings are generalizable beyond the immediate case study (Yin, 2009). In the context of this thesis and the case study findings, some of the factors identified could be considered as generalizable as they represent factors caused by the natural characteristics of ETO companies. Although other factors may be situational depended at Brunvoll, it is not unlikely that companies with similar attributes as Brunvoll experience the occurrence of the same factors. In the scope of the IoT-enabled MPCE system developed, the applicability of such a system is not only limited to Brunvoll,

but to other companies in the scope of MPCE and Industry 4.0. This means that although the system architecture have the capabilities of handling the high level requirement rooted in the case study findings, the system in itself might me applicable to many other companies, which is rooted in the flexible nature of the system vast possibilities and potential provided by the technologies.

Reliability addresses whether the case study findings and conclusions would be the same if the case study were to be repeated (Yin, 2009). In order to support the reliability of this case study, a lot of emphasis has been put into describing the methodological approach to performing both the qualitative and quantitative data collection. The biggest concern regarding the reliability of the case study findings lies in the qualitative interviews and observations, whereas the nature of the questions where based on semi-structured interviews where the researchers interpretation regarding one question might have led to more burrowing questions. In addition, performing observations as a basis for conducting interviews might be difficult to replicate as the researcher might have observed a phenomena which inly occurred in that instance.

Construct validity addresses the establishment of proper operational measures. This involves using multiple sources of evidence, establishing a chain of evidence, and reviewing drafts with key informants (Yin, 2009). In this thesis case study, multiple sources of evidence has been collected by interviewing several key informants and performing observations, before collecting quantitative data form the ERP system to support the findings from the first two sources. A strong chain of evidence has been established by presenting findings that coincide with what has been presented in earlier literature. In addition, the rigorous research design model has been designed with the purpose of breaking down the case study from the value chain to very specific processes and underlying factors that cause challenges, which enables the researcher to follow the chain of evidence as the level of analysis is broken down into more specific areas. Lastly, review sessions with the key informants were conducted to validate the main takeaways from the earlier interviews.

Internal Validity is only a concern if the case study is explanatory in nature (Yin, 2009). In the context of this thesis, the nature of the case study has been defined as only partly explanatory. However, as the findings suggest, it was not possible to draw any strong conclusions as to the relationship between the occurrence of process dynamics and the underlying factors. One reason for this was the research design, where the both the process dynamics and underlying factors first had to be explored within the exploratory phase of the research and on a more general basis. This meant that the research design lacked some of the ability to go into depth and truly analyze the relationship between the variables/factors, which would require an in-depth investigations into each instance of process dynamics. In addition, the limited capabilities of the ERP systems in terms of capturing and providing information meant that the analysis of the relationship between the variables was missing essential and complete information.

4.0 Case study findings and analysis

In this chapter, the empirical findings from the case study will be presented and analyzed in context of the of the first and second research questions.

RQ1: What is the As-Is situation for the intended manufacturing planning, control and execution processes at Brunvoll

RQ2: What are the main underlying factors behind the occurrence of process dynamics in the manufacturing planning, control and execution processes at Brunvoll?

4.1 The As-Is approach to MPCE at Brunvoll

This section contain the detailed descriptions and mapping of the As-Is situation for the processes and subjects defined in the unit of analysis.

4.1.1 The M53 machining center

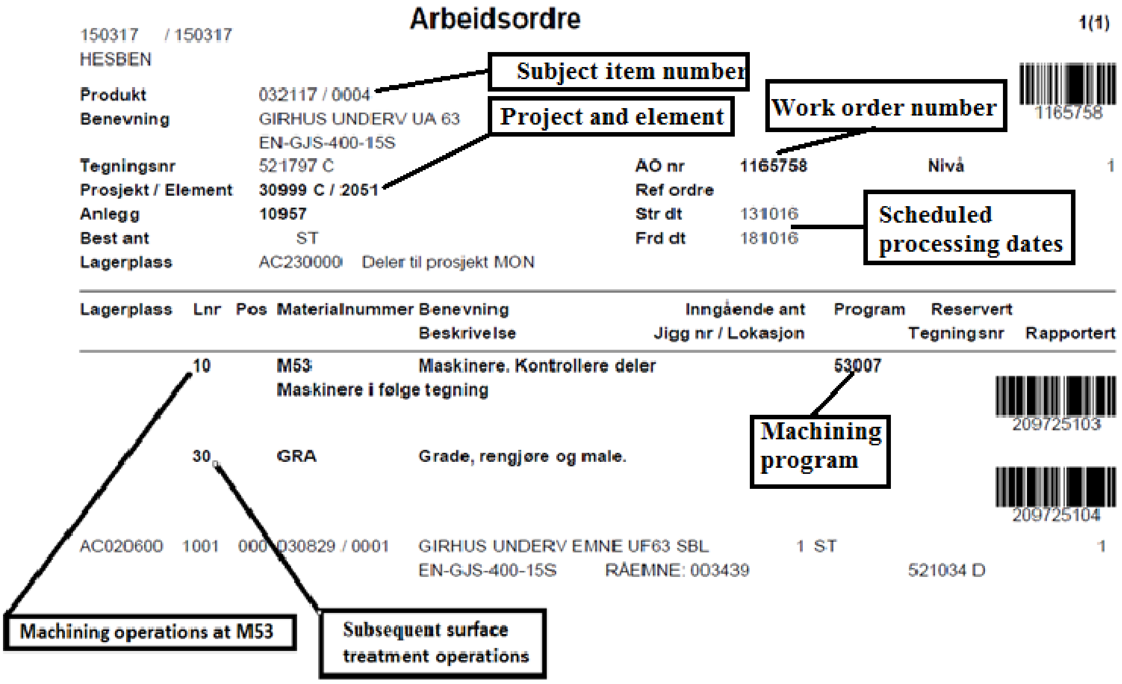
Machining center M53 is the largest machining center in the machining department at Brunvoll. The make and model of M53 is Pama Speedmat 3, which is characterized by the producer as a horizontal boring and milling center used for the most demanding machining applications requiring precise boring and milling (Pama). The Speedmat 3 is based on the Computer numerical control (CNC) logic, which means that the automation of the machining process is based on pre-programmed sequences and commands that control motion along the different axes, as well as automated tool selection based on RFID technology identification. In its current application at Brunvoll, M53 is used for machining larger casted components (subjects), such as gear-housings, lifting-yokes, and propeller blades. The operator operates the machining center through a local machine interface, which currently is not integrated with the M3 ERP system.

4.1.2 The Subject

Objects such as the different individual components that together make up a thruster system is named subjects within the internal manufacturing process at Brunvoll. Subjects are the central part of all work orders, as they represent the object that is to be the processed according the work order operations. As in accordance to the research design and unit of analysis, the focal subject for the analysis will be the Gear housings machined at M53, which is a core component of all complete thruster system produced at Brunvoll, where it is designed to encapsulate and protect the internal transmission of a thruster system.

4.1.3 The work order and the work order process levels

In order to understand the how subjects move through the internal supply chain at Brunvoll, one must understand the concept of subject and work order levels. As mentioned, subjects are the central object of each work order. Work order levels represent the different process levels within the over manufacturing process at Brunvoll. When subjects move from process to process, they are governed by the work order, which dictates their schedule, technical configuration, and their associated project. Within work orders, the subjects are identified by the subject’s item number, which in many cases is not a unique number, which only identify the subject type/variant. However, since a subject belongs to a work order, the specific subject can be uniquely identified by either the work order number or by combining the project number and the element number for work orders associated with a project. Furthermore, Brunvoll uses different subject item number for each work order level. In the scope of this case study, two relevant work order levels have been identified as the surface treatment process work order level and the machining process work order level. This means that the same subject will have different item numbers according to the process at which the subject is currently located. The above mention identification scheme explains how the specific subject within a work order can be identified. Figure 24 shows an example of work order number 1165758 at the machining process work order level, where all the information described can be found within the work order.



150317 / 150317
HESBEN

Arbeidsordre

1(1)

1165758

Produkt 032117 / 0004
Benevning GIRHUS UNDERV UA 63
EN-GJS-400-15S
Tegningsnr 521797 C
Prosjekt / Element 30999 C / 2051
Anlegg 10957
Best ant ST
Lagerplass AC230000 Deler til prosjekt MON

AO nr 1165758
Nivå 1
Ref ordre
Str dt 131016
Frd dt 181016

Lagerplass	Lnr	Pos	Materialnummer	Benevning Beskrivelse	Inngående ant Jigg nr / Lokasjon	Program	Reservert Tegningsnr	Rapportert
	10		M53	Maskinere. Kontrollere deler Maskinere i følge tegning		53007		209725103
	30		GRA	Grade, rengjøre og male.				209725104
AC020600	1001	000	030829 / 0001	GIRHUS UNDERV EMNE UF63 SBL EN-GJS-400-15S	1 ST RÅEMNE: 003439		521034 D	1

Figure 24. Work order from M3.

As mentioned, the work order consist of a subject, the operations to be performed and their schedule. Figure 24 shows that the there are two main subsequent set of operations that are to be performed within the machining process work order level. First the machining operations, then some subsequent surface treatment operations. In addition, the work order provides the operator with the information that machining program 53007 is to be selected during the machining operations and that the work order is scheduled to be processed between the 13.10.2016 and 18.10.2016.

Figure 25 illustrates a section of the shop floor layout at Brunvoll. Here, the flow between the two mentioned work order process levels are shown. As will be described later, the first of the two processes is the surface treatment process which is denoted in the layout as the "AOVF". Once the work order is completed and reported at this level, the subject is moved directly to the next process and work order level, which in this case is at the machining center M53. Since this work order level usually consist of two operations as seen in figure 24 above, the subject is moved after the first operation is reported as completed. Once the second operation denoted in the layout as "GRA" is completed and reported, then the process described above continues for any subsequent process levels, in this case the mounting process.

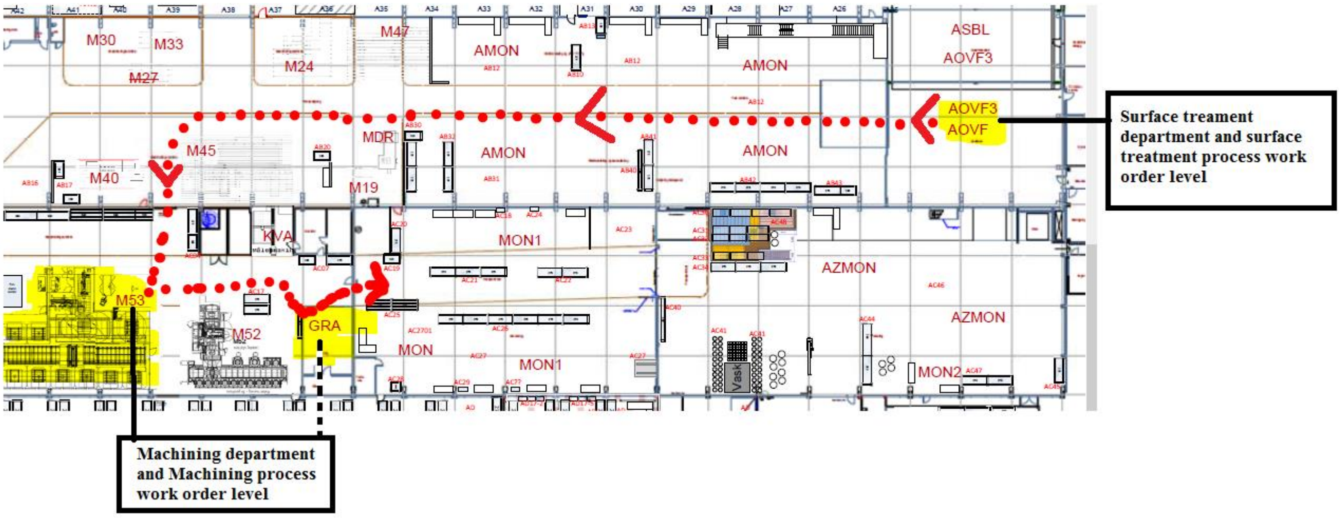


Figure 25. Shop floor layout Brunvoll. Source: Brunvoll

4.1.4 The planning, control and execution processes

This section will provide the mapping and description of the As-Is process related to the key processes that forms the systematic approach to MPCE at Brunvoll within the scope of the unit of analysis.

4.1.4.1 The Process planning process

The process planner, who is responsible for planning all technical aspects of the machining process, performs the process planning whenever a new variant of a subject type is ordered by a customer. This means that the process is only relevant for the machining of gear housings that are unique, i.e. has never been machined before according to the specific requirements.

According the process planner, about 90%+ of all gear housings made are standardized and have been produced before. In total, there are about 20 different variants of standardized gear housings, where typically the larger versions are machined at M53. In the case of new gear housing variants, the process planning will consist of the following subsequent steps that are initiated by the completion of the customer order placement and engineering phase.

The process planner first looks at the technical drawing of the thruster gear housing and determines the routings for the machining process. This includes choosing the appropriate machining center node along with the sequence of tasks needed to machine the subject. The routings are added to the M3 ERP system along with alternative routing in case of unexpected events.

The processes planner is also responsible for estimating the lead-times of the machining process, which is mostly based on the knowledge and experience of the process planner. The lead-times for the subject variant is stored in the M3 ERP system and the estimate is a part of the total lead-time estimation for the whole thruster system.

The process planner then creates the program to be run by the machining center based on the gear housings technical specifications. The programs are stored on a server where they can be accessed and loaded from M53 and other machining centers. The program number is also attached to the work order in M3, where the program is linked to the item number. This means that the next time a work order for a item number is created, the M3 ERP system can assign the right machining program to the work order.

The process planner then creates drawing for the mounting fixtures, showing how the subjects are mounted onto the jigs.

Figure 26 shows the BPMN model of the process planning process. As can be seen in the figure, the process planner is only involved when a component is unique, meaning that it has not been manufactured before to those exact specifications.

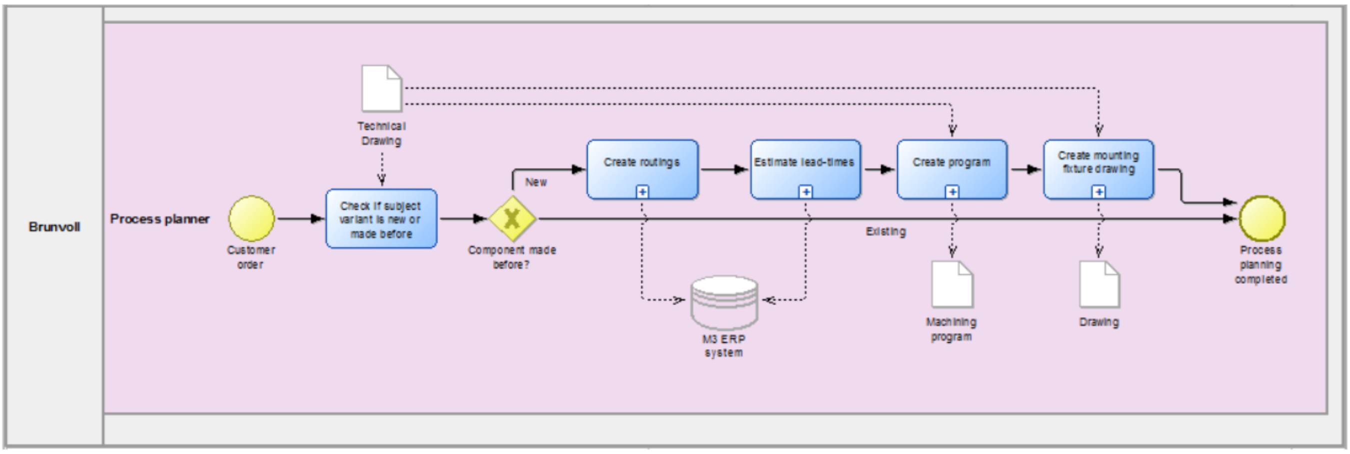


Figure 26. The Process Planning process.

The following is the list of activities whose completion is a prerequisite for the subsequent production planning process and machining process execution, where the production planner plans, schedules and releases the operation to be executed within the planned process as work orders.

- Define machining process routing in M3
- Estimate lead-time to be added to the machining process routing in M3
- Link technical specifications and program to subject variant item number

4.1.4.2 The Production Planning Process

The planning process at Brunvoll follows the typical characteristics of MTO and ETO manufacturing where planning and manufacturing activities are pulled by the customer order. This means that the planning of the manufacturing operations start after the sales and engineering phases have been completed and the technical specifications of the product is determined. The production planning process at Brunvoll begins with the master production scheduling (MPS), which determines the requirements for the materials, components, subjects, etc. that are needed, which in turn might trigger purchasing demand, etc. The production planner’s responsibility is to transform the top-level MPS into a more detailed production schedule by linking subjects to work orders and releasing them within their appropriate horizon to meet the scheduled delivery dates. On one hand, it is important that work orders are not processed to early in order to avoid unnecessary buildup of inventory and the amount of capital tied up. On the other hand, it is also important not to process work orders to late, which can affect the ability to deliver the final products as promised. Therefore, the processing of work orders are assigned to time horizon schedules in order to ensure that the execution of manufacturing operations happens is neither too early nor too late.

As mentioned, the production planning process is initiated by the release of the MPS. The gear housing subject is first allocated and assigned to the surface treatment work order level, then to the subsequent machining work order level. Figure 27 shows the business process model for the production planning at Brunvoll. Below the figure, the tasks and information flow is explained in their subsequent order.

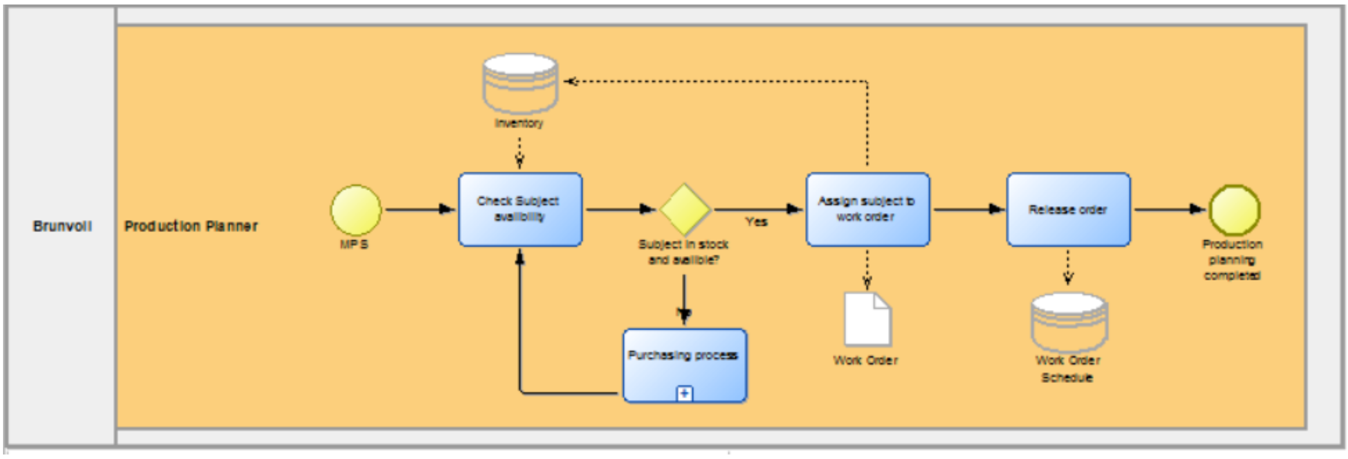


Figure 27. The Production Planning process

MPS: The production planning process is initiated by the release of the MPS. Once released, the production planner can begin the processes of allocating, planning, and releasing work orders.

Check subject stock level: the first task towards releasing a work order is to check the availability of the subject in stock. The relevant subject has to be in stock and not assigned to other work orders. If no such subjects are available then the demand for purchasing is triggered, shown as a sub-process in the model.

Assign subject to work order: once the subject is allocated from stock, it is assigned to a work order. As explained before, the gear housing subject is first allocated and assigned at surface treatment work order level, then subsequently to the machining work order level.

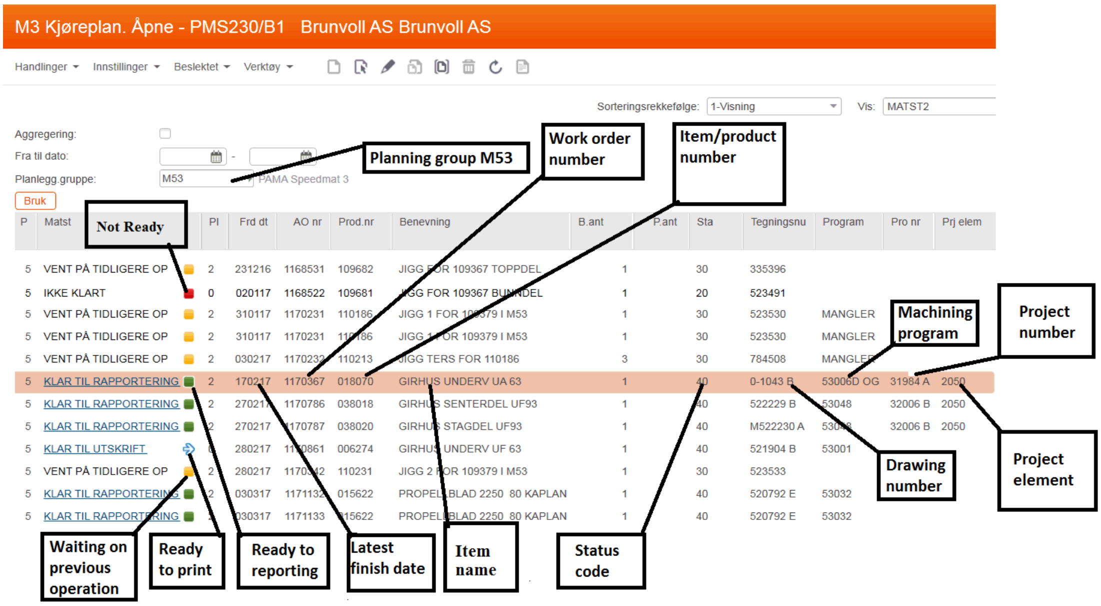
Release order: The order can now be released onto the work order schedule. An important distinction is that the completed release and execution of work orders is a two-step process. First, work orders are released onto the work order schedule, which means they have been assigned to a process routing and time horizon for processing. The second release consist of releasing the work order onto the shop floor for the actual processing of the work order, which is performed only when the work order is within its planned schedule and previous operations has been completed. One note is that work orders can be released even if some of the prerequisite are missing, such as the technical aspects derived from process planning. In those cases, the work orders can be released onto the work order schedule, but it will not have the necessary information needed to initiate order processing, i.e. no shop floor release. More on this topic will be covered in the M3 related process.

Once the orders have been released, the planner has in theory completed his process. He does however have a shared responsibility for controlling the conformance to the planned activities. As we will see, putting plans into action doesn’t always go as planned, which means the production planner often have to make adjustments to the schedules along the way. The planning process described above is the ideal situation, or say the designed process, where all operations, activities, and iterations goes as planned and events follow their intended procedures.

4.1.4.3 The role of the M3 ERP system

The M3 ERP system is the main MPC system for the manufacturing activities at Brunvoll, where the system is positioned between the planning processes and the physical machining process. Here, work order operations are planned, scheduled, released, monitored and controlled. In addition, the system manages the inbound and outbound information flow related to the physical flow of subjects in the Machining process. The inbound information flow includes providing the shop floor operators the necessary signals and information needed to execute the scheduled manufacturing operations at M53. The outbound information flow consist of capturing major business events that track the progress and completion of the scheduled work order operations at M53.

As mentioned, all planned work orders and operations is scheduled in the work order schedule in the M3 ERP system. Figure 28 shows the work order schedule for the machining center M53 showing all the planned work orders at the time of the screenshot.



Sorteringsrekkefølge: 1-Visning Vis: MATST2

Aggregering: ☐
Fra til dato: -
Planlegg.gruppe: M53 PAMA Speedmat 3

P	Matst		Pl	Frd dt	AO nr	Prod.nr	Benevning	B.ant	P.ant	Sta	Tegningsnu	Program	Pro nr	Prj elem
5	VENT PÅ TIDLIGERE OP	🟨	2	231216	1168531	109682	JIGG FOR 109367 TOPPDEL	1		30	335396			
5	IKKE KLART	🟥	0	020117	1168522	109681	JIGG FOR 109367 BUNNDEL	1		20	523491			
5	VENT PÅ TIDLIGERE OP	🟨	2	310117	1170231	110186	JIGG 1 FOR 109379 I M53	1		30	523530	MANGLER		
5	VENT PÅ TIDLIGERE OP	🟨	2	310117	1170231	110186	JIGG 1 FOR 109379 I M53	1		30	523530	MANGLER		
5	VENT PÅ TIDLIGERE OP	🟨	2	030217	1170232	110213	JIGG TERS FOR 110186	3		30	784508	MANGLER		
5	KLAR TIL RAPPORTERING	🟩	2	170217	1170367	018070	GIRHUS UNDERV UA 63	1		40	0-1043 B	53006D OG	31984 A	2050
5	KLAR TIL RAPPORTERING	🟩	2	270217	1170786	038018	GIRHUS SENTERDEL UF93	1		40	522229 B	53048	32006 B	2050
5	KLAR TIL RAPPORTERING	🟩	2	270217	1170787	038020	GIRHUS STAGDEL UF93	1		40	M522230 A	53048	32006 B	2050
5	KLAR TIL UTSKRIFT	⇨	0	280217	1170861	006274	GIRHUS UNDERV UF 63	1		40	521904 B	53001		
5	VENT PÅ TIDLIGERE OP	🟨	2	280217	1170342	110231	JIGG 2 FOR 109379 I M53	1		30	523533			
5	KLAR TIL RAPPORTERING	🟩	2	030317	1171132	015622	PROPELLBLAD 2250 80 KAPLAN	1		40	520792 E	53032		
5	KLAR TIL RAPPORTERING	🟩	2	030317	1171133	015622	PROPELLBLAD 2250 80 KAPLAN	1		40	520792 E	53032		

Figure 28. The Work Order Schedule in M3.

In the work schedule, the status and to some degree the progress of work orders can be monitored by looking at the color-coded status of the individual work order. There are four different main symbols used to represent the status of work orders in the work order schedule. The following is a description of the status symbols seen in figure 28:

Not ready (Red) means that the work order has been released onto the work order schedule by the production planner, but is not ready to be processed, i.e. not ready to be released onto the shop floor. This means either that the work order is outside its scheduled horizon or that the previous work order level is not completed, or as will be discussed later, not reported as completed.

Waiting on previous operation (Yellow) means that the previous operation within the same work order level has not been reported as completed and is by its definition not ready for the next operation. For gear housings, the first operations at the machining level is usually the machining operations, meaning that this status will only occur for the second and subsequent set of operations at the same work order level.

Ready to print (blue/white arrow) means that the work order is within its scheduled time horizon and is thus ready to be printed and processed, i.e. released onto the shop floor.

Ready for reporting (Green) means that the work order has been printed at the shop floor in the machining department, which by its definition means that the operator has initiated the machining process and the systems is awaiting the reporting when the work order operations and related tasks are completed.

As mentioned above, the planning, control, and machining processes are integrated through the work schedule in M3. Figure 29 shows the business process model for the tasks performed within M3, with the flowing descriptions of the model.

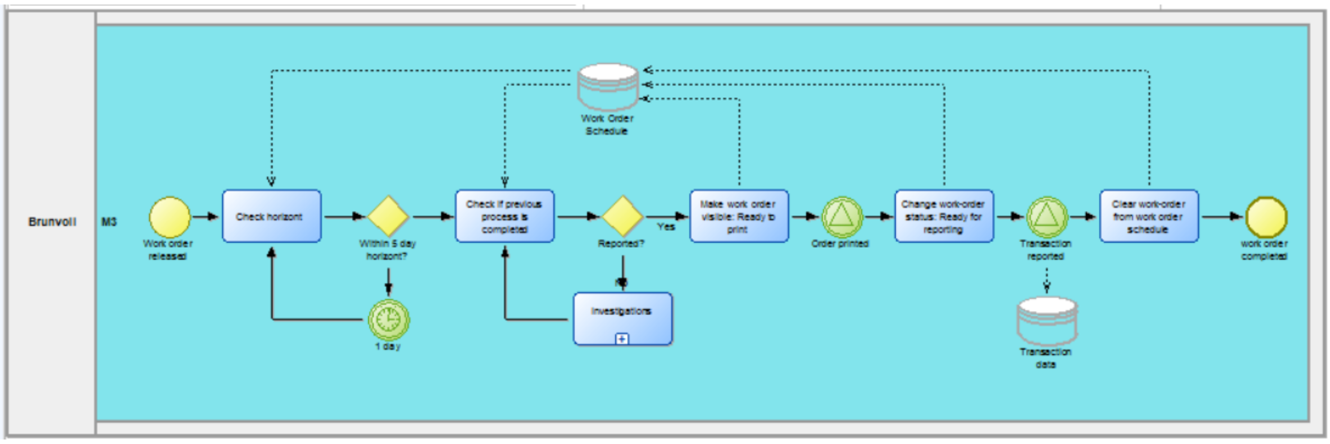


Figure 29. The Role of M3.

Work order released: the whole process is initiated by the release of a work order onto the work order schedule. The subsequent tasks and steps is then performed automatically by the M3 ERP system.

Check horizon: In order for a work order to be released onto the shop floor, it typically needs to be within a 5-day horizon of its scheduled starting date. If the work order is not within the 5 day horizon, the M3 ERP system will hold back the release (at shop floor) of the work order until the order is within its scheduled horizon by using the red status symbol red: “not ready”.

Check if previous work order level/operations is completed: the second checkpoint in the M3 ERP system is whether the previous work order level/process or previous operations within the same work order level is completed, which for in this case is the surface treatment process. The status of the previous process is determined by whether or not the work order operations were reported as completed, which in the case of the red status symbol doesn't necessarily mean the actual work order is not completed as reporting is performed manually. If a work order is not ready to be processed within its scheduled horizon based on failing one of the two process gateways, then the relevant stakeholders need to coordinate and investigate the reason behind the individual situation. This usually require the collection information outside the capabilities of the M3 ERP system, which will be discussed later on the topic of process dynamics.

Make work order visible: Ready to print. Once the previous tasks and gateways have been validated, the work order status is changed to "Ready to print", which means the work order operations are ready to be executed.

Order printed: the previous tasks works as an signal to the machining department that the processing of the work order can start. The machining manager or operator will then print the work order from the M3 ERP system.

Change work-order status: Ready for reporting. After the work order has been printed in the machining department, the status of the work order is automatically changed to "Ready for reporting" which serves as an indication and status that the processing of the work order operations has been initiated but not yet finished.

Transaction reported: once the operator has completed the work order operations and related tasks, he/she then reports the completion of the work order operations in the M3 ERP system. This transaction is stored in addition to triggering the following task in the system.

Clear work order from work schedule: once the operator has reported the completion of the work order operations, the work order level is considered as completed and is thereafter removed from the work order schedule. This also sends a signal to the subsequent process/work order level so that processing can be initiated there.

As have been described, the M3 related process represents the integration between planning and control and the execution of machining operations. This means that the system lies between two set of human resources that both provide to and receive information from the system. This implicitly means that the system must be receive quality information in order to be able to provide quality information. More on this topic will be analyzed and discussed later.

4.1.4.4 The machining process

The machining operations at M53 is governed by the work order schedule, which provides the operator with the work orders and their operations, technical information, schedule, and priority. Figure 30 shows the business process model for the machining process that is initiated once the work order status becomes “Ready to print”, with the following description of the sequential tasks performed by the operator in order to process and complete the work order operations at M53.

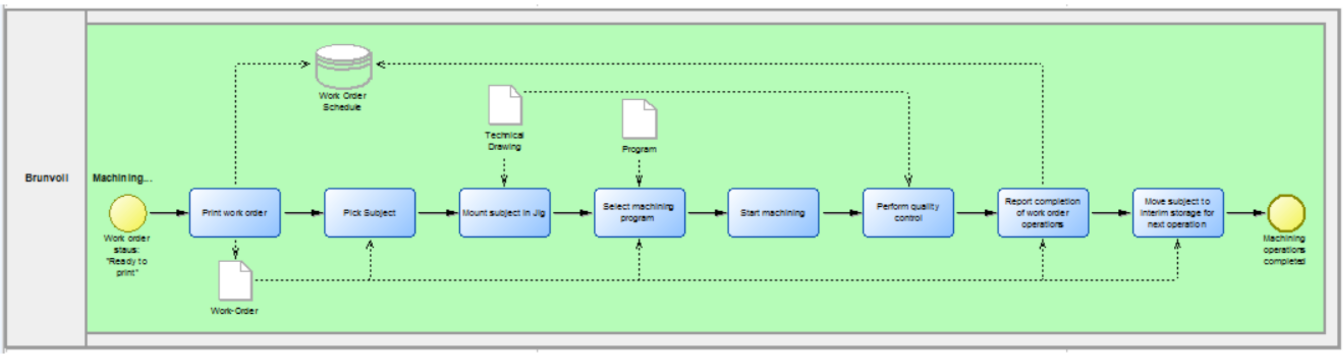


Figure 30. The Machining process at M53.

<u>Print work order</u>: The first tasks consists of printing the work order at the machining department shop floor, which provide the operator with the necessary documentation and information needed to the process the work order.

<u>Pick Subject</u>: the work order provides the operator or warehouse staff the information needed to identify and pick the work order related subject.

<u>Mount subject in jig</u>: The next tasks is to correctly mount the subject in a Jig. It is important that mounting is done correctly and that the subjects is as centered as possible. To support this task, the operator can use the technical and mounting fixture drawings attached to the work order.

<u>Select machining program</u>: once the subject is mounted and placed at the inlet of the M53 machining center, the operator selects the correct program for the machining operations. The program is selected from a control panel at M53, which is not integrated with M3. This means that the operator has to manually select the program and check it against the program listed at the work order in order to validate the correct machining program selection.

<u>Start machining</u>: this task involves initiating machining operations by basically clicking the start button the M53 control panel. For operations such as fine machining and machining of gear housings casted in steel, the operator has to be on site to monitor the operations. Other

less critical operations can be perform during the night without supervision. In addition to performing the work order operations, the operator has to manually check the condition of the machine and of the tools used, whose durability and wear can vary a lot depending the type of metal being processed. This task require the operator to have the experience required for determining the state and quality of the tools used.

Perform quality control: once the machining program is completed, the operator does a visual inspection before using fine graded inspection tools to check the quality of the machining operations performed. The inspection and measurements are controlled manually against the technical drawing and specifications.

Report completion of work order operations: once the quality of the machining is controlled and approved, the work order for machining is ready to be reported as completed. The operator uses a computer terminal at M53 with access to M3 where the operator manually type in several fields of input to record the transaction. When the transaction is reported, the work order will disappear from the work schedule as it by its definition is completed.

Move subject to interim storage for next operation: the operator then moves the subjects with the work order attached to it to the interim storage for the next operations on the work order.

The prerequisites for the initiation of the machining process is very much grounded in the successful completion of the previous production- and process-planning processes and the process related to the tasks performed by the M3 ERP system. Furthermore, the completion of the process is very much depended on the operator’s ability to perform the tasks and operations according to the process procedures, a topic that will be analyzed and discussed more later in the case study.

4.1.4.5 The Plan-to-Machine business process

The processes described and mapped shows the intended As-Is situation for the planning, control, and execution of gear housing work orders at the M53 machining center. Figure 31 shows the complete business process model, which stretches out over three lanes representing the three processes that are integrated and the overall sequence of the entire process. The reasoning for not including the process planning process is that even though the process is a prerequisite for the entire process it can still view as an independent process, as it may or may not occur depending on the specific subject.

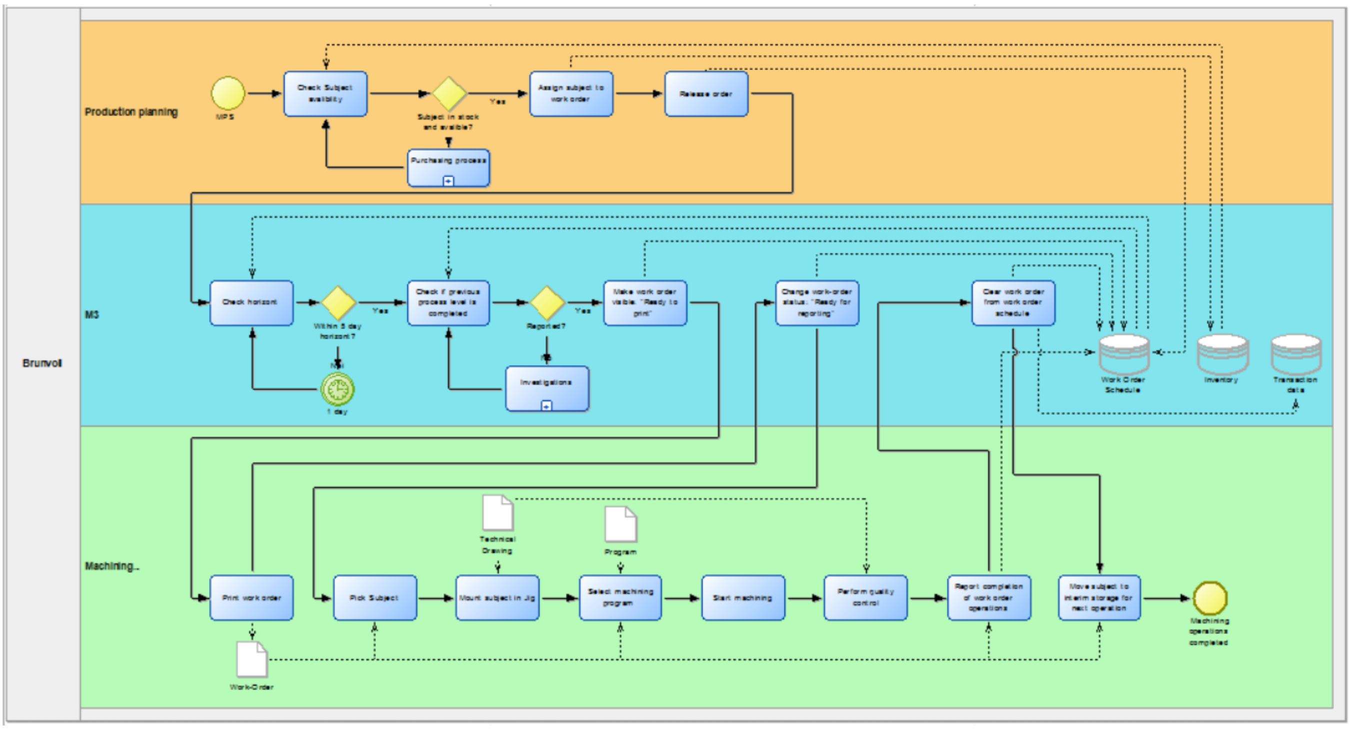


Figure 31. The Plan-to-Machine business process.

One popular way of defining and naming business processes is to name the process according to is beginning and end, such as for instance the “Plan-to-Produce Business process” used by ERP provider SAP to describe the processes and tasks involved in going from the planning process to the completion of the production process. In the context of this case study, the overall process presented in figure 31 is thereby named the Plan-to-Machine business process, a term that will hereafter refer to the processes involved in the planning, control, and execution of gear housing work orders at the M53 machining center at Brunvoll.

The Plan-to-Machine business process is the representation of how the process is designed to be, or in other words, how the process is ideally operated. However, due to the high degree of product and process variation in ETO manufacturing and the occurrence of unexpected events, it is difficult create a business process model that represent the all real life iterations of the process, which is also related to the complexity of managing such processes. Although the Plan-to-Machine business process roughly follows the described process, sequence and logic, occasionally there will be events and factors that cause deviations and problems that requires handling outside the basic process. One interesting aspect of the Plan-to-Machine business process is that it follows the traditional top-down planning structure, provided by the MPR logic behind ERP systems, where all planned manufacturing operations are planned in advance of the execution. This can be seen by looking at the sequence of the tasks in the process model (figure 31), where all planning tasks are completed before any machining related tasks is initiated. As will be discussed later in more detail, this approach works fine as long as the planned operations follow the sequence of tasks according the process design and procedures. However, if some event create disruptions to the sequence, then the whole processes needs to be reversed, or in other words, planning needs to be adjusted from the bottom-up. This is the basis for the next part of the case study, which will be an investigation and analysis into the situations where the process do not follow its natural or say designed form.

4.1.5 The As-Is MPC system at Brunvoll

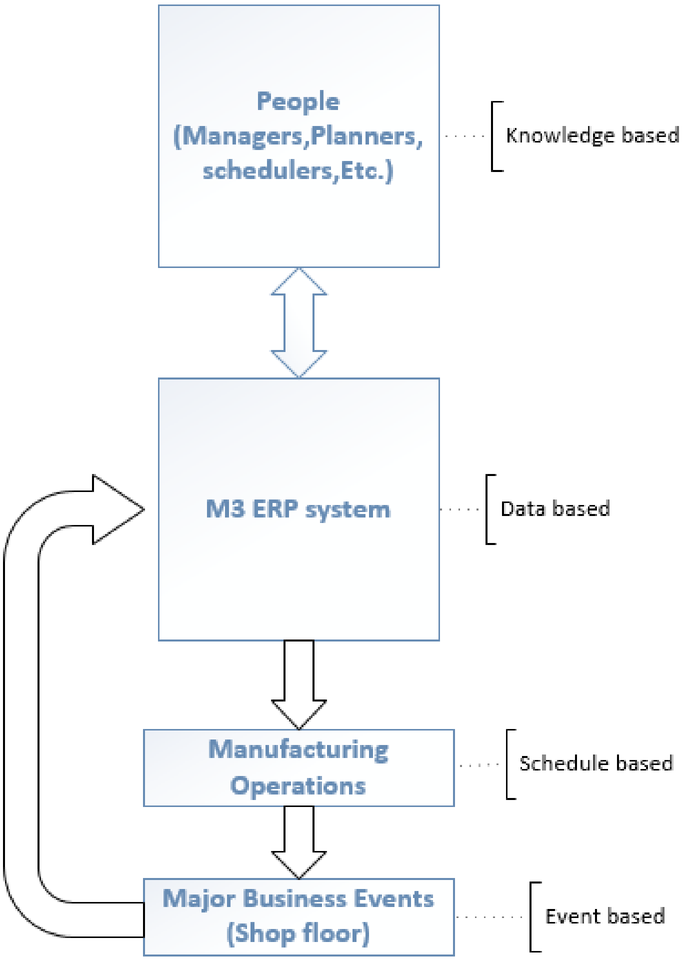


Figure 32. The As-Is the MPCE system at Brunvoll.

Figure 32 illustrates how the current MPC system is configured at the Plan-to-Machine business process and other processes at Brunvoll. As can be seen, the M3 ERP system represent the focal planning and control system within the manufacturing environment, which emphasizes its critical role in both planning and control activities. This system architecture is predominately based on a top-down approach, where the M3 ERP system plays a key role in supporting the production planner in planning, initiating, and controlling manufacturing operations. The data based nature of this system is based on Master Production Scheduling and Material Requirements Planning, where the manufacturing operations are scheduled and released based on a backwards scheduling approach from the agreed date of delivery in the customer order. Once the manufacturing operations has been planned and scheduled by the planner in the M3 ERP system, the operations are released as work orders that aid in the execution of the work order operations. Only when these operations trigger the predefined business events are they captured by the M3 ERP system as a way of controlling the planned and released manufacturing operations. This also illustrates that the only information available externally from the shop floor is the information captured and stored in the M3 ERP system.

4.2 The As-Is challenges within MPCE at Brunvoll

The first part of the case study findings showed the As-Is approach to MPCE at Brunvoll. This section is concerned with analyzing the potential challenges at the process level within this approach through investigating the occurrence of process dynamics and underlying factors, which is related to answering the second research question.

4.2.1 Business process dynamics

Process control and process dynamics are widely used terms within process industries, where increased competition has made the management of processes increasingly important (Seborg et.al. 2010). The primary objective of process control within industrial processes is the ability to:

“Maintain a process at the desired operating condition, safely and efficiently, while satisfying environmental and product quality requirements” (Seborg et.al. 2010:1).

Industrial processes usually rely on control systems to handle, measure, and control the vast amount of process variables handled by processes. The ability to control and manage process variables is an essential part of designing and controlling processes that are able to deliver on the objectives of process control (Seborg et.al. 2010). According to quality management pioneer Dr. Genichi Taguchi, there are two main types of critical process variables that affect business processes (Oakland, 2003). The first is called the control factor, which includes all the variables that are or can be under the control of management, such as for instance process and procedure design, the level of automation, and the integration and support from ICT. The second type of variable is called the noise factor, which includes all the variables and variations that cannot be controlled and managed in a stable manner, such as for instance variations in the performance and decision making capabilities of humans, and other environmental disruptions. Seborg et.al (2010) uses the term process dynamics when referring to the unsteady or transient state of a process. According to this definition, process dynamics is something that occurs due to both unusual process disturbances and planned transient operations such as start-ups, shutdowns and product changes.

In the context of this case study analysis, the main objective is to analyze the occurrence of process dynamics, which in this case study is defined as:

"Process dynamics in The Plan-to-Machine business process consists of the instances where the actual process deviates from the intended process, i.e. the designed and/or planned process."

The process as it has been designed has already been described and mapped in the first part of this case study as the As-Is approach to MPCE at Brunvoll, which includes the process prerequisites, tasks, procedures, data flows and sequences. Any deviations within these elements might lead to process dynamics in terms of what Seborg et.al (2010) is referring to as the unusual process disturbances. The planned process is concerned with the operational planning of the process, where the main objective is to schedule and execute work order operations within the scheduled time horizon derived from MPS and MRP planning. Together, these factors represent how the machining process and the planned work order operations is intended to execution at each process iteration. This implicitly means that the occurrence of process dynamics can be associated with one of two reasons. The first is whether scheduled operations are planned realistically taken into considerations all relevant variables involved in the process, such as for instance lead-times and machining center capacity. What is meant by this is that for instance process dynamics can occur if the scheduled activities are planned unrealistically, or for instance with a too small buffer to handle uncontrollable process variation. However, in the context of this case study it is assumed that the scheduled operations are planned realistically, meaning that the scheduled starting and finishing dates for work order operations should be attainable under normal circumstances. This is supported by the fact that most gear housing work orders can be processed at M53 with a lead time of a couple of hours, while the scheduled time horizon for the work order may be stretched out over several days as a buffer. The second reason is based on the instances where unplanned factors cause the occurrence of process dynamics, which is where the case study analysis will mainly be aimed at. In other words, this is where actual process deviates from the designed process, which is mainly rooted in events such as procedural violations and unexpected events. However, as will be analyzed later, the designed and planned aspects of the process are interrelated as any violations to the process design objectives may affect the conformance to the planning objectives.

Furthermore, it important to note that the occurrence of process dynamics does not necessarily lead to any significant impact on the process control objectives. The ability for the process to handle process dynamics will depend on several factors such as for instance the capacity, utilization, and buffers built into the process. This is closely related to the concepts of Lean and Agile manufacturing processes, where an Agile process is designed to be more flexible and is thus more able to handle process dynamics without violating the process control objectives. While on the other hand, Lean processes are far less receptive to process dynamics, as the process is designed to operation with the absolute minimum amount of buffer capacity and with the highest degree of utilization in order to maximize the reduction of waste.

In order to analyze the impact and occurrence of process dynamics in the Plan-to-Machine business process, the main control objective of the process had to be defined. Based on the case study findings, the process control objectives process is defined as the ability to:

"The main process control objectives of the Plan-to-Machine business process is to plan and execute work order operations within their scheduled time horizon, in a state that conforms to technical and quality requirements, and without negatively impacting the control objectives of other work orders and subsequent processes and work orders levels.

As defined, process dynamics leads to instances where the actual process deviates from the intended process. However, there is still some lack of understanding as to what the actual outcome of process dynamics really is. Based on the case study findings, two main process dynamics outcomes has been classified as:

- The Type 1 process dynamics outcome are based around the instances where the occurrence of process dynamics violates the central aspects of the process control objective, namely the ability to process the work order within its scheduled time horizon. In practice, this means that the occurrence of process dynamics cause one or more work orders to be delayed according to their scheduled finishing date.

- The Type 2 process dynamics outcome are based around the instances where the occurrence of process dynamics create substantial risk of violating the process control objectives, but where additional actions can prevent the permanent violations of the process control objectives. In practice, this involves the situations where the production planner or some other stakeholder might spend additional time and resources to make the corrections and adjustments needed to prevent the type 1 process dynamics outcome.

The main reason behind classifying the outcome of process dynamics is to aid in the understanding and simplification of the case study analysis. Much of the quantitative case study analysis will be based on analyzing historical work order transaction data stored in the M3 ERP system. As will be analyzed in detail later, the M3 ERP system is configured to capture business events such as the date at which work orders are reported as completed. This means that the overall occurrence of type 1 process dynamics outcomes at the work order level can be measured by comparing the actual finishing date with the planned finishing date, both data stores in the M3 ERP system. On the other hand, analyzing the actual occurrence of the type 2 processed dynamics outcome is inherently more complicated as it involves analyzing the occurrence of tasks and actions that fall outside the intended, or say designed process. This means that the occurrence of the type 2 process dynamics is less supported by quantitative findings and more supported by qualitative findings based on the information provided the key informants, who performs these tasks and actions as part of their work. As will be discussed, many of these tasks are manual tasks that falls outside the original process design, meaning that their occurrence are not captured by the M3 ERP system, which is something that challenge the main objective for industrial control systems in terms of being able to handle all process variables. Furthermore, this challenged the possibilities for providing quantitative data from the M3 ERP system that might support the qualitative findings for certain types of event and factors.

In order to support the qualitative findings and to measure the actual occurrence of process dynamics and underlying factors, two main methods of quantitative analysis was developed. The first method consisted of extracting and analyzing historical work order transaction data using SQL quires against the M3 ERP system database. As mentioned, the ability to measure process dynamics is much more achievable for the type 1 process dynamics outcomes than for the second type as the ability to capture these instances can easily be identified and measured by looking at and comparing the business events captured by the M3 ERP system.

Thereby, an SQL query was created to extract work order transaction history by selecting the relevant tables and columns from the M3 ERP system database. This task was supported by an internal ERP-consultant at Brunvoll, who possessed high levels of skill and knowledge concerning the system and the method of extracting data through SQL queries. The query consisted of joining two tables, which consisted of the machining process work order level for the planning group M53, and the previous surface treatment process work order level. The columns selected provided the information needed to analyze the first three situational events that will be described in the next section. The initial output from the query yielded all work order that where processed at both the surface treatment work order level and the machining work order level in the period 1.1.2016 to 26.04.2017. The initial query output contained a lot of duplicated data, as well as a lot of work orders without affiliation to an project number and element. The data was therefore first cleaned by using spreadsheet software in order to remove duplicated data and only include work orders with an associated project number. The reasoning behind this selection is that work orders linked to a project number could then be identified analyzed across both process/work order level.

By using spreadsheet software, the query result was then sorted and analyzed to identify the work orders where the actual finishing date, which is the date when the work order was reported as completed in the M3 ERP system, was reported later than the planned finishing date. If such work orders would appear, it would mean that some or several underlying factors had caused a type 1 process dynamics outcome. From a total sample of 86 work orders processed at M53 in the period with project affiliations, 74 work orders was by the definition a type 1 process dynamics outcome, which means that a significant portion of gear housing work orders do not conform to the main process control objective of the Plan-to-Machine business process. From these 74 delayed work orders, the average delay between the reporting and the scheduled finishing date was 15 days, with the biggest delay at 40 days. Figure 33 illustrates graphically the findings of the type 1 process dynamics outcome

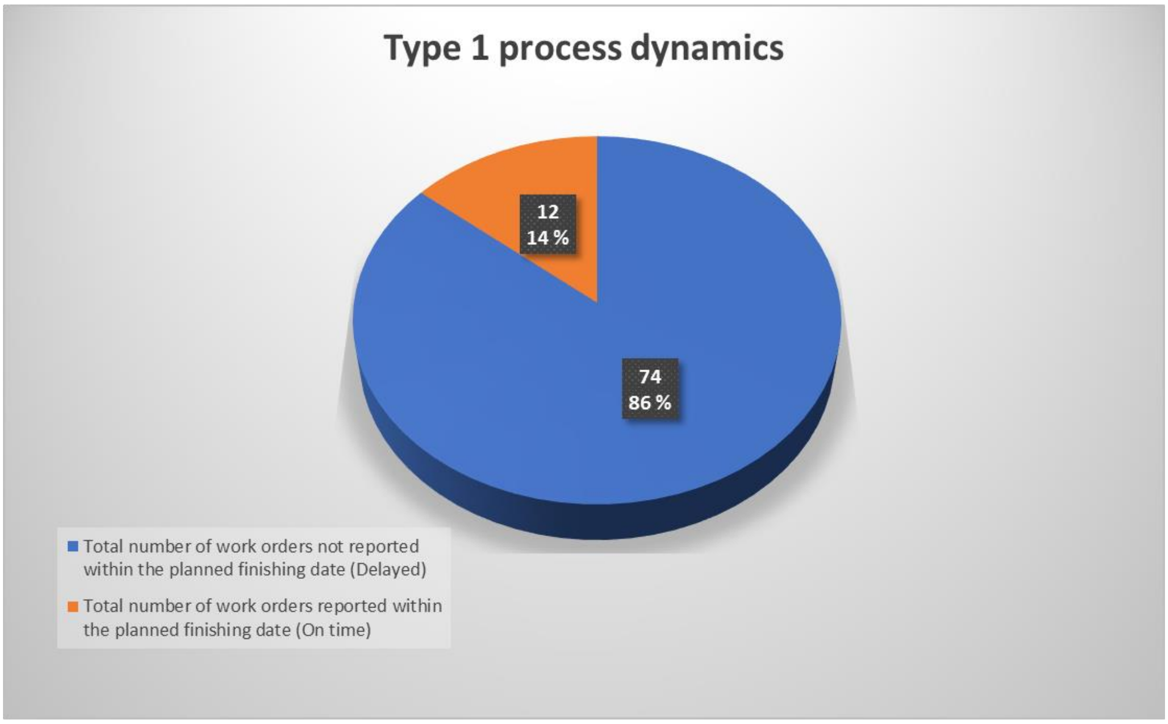


Figure 33. Findings: Type 1 Process dynamics outcome at M53.

Not all occurrences of process dynamics or underlying factors could be quantified, either due to the complexity of extracting the historic information or that the information required was not captured by the M3 ERP system. A second method was therefore developed that consisted of monitoring the process in real-time over a period, where findings could be captured through the use of screenshots and dynamic monitoring of the work order schedule in the M3 ERP system. Due to the limiting factors of a master thesis, this method was not applied to his case study analysis, however, the method itself will be explained later for the purpose of potential further studies. Furthermore, due to the limitations set by selecting a specific type of subject, in a specific process, and in a specific period, not all occurrences of process dynamics and underlying factors could be identified and quantified. This is also due to the difficulty for the informants to remember specific process dynamics and factors for specific products and processes, which might make the findings from the qualitative interviews a bit more generalized than just the scope of the case study. This is also supported by the fact that the quantitative findings are analyzed at the individual work order level, whereas the qualitative findings are more centered around the process level, which in turn make the two sources difficult to compare in light of investigating the relationship between them.

4.2.2 Dynamics Factors

As mentioned, control factors and noise factors represent two important distinctions in the type of underlying variables that influence the performance and control objective of processes. This inherently means that process dynamics is something that is inevitable bound to occur in real world industrial processes, even more so in manufacturing environments characterized by variability in products and processes, and where humans perform tasks and make critical decisions.

If process dynamics occur when the actual process deviates from the intended process, then process dynamics factors are the underlying events, variables, factors, and mechanisms that cause or contribute to the occurrence of process dynamics. Like all other processes, the Plan-to-Machine business process was designed to deliver output that conforms to the process control objectives, at each iteration. When moving from process design to implementation and to operations, many unforeseen and new factors can occur causing process dynamics. This is the reasoning behind many of the process and quality paradigms such as BMP, Six Sigma and TQM, where process design/redesign and control is an iterative process that runs continually alongside the operational process, and where the design parameters are continually adjusted to match the real-time requirements of the operational process. The conformance to the process control objectives is very much rooted in the ability to design and abide by solid and reliable process procedures at each process iteration. This means that companies should have a clear strategy as to how their processes are designed, implemented managed, controlled and improved.

This part the case study will be an investigation into occurrence of process dynamics by investigating the underlying factors behind them. After explaining how the intended processes works, the key informants were asked to describe situations within the Plan-to-Machine business process where process dynamics would occur according to the definition**.** By associating process dynamics with situational events in the process, it was easier for the informants to identify which and where process dynamics would occur in the Plan-to-Machine business process based on their experiences.

Based on the findings from the qualitative interviews, process dynamics manifested itself in four main situational events. The following first describes these situational events, and then tries to capture and analyze the relevant factors behind them. This is done to gain a deeper understanding into which and why process dynamics factors occurs, where in the process they occur, how are they handled, and what are the effects. If needed and/or possible, the factors are further broken down into more specific factors and mechanisms that represent more the root cause behind the process dynamics.

4.2.2.1 Situational event 1: Business event reporting

As defined before, controlling the efficient flow of goods, services, and information is a central part of successful logistics management. Control is directly associated with the concept of having visibility into all processes and operations across the value chain, which is an important driver for improving performance and decision-making.

As described earlier by using the GS1 standards as an example, great supply chain visibility is achieved by using a systematic approach for identifying, capturing, sharing, and using the information related to the flow of goods through the value and supply chain. The same logic applies to the internal flows within the company's value chain and the Plan-to-Machining business process at Brunvoll.

Apart from the ability to plan, allocate, and scheduled the resources and operations needed to fulfil a customers' order, the M3 ERP system is also responsible for capturing information regarding the execution of operations in the internal manufacturing processes. The information captured is mainly transaction based, which means it is captured whenever predefined business events are initiated or completed. Following the GS1 standards logic of capturing business events, information from important business events needs to the captured and shared in order to achieve transparency and visibility across the internal manufacturing supply chain. In addition, the capturing of these business events are important triggers and signal to the initiations of various processes and tasks. In the machining process at Brunvoll, the business events captured by the M3 ERP system consist of three major business events that are captured by the M3 ERP as work orders are being processed. Figure 34 shows which business events are captured by the M3 ERP system, and where in the machining process they occur. These business events represents the integration points between the physical process and the M3 ERP system as the control system.

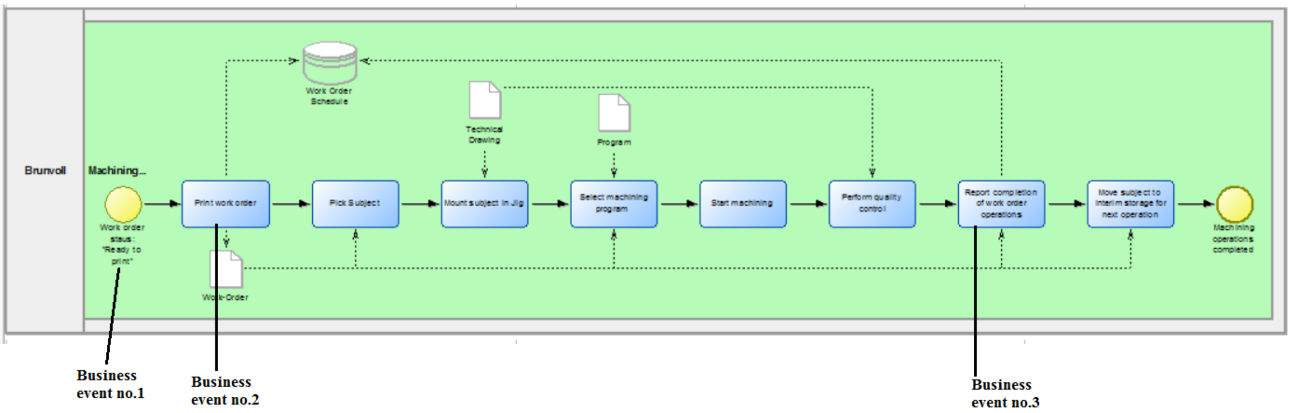


Figure 34. Business event captured by M3 in the Machining process.

<u>Business event number 1</u> is captured whenever a work order meets the criteria for the release of the work order onto the shop floor. Once the order is ready to be released, the work order status is changed to "Ready to Print" in the work order schedule. Following the GS1 logic, 4 main questions answer the rationale behind the capture of this business event.

Table 5. Business event number 1.

Question	Reason
What is captured?	A work order shop floor release, uniquely identified by the work order number and/or project number and element.
Where is it captured?	In the M3 ERP system.
When was it captured?	Whenever the work order was within the scheduled time horizon.
Why was is captured?	To provide a signal to the machining department that the work order is ready to be processed.

<u>Business event number 2</u> is captured whenever a work order is printed at the shop floor. Once the work order has been printed, the status of the work order in the M3 work order schedule is automatically updated to "Ready to Report". This defines the work order as being under processing.

Table 6. Business event number 2.

Question	Reason
What is captured?	The printing of a work order uniquely identified the work order number and/or project number and element.
Where is it captured?	At the shop floor in the machining department.
When was it captured?	Whenever the work order was printed.
Why was is captured?	To initiate the processing of work orders and confirm that a work order is under processing.

Business event number 3 is captured when the operator reports the work order operations as completed in the M3 ERP system. Once reported, the work order is considered as completed and the work order is removed from the work order schedule for M53.

Table 7. Business event number 3.

Question	Reason
What is captured?	The completion of the work order operations, uniquely identified by the work order number and/or project number and element, and the employee who performed the reporting.
Where is it captured?	In the machining department, through manual reporting in the M3 ERP system.
When was it captured?	Whenever the work order was reported.
Why was is captured?	To capture the completion of a work order operation (machining).

As can be seen in figure 34, there are five tasks between the second and third business event where no information is captured by the M3 ERP system. This means that the production planner or anyone that is not physically present at the shop floor has basically zero visibility into the status and performance of these tasks. In addition, the system has to trust that the reporting performed by humans is of the adequate information quality, meaning that the system is provided the right input at the right time. The lacking integration between the physical machining process and the M3 ERP control system leads to poor visibility and flexibility in the presence of process dynamics factors. This means that once the process dynamics has occurred, the production planner often needs to manually investigate and make decisions without much support from the M3 ERP system.

In most of the manufacturing process at Brunvoll, reporting the completion of work order operations trigger the distribution of important signals to the subsequent processes through the M3 ERP system. When for instance a work order is completed at the surface treatment work order level, the transaction needs to be reported so that an initiation signal can be given to the subsequent machining process, which is managed through the status symbols in the work order schedule. This is why reporting the completion of work orders is a critical part off in the manufacturing processes at Brunvoll, where any deviations may result in process dynamics. As described before, the completion of the work order operations is reported manually by the operator through the M3 ERP system. The main problem with the manual reporting procedures is the risk of input errors and input timeliness, or even the oversight of reporting. This is supported by the fact that the initiation signal for the processing of a work order is only provided by the reporting on the previous work order level and not the actual completion itself. This means that type 1 and 2 process dynamics outcomes can occur as a result of waiting on the right signal even if the signal should have already been given, i.e. the actual operations are completed, but not reported. This also highlights the importance of reporting business events in as close to real time as possible, especially in direct flow processes as practiced in the Plan-to-Machine business process. If the timeliness of reporting is not as close to real time as possible, then the information in the M3 ERP system is per definition not reflecting the actual situation, which means the various planning and decision making processes lack the right input and visibility. This obviously might lead to waste occurring in the processes in terms of waiting and delays.

The main dynamic factor in this situational event is thus procedural deviations occurring within the task of reporting the completion of the work orders. The production planner stated that input errors or the lack of reporting is one of the main factor that the planner have to use time and resources to correct manually, which also can lead to type 1 process dynamics. The main underlying factor is thus related to human errors with regards to input quality and timeliness within the task of reporting. In addition, lacking integration between the physical process and the M3 ERP system in terms of having fewer business events captured than process tasks means that there are a lack of visibility into the intermediated tasks, where zero external visibility can be obtained.

In order to measure the occurrence of process dynamics and underlying factors related to business event reporting, the SQL query of the historical work order transaction data was used as the source of quantitative information. In the context of the Plan-to-Machine business process, there are two relevant levels of reporting that must be analyzed in order to investigate their impact on process dynamics. The first level is the reporting that is done at the completion of the surface treatment work order level. The surface treatment work orders is by its definition only completed once the business events are reported correctly, which then triggers the processing of the subsequent machining process and work order level. If these events are not reported correctly as a result of for instance procedural violations and subsequent low information quality, they could certainly cause delays for the subsequent machining processes. The second level is related to the second to last task described in the As-Is machining process where the operator reports the completion of the machining operations in the work order. The SQL query joined the tables for the two work order levels surface treatment and machining, and then extracted the name and department of the employee who performed the most recent version of the reporting. By looking at the name of the employee and their associated department, work orders where the reporting was performed by someone outside the work order related department could be identified, which would indicate issues related to the reporting. Findings show that at the surface treatment work order level, 8 out of 68 work orders were reported by someone outside the surface treatment department, which is an indication for the occurrence procedural deviation in the task of reporting the work order as completed. Even though 6 out of 8 work order with reporting issues ended up as type 1 process dynamics outcomes, there can still be a number of other underlying factors involved which contributed to the delay at the surface treatment work order level and any delays at the subsequent machining process work order level. Figure 35 shows the findings with regards to reporting issues at the previous process level (surface treatment work order level).

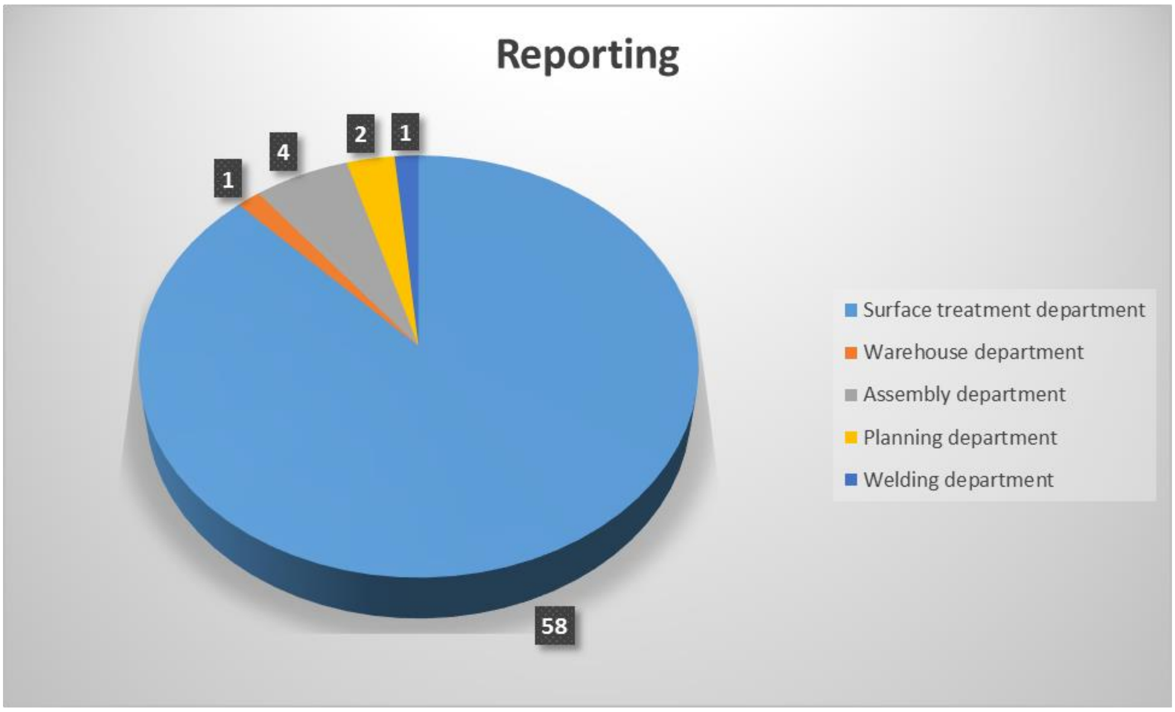


Figure 35: Findings: Reporting issues at the Surface Treatment work order level.

At the machining work order level, zero instances of reporting issues were captured by the SQL query with the delimited unit of analysis, which may be a coincidence since the reporting procedures is the same as with the other processes where reporting issues have been identified.

Given the historic information provided by the M3 ERP system, it is difficult to draw any strong quantitative conclusion as to the correlation and causation of the reporting of business events on the occurrence of process dynamics. However, it is important to note that the occurrence of type 1 process dynamics shown in figure 33 is determined by the date at which the work order was reported as completed compared with the planned finishing date. This highlights the importance of reporting the event when the actual event occur. This implicitly means that the occurrence of type 1 process dynamics outcome can be caused as direct result of reporting faults.

4.2.2.2 Situational event 2: Subject availability

As explained in the first situation event, the visibility of the process and the processing of work orders is mainly supported by the business event that are captured by the M3 ERP system. Lacking process and subject visibility will usually manifest itself with problems allocating subjects during the processing of work orders, causing both type 1 and type 2 process dynamics outcomes.

As described in the production planning process, one of the key task performed by the production planner is to allocate subjects and assign them to work orders. Since this is done through the M3 ERP system, it becomes vital the system represent the actual availability in the warehouse, storage locations, and at the shop floor. If a subject assigned to a work order somehow disappears and cannot be identified and/or found during the manufacturing process, then the worst-case scenario would be that the planner would need to reverse the work order in order to zero out the reporting of previous operations, and if needed, create new purchasing demands that for many subject types equals substantial purchasing lead-times.

The main dynamic factor behind missing subjects is procedural violations in processes where the subject is handled, including the tasks where the work order operations are reported (Situational event 1). The systematic design of the process could also be considered a dynamic factor as the M3 ERP system do not possess the capabilities of monitoring the flow of subjects in real time across the entire machining process, but rather through the reporting of the major business events. When combining this with the methods used to identify and tag subjects which consist of attaching paper printed work order to subjects, and with the risk of low information quality as a result of human performed reporting, it basically means that the M3 ERP system as an information system may not always reflect the actual situation in real time. This is obviously a problem in itself in terms of planning, controlling, and executing manufacturing operations and the handling of process dynamics with regard to the optimal decisions making support. This results in the occurrence of process dynamics caused by factors such as human errors and lacking integration between the physical process and the planning and control system resulting in lacking visibility, weak process design, and low information quality to support decision making.

The next step is to measure the occurrence if work orders that have had issues related to the availability of subjects. This involves analyzing the historical transaction data provided by the SQL query in order to identify work orders where the subject was not available, defined as not issued, on the planned starting date for the work order. If a subject has been issued after the planned stating date, then this would be an indication that the subject for some underlying reason was not available when it should be according to the schedule. The SQL query has already shown that a large portion of work orders at the machining work order level are delayed with regards to with regards to being reported after the planned finishing date. Additional columns such as the planned starting date and date when the subjects was issued was also captured by the SQL query. This enabled the possibility to analyze and identify work orders where the subject was issued later than the planned starting date. Findings show (figure 36) that from a total sample of 86 work orders at the machining process work order level, 54 work orders had issues related to subject availability as the subject was issued after the planned starting date.

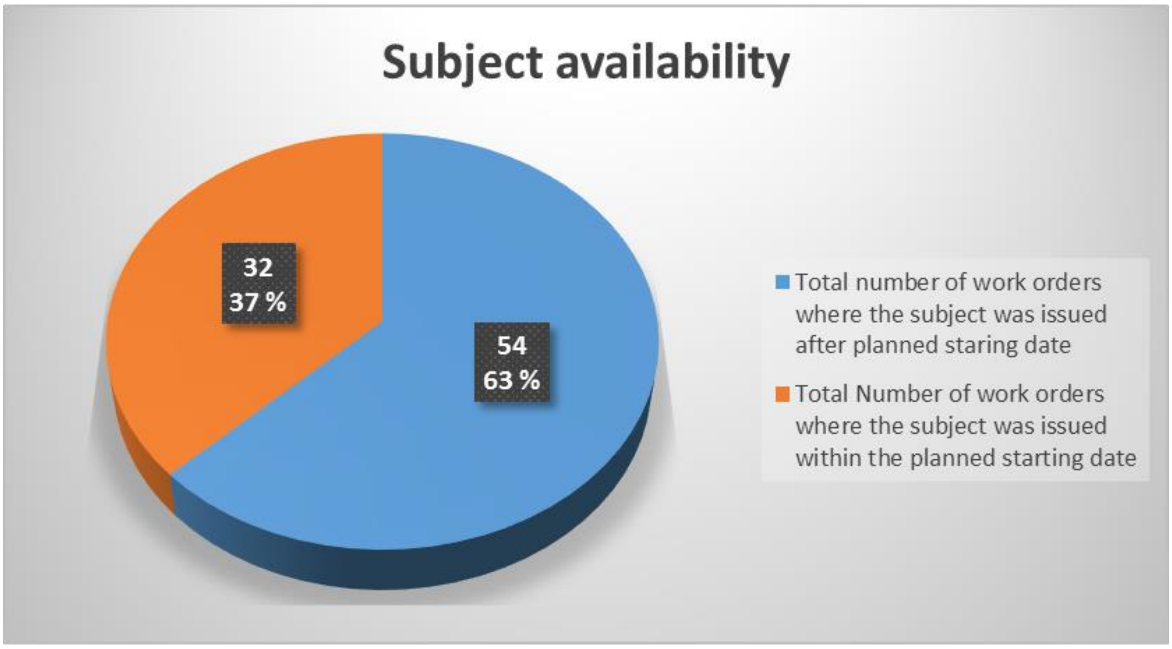


Figure 36: Findings: Subject availability at M53.

Since we now have two similar sets of data, one representing the number of days each delayed work order was delayed as the dependent variable, and the other representing the number of days each work order subject withdrawal was delayed as the independent variable, a correlation analysis between the two variable could be made. From a sample of 54 work orders, the analysis yielded a coefficient of .75, which indicates that there is a fairly strong positive relationship between the variables. Figure 37 shows the correlation between the two variables in a scatter diagram.

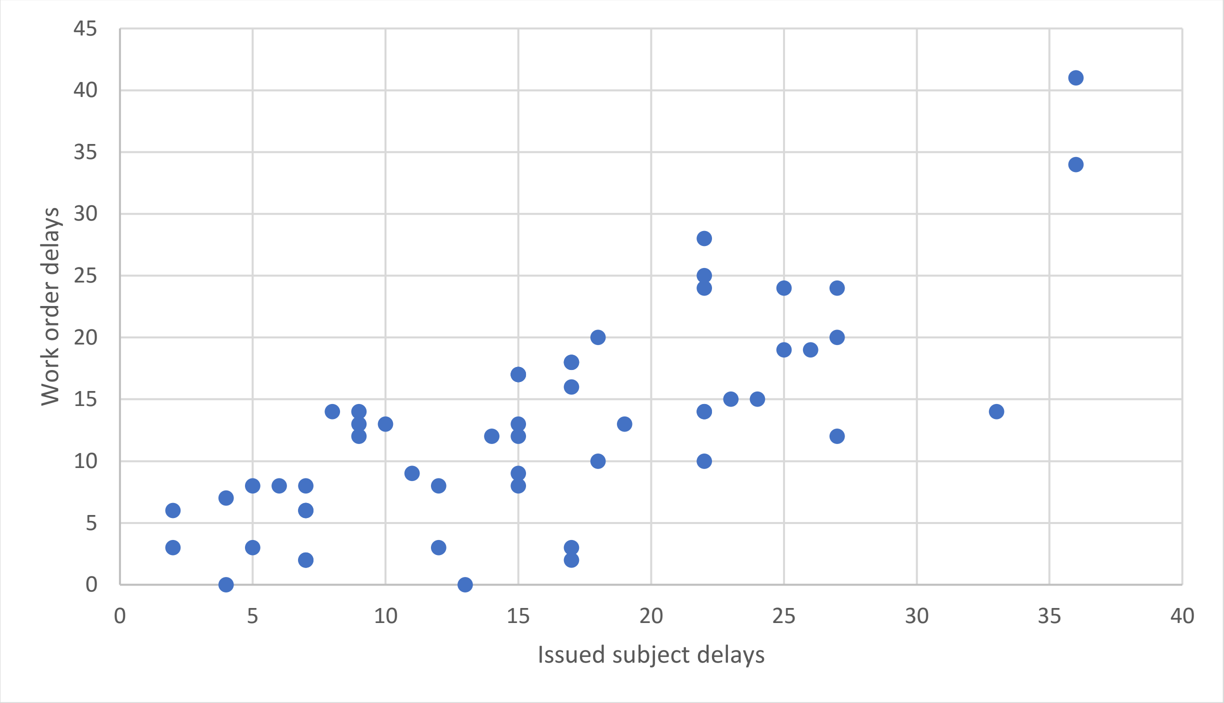


Figure 37. Findings: Relationship/Correlation between the type 1 process dynamics outcome and subject issue delays

However, the correlation between these two variables do not provide any evidence for the causation behind the problem related to subject availability. In addition, it is it very likely that several more independent variables/factors are involved in the relationship with the depended variable, such as the other factors and situational events covered in this case study. The lack of evidence for the causation is supported by investigating two work orders in more detail based on the information provided by the SQL query. The following is a comparison of two gear housing work orders across the surface treatment and machining process work order levels, connected by the project number and element. Table 8 shows the abbreviation used in the work order tables.

Table 8. work order abbreviations.

Column	**Abbreviation**
Work order level (process)	WOL
Project number	PN
Project element	PE
Subject/product	WO
Planned starting date	PS.d
Subject Issue date	SI.d

Difference in days between planned starting date and material issue date.	D1
Planned finish date	PF.d
Actual finishing date	AF.d
Difference in days between planned finish date and actual finishing date.	D2

The first work order contained the following information:

Table 9. Work order example 1.

WOL	**PN**	**PE**	**WO**	**PS.d**	**SI.d**	**D1**	**PF.d**	**AF.d**	**D2**
Surface treatment process	31557 A	2051	1158486	31.03.2016	08.04.2016	8	04.04.2016	12.04.2016	8
Machining process	31557 A	2051	1157875	22.04.2016	11.05.2016	19	28.04.2016	23.05.2016	25

As can be seen from the above table (9) starting at the surface treatment work order level, the date at which the subject was issued was 8 days later than the planned starting date and 4 days later than the planned finishing date, which results in the work order being delayed by 8 days. The SQL query does not provide any information as to why the subject was issued later than the planned starting date, but there is a clear indication that the delayed withdrawal of the subject had a direct impact of the completion of the work order. However, was it very interesting is what can be observed at the next work order level, where the subject is issued 19 days after the planned starting date. This is very strange, as the subject was completed at the previous work order level 10 days before the planned staring date for the subsequent level, which should mean that he subject was ready to be issued at the planned starting date. Again, since the subject was issued such a delayed manner, the completion of the work order was in the end delayed by 25 days.

The second work order contained the following information:

Table 10. Work order example 2.

WOL	**PN**	**PE**	**WO**	**PS.d**	**MI.d**	**D1**	**PF.d**	**AF.d**	**D2**
Surface treatment process	31557 C	2052	1164145	15.09. 2016	02.09. 2016	-13	20.09. 2016	02.09. 2016	-18
Machining process	31557 C	2052	1164263	26.10. 2016	16.09. 2016	-40	01.11. 2016	11.11. 2016	10

As shown in the table (10), all operations at the surface treatment work order level appear to be completed well on time, with the subject issued 13 days before the starting date and the completion of the work order 18 days before the planned finishing date. It would appear that this work order is planned with a lot of slack in terms of available buffer capacity. Even with the planned finishing date for the surface treatment work order, the subsequent machining work order is not planned to start in over a month later. Even though the subject was issued 40 days before the planned starting date at the machining work order level, the completion of the work order ended up with a delay of 10 days. This support the fact that even though there is a correlation between the subject withdrawal delays and the work order completion delays, more variables, factors and mechanism may be the underlying causes of the type 1 process dynamics outcome. One explanation behind this scenario could be the occurrence of lag in the processing of work orders, which means that the machining center will have less capacity than what is required from the schedule, thus creating type 1 and 2 process dynamics outcomes. This would mean that even if the subject was issued before the planned starting date, the completion of the work order could still end up as delayed, This topic is related to the topic of re-scheduling that will be investigated in detail later.

4.2.2.3 Situational event 3: Production faults

The occurrence of production faults means that some of the physical processing tasks in the machining process has faulted the subjects in such a way that it no longer conforms to the technical and quality requirements of the work order and the process control objectives. This means that production faults will lead to situations where the subject no longer can be used as it was initially assigned in a work order. Depending on the severity, the outcome of a production fault is either to scrap or reassign the subject to another purpose. Either way, the occurrence of production faults is very likely to lead to proceed dynamics and subsequent delays as the purchasing lead-times for these types of subjects are considerable and that they are not purchased as safety stock. The way production faults is handled by the production planner or other stakeholders is to decide whether or not the subject can be used to alternative purposes or if it has to be scrapped. In both cases, the work order needs to be reversed in the M3 ERP system in order to reverse and zero out the transactions related to previous executed processes and operations. This might be done all the way back to the MPS level, where new purchasing demand can be created if needed. Alternatively, the work order is reversed back to the point where the subject can be reassigned to another alternative work order. Handling production faults will trigger a highly manual process that require extensive coordination and communication between the parties involved. Such coordination is usually conducted through human interaction by the means of phone calls, emails, or meetings.

Related to the occurrence of production faults and associated process dynamics, two main underlying factors have been identified through the qualitative study. The first type is related to factors such as quality discrepancies, either from the externally purchased subjects or from internal processing, i.e. from previous processes. The main dynamic factor behind quality discrepancies is procedural deviations in tasks of executing operations and performing quality controls. This inherently means that the process of controlling the quality of both the purchased and processed subject needs to be based on a solid process design in order to minimize the risk of procedural violations and subsequent process dynamics. Only the internal processing and quality control for the machining process lies within the scope of this case study. Assessing the procedural design of the machining process becomes somewhat based on the researchers interpretation based on and grounded in the observation and analysis of the As-Is situation for the machining process. For instance, during the case study analysis of the As-Is situation, it was found that the operator manually selects the machining program at the M53 user interface by cross checking the program against program listed on the printed work order. Since this is a human performed task, it is quite possible to selects the wrong machining program when selecting the program machining among several available ones. If such event would occur and lead to a production fault, then the question would be whether the main dynamic factor was procedural deviation, which it clearly was, or that the dynamic factor is rooted in weak process design, and that safeguarding against such human errors should have been implemented. The second type of factors is related to unexpected events such as machine breakdowns or malfunctions that cause production faults, both factors that are hard to predict and to safeguard against. These kind of events have two possible outcomes, one is that for instance the machining center goes out of operations, which could affect all the work order queued up in the work order schedule, while the other is that the subject under processing become unusable which only affects one work order. The ability to handle unexpected and disruptive events are directly related to the design of processes and systems, where flexibility is a characteristic that can create safeguarding against such events. One way such safeguarding is implemented at Brunvoll is that the process planner creates alternative routing for the process, which acts as a reactive response to process dynamics. This means that subsequent queued work orders may not end up as delayed according the definition of the type 1 process dynamics outcome. In addition, the ability to maintain manufacturing equipment and machines in operating conditions is also an important part of process design in order to safeguard against the occurrence of process dynamics in a proactive.

The occurrence of production faults could be quantify by extracting historical transaction data from the M3 ERP system. Whenever a production fault lead to the scrapping of a subject in a work order, the M3 ERP system captures the events along with a code representing the reason behind the scrapping, which was also included in the SQL query. Findings show that only 1 out of 86 gear housing work orders was scrapped in the period of the analysis, which was caused by a machining fault represented by the code “04” in the M3 ERP system. This information only provides some insight into the underlying factors as being a machining fault, which as mentioned could be caused by a several underlying factors.

4.2.2.4 Situational event 4: Re-scheduling/-prioritization

Re-scheduling is related to situations where the production planner has to make changes to the work order schedule that may affect the work orders that have already been released and scheduled. As described in the As-Is production planning process, the objective for the production planning is to allocate subjects and schedule work order operations so that they can be released and processed within the scheduled time horizon and in state that conforms to the overall product and process requirements. One of the most common underlying factor that cause the occurrence of re-scheduling are rush orders. A rush order has been defined as either a new or existing work orders that is re-scheduled and/or given priory over already scheduled work orders in the work order schedule. Just like all planned orders, rush orders are broken down into work orders operations, which are scheduled and released according to their priority and time horizon in the work order schedule. Rush orders can originate from both internal and external demand.

Internal rush orders are created as a result of intra-company events that lead to the re-scheduling and/or reprioritization of existing work orders in the work order schedule. The underlying factors behind such events can occur in any of the processes where manufacturing operations are governed by the work order schedule, including the Plan-to-Machine business process. This means that many events, including the situational events described previously and their associated factors might create the need for re-scheduling. Thus, re-scheduling becomes one of the main response to the occurrence of process dynamics, even though re-scheduling in itself might cause process dynamics for other work orders and subsequent work order levels.

External rush orders are created by inter-company events that generate the need for the creation and release of new work orders, which in turn is given a higher priority than the already scheduled work orders in the work order schedule. The characteristics of the ETO strategy typically means that the product is only produced after the customer has placed an order, as opposed to products that are produced to stock. This means that the lead-times for ETO products are usually much longer than for MTS produced products. A thruster system is a critical component for the operation of vessels, which in the event of malfunctions or breakdowns becomes an urgent matter to handle for the vessel owners, i.e. Brunvoll’s customers. A common situation is thus the occurrence of rush orders and service orders from customers where delivery time is of an urgent matter. These types of rush orders are often given priority because they might be more profitable and important for creating high service and customer satisfaction levels. The main factors behind the occurrence of external rush orders is thus related to the both market factors and the nature of the ETO manufacturing strategy.

In the occurrence of re-scheduling, the production planning will make a decision as to the priority given to the rush work order in the work order schedule. Depending on the event that created the need, the production planner can either re-schedule an existing work order by prioritizing it upwards in the work order schedule or create a new work order were the priority is forced to the top. Whenever the priority of a work order re-scheduling is forced like this, there is a subsequent risk of violating the logic being ERP/MRP based planning principles, where demand information is leveraged against supply capacity to ensure realistic scheduling of manufacturing operations. Re-scheduling can therefore lead to the situations where the supply capacity becomes less than the demand, which leads to the type 1 process dynamics outcome. What is meant by this is that if an rush work order is given a forced prioritization over the existing work orders, and the rush work order consumes more resources than what is available as an buffer, it inevitably entails that the rush order will start consuming resources assigned to the existing work orders in the work order schedule and thus result in them being delayed. This creates quite a vicious cycle, where work orders will basically cannibalize on each other by consuming the allocated resources from the top to the bottom of the work order schedule, causing a bullwhip like effect that may also propagate to subsequent processes. Furthermore, as the production planner re-schedules one work order, he/she potentially have to re-schedule several subsequent work orders in the work order schedule. This is supported by the lacking ability of the M3 ERP system to automatically adjust the work order schedule after a re-scheduling event has occurred. Once work orders have been scheduled and released onto the work orders schedule, only the production planner or some other employee have the ability to change the work order schedule manually, as for instance when re-scheduling. The fact that the M3 ERP system does not perform any re-scheduling of released work order emphasizes the important role of the production planner to make the adjustments needed in the occurrence of such process dynamics.

Therefore, re-scheduling affecting other work orders will only result in the M3 ERP system generating proposed measures for the affected work orders. The two most relevant proposed measure codes provided by the system is either code B1, which suggest that the production planner should advance the work order about to be delayed, or the code C1, which basically tells the production planner that the work order inevitable will be delayed. If the production planner does not advance the B1 suggested work orders fast enough, it will become a C1 work order and the occurrence of type 1 process dynamics will be a fact. The production planner stated that since such events and disturbances can occur in all the manufacturing processes in Brunvoll, it could at times be very time consuming and difficult to handle all the proposed measures quickly enough to avoid the type 1 process dynamics outcome. This is due to the nature of the re-scheduling process, which require the planner to coordinate and investigate both causes, effects and decision as to how to best handle the situation.

Another problem related to the events where work orders are re-scheduled is the data captured in the M3 ERP system whenever re-scheduling occur. If for instance the re-scheduling of one rush work orders causes another work order to be delayed, then there is no connection between the two events, meaning that the delay of one work order cannot directly be linked to the re-scheduling of another as of how the current M3 ERP system is configured. In addition, since the re-scheduling of rush work orders does not lead to the automatic adjustment and scheduling of other work orders, the KPI measurement of the affected machining center can result in a poor performance measurement even if the source of the process dynamics originates from outside the process, i.e. externally from the customer.

Re-scheduling that lead to the occurrence of process dynamics cannot be identified and measured by looking at the transaction historic work order transaction data as with the previous situational events. As mentioned, one reason behind this is that the work order history is stored as a single entity, i.e. at the individual work order level, which means that there are no relationship between different work orders. What this means in practice is that in the event of a re-scheduling, the subsequent affected work orders do not capture the reason why they all of a sudden were given proposed measures and warnings. This also poses a great challenge for the production planner or some manager when trying to investigate the reason why a work order ended up as delayed, which could be highly valuable information to be used within process improvement measures. This means that the occurrence of re-scheduling need to be measuring by using the second type of quantitative data collection method described before. In the context of this case study, this would entail the task of dynamically monitoring the work order schedule for a period of time to observe work orders that are either scheduled after they were released or new work orders that were prioritized. If such events would occur, then the proposed measures of the subsequent work orders could be monitored to observe the outcome of the re-scheduling/prioritization. This would also be an investigation into the production planner's ability to mitigate the effects of re-scheduling/-prioritization. Due to the limiting factors of a master thesis in terms of having a limited period of data collection combined with the limited scope of this case study, it was decided to not put this method into practice during the case study data collection. One aspect of this was the lacking possibility to analyze these event in the same period and scope as was performed for the historical work order transaction data used in the analysis of the other situational events. An additional aspect was whether the effort of performing this method would yield any findings during the limited period and scope.

4.2.2.5 Summary of the process dynamics factors

The following factors have been identified through analyzing the 4 main situational events, which sums up the underlying factors that contribute to the occurrence of process dynamics.

4.2.2.5.1 The human factor

Humans are not made as completely rational decision makers which inevitable leads them to making misjudgments and errors from time to time, which off course is a natural part of human nature. In the context of the Plan-to-Machine business process, several tasks have been identified where human misjudgments and errors may result in process dynamics. This is especially relevant for the machining process where human errors manifests themselves as procedural deviations in the execution of critical tasks such as machining program selection, quality control, and business event reporting, where any deviations might lead to the occurrence of process dynamics. Procedural violations within the reporting of business events is especially critical as it creates issues related to the quality of information that is captured by the ERP system, which in turn support decision making processes and governs subsequent manufacturing processes.

4.2.2.5.2 The process factor

The process factors is very much related to the human factor, as the ability to design processes and procedures that safeguard against the occurrence of humans errors and procedural violations are critical success factors for stable processes that conform to the process control objectives at each iteration. In, addition, the nature of ETO manufacturing implicitly means that the process needs to be able to handle variations in products configuration and processes capabilities. As is supported by findings from the case study analysis, many critical tasks are executed manually by humans without much support from the control systems and/or safeguarding against human errors. This inherently means that although the occurrence of process dynamics might be caused by the human factor, some of the responsibility should be shared with the weaknesses found within the design of the process.

4.2.2.5.3 The Integration factor

The case study findings support that there is a lack of process visibility in the Plan-to-Machine business process, especially in the occurrence of process dynamics. One source of lacking visibility is the level of integration between the physical operations performed at M53 and the M3 ERP information system that support, monitor and capture business events in the process. According to the As-Is analysis, there is no integration between the M3 ERP system and the machine interface at M53, and the only integration points are the major business events captured by the M3 ERP system mainly through predefined events and manual reporting. This poses a great challenge as to capturing the business events that fall outside the predefined business events in the occurrence of process dynamics, which are events that represent important input to any process dynamics response processes.

The lack of flexibility in the MRP based logic of ERP systems in the presence of process dynamics is one of the main disadvantages of ERP systems (Arica and Powell, 2014). Within MPR logic, planning is performed top-down from the Master production schedule to the detailed planning performed trough the scheduling and the release of work orders. As with the Plan-to-Machine process, this logic works just fine as long as work orders are processed according to their schedule and to the process procedures. However, in the occurrence of process dynamics, the direction of the information flow is much more focused on bottom-up in order to adjust planning and make decisions in order to best handle the occurrence of process dynamics and reduce the severity of the outcome, which in this case is not very well supported due the lack of integration between the planning and control system and the physical manufacturing process.

4.2.2.5.4 The ETO factor

Several of the process dynamics factors found in the case study analysis are related to the characteristics of ETO manufacturing. An ETO manufacturing strategy will often lead to more complex manufacturing processes compared to the manufacturing of standardized products. The nature of ETO and the required capabilities of the processes increases complexity by introducing variety in product and process configurations, which naturally leads to more process variables that need to be controlled and managed in order to conform to process control objectives and to avoid the occurrence of process dynamics. Furthermore, ETO market factors are often characterized by variability in terms of product requirements and demand, which often manifests itself in situations such as the external rush orders. In the context of the Plan-to-Machines business process, the complexity of the ETO manufacturing strategy challenge the ability to establish efficient and streamlined processes that is able to handle all the process variables, both in terms of the ability to plan and execute operations as intended, and the ability to handle uncontrolled variation.

4.2.2.5.5 Conclusion on the process dynamics factors

The main takeaway from the investigations into the process dynamics factors is that process dynamics are complex and highly situational depended events that are composed of a number of underlying factors, which in turn are highly composed and interlinked with each other. Although the findings showed that 86% of work orders was by the definition a type 1 process dynamics outcome, the composition of factors might as well be unique for each of the 74 delayed work orders. As a result of this, it was not possible to make any strong evidence and conclusion as to the actual impact and causation of each factor on the outcome of each instance of process dynamics. However, these individual factors still provide important insight into factors that should be taken into consideration when discussing ways of improving the processes and systematic approach to MPCE.

5.0 Discussion

This chapter is devoted to discussing the finding from the case study analysis in conjunction with the third research question:

RQ3: How can Industry 4.0 related concepts and technologies be used improve MPCE at Brunvoll?

The case study analysis yielded several factors that contribute to the occurrence of process dynamics, and the next question becomes how do one handle these factors? The varying nature of the factors means that the approach to handle them with the objective of reducing process dynamics is quite varied. As the findings suggest, even if one eliminated the occurrence of the factors that have been identified, there could still be several unidentified factors causing the process dynamics. In addition, the nature of some factors are integrated parts of the manufacturing environment and is thus not possible to eliminate. This is why the occurrence of some factors can only be handled in a reactive manner and/or in a more optimal way, while the occurrence of others might be reduced or eliminated in a proactive manner.

Because of this, the objective of the third research question explore ways of improving performance within the scope of MPCE through either handling, reducing or eliminating the occurrence of the underlying factors identified and the subsequent process dynamics.

5.1 High-level requirements for a To-Be MPCE

The theoretical approach to MPC/MPCE is very much centered around the systematic approach companies take to plan, control, and execute planned manufacturing activities. The objectives and design of such systems in the traditional sense have already been outlined during the section on MPC (2.2.4). This approach has already been extended with an emphasis on the execution aspect within MPCE, which in this discussion will be extended further by incorporating elements from Industry 4.0. This is very similar to what Arica and Powell (2014) did when they developed a real-time Production planning and control system (Figure 17), which became a revised framework for PPC/MPC based on adding concepts and technologies such as APS, MES, and RFID. In its utmost sense, answering the third research question implies revising the systematic approach to MPC in the scope of Industry 4.0. However, since the research question is rooted in the case study finding at Brunvoll it is important that any revisions is be grounded in the case study findings and the handling, reduction, or elimination of the underlying factors that contribute to the occurrence of process dynamics. In order to ensure this, the findings from the case study analysis with regards to the situational events and underlying factors have been translated into high-level requirements that the To-Be MPCE system need to possess as capabilities. The following is an introduction to the high-level requirements defined for the revised MPCE conceptual system.

5.1.1 Integrated and interoperable manufacturing environment

The case study findings showed that there is a lack of integration between the physical manufacturing environment at Brunvoll and the M3 ERP as the planning and control system, both in terms of the ability to have visibility into the physical manufacturing process and the ability to control/execute manufacturing operations externally/automatically. Therefore, process dynamics related to the Integration factor require a more integrated and interoperable manufacturing environments.

Close integration is a key part of any cyber physical system, which is one of the key concepts within Industry 4.0. This means that the physical manufacturing environment should be as integrated as possible with the systems that plans, controls, and support the execution of operations in the manufacturing environment. The key enabler for CPS within Industry 4.0 is the IoT, which enables the integration between the digital and virtual world through the use of embedded and wireless technologies applied to the things of the physical world. Not only does this provide real world visibility, but is also enables interoperability and automation as things might receive information and instructions. The ability for this two-way communication between things and digital systems is the key enabler for both top-down and bottom-up planning that will be discussed later as an important requirement for dynamic planning.

5.1.2 Real world, real time process Visibility

Handling the occurrence of process dynamics should always be based on having the right information needed to make optimal decisions. The level of visibility into the actual processes is very much related to the level of integration between the control system and the physical environment. Furthermore, the quality of information will determine if the external visibility provided by the system actually reflects the actual situation of the physical world. The case study findings supports that there are limited visibility into the physical machining processes based only on the major business events captured along with a questionable level of information quality, and more so in the occurrence of process dynamics. Within the scope of Industry 4.0 and the capabilities provided by the IoT and CPS, a requirement should be that all relevant business events are captured and in turn provide visibility into the real world situation, on a real time basis, which in turn becomes important input for both human and system decision making.

5.1.3 Assisted or Automated decision-making

The case study findings has showed that the occurrence of human errors and procedural deviations within critical tasks is an important factor that needs to be eliminated as much as possible. Safeguarding against human errors can be accomplished in many different ways. At one end of the scale, the processes and the support from the control system can be designed to aid in decision-making and validate the actions taken by humans. On the other end of the scale, critical tasks could become fully automated if possible. Because of this, the revised MPCE should incorporate the technological foundation needed to support the automation and/or automated support of physical tasks.

The ability to support or automate the decision making and execution of critical tasks can yield higher operational efficiency and reduce the risk of human related errors and subsequent process dynamics. Furthermore, the same tasks and processes might be re-designed as a result of new possibilities provided by the technological developments within Industry 4.0, which in turn is less exposed to the human and process factors.

5.1.4 Process Flexibility

As explained, the natural characteristics of ETO manufacturing creates variation within both product and process configurations. In addition, many external factors and events may affect the processes and create process dynamics. This requires two types of flexibility within the MPC processes. One is the ability to efficiently handle the processing of different product types and product variants within the same process. The other is the ability for the MPCE system as a whole to respond to the occurrence of unexpected events in a responsive manner to minimize the process dynamics outcome.

5.1.5 Dynamic MPCE

In some way, the final requirement summarized the other requirement into one high level-requirement at the overall MPCE level. As the case study findings suggest, it is clear that the static planning structure of the M3 ERP system does not work optimally in the occurrence of process dynamics. Based on the factors identified, it is suggested that the Plan-to-Machine business process should be support by dynamic planning capabilities that enable the MPCE system to automatically adjust schedules and govern the execution of operations as opposed to the current manual approach performed by humans. Dynamic planning simply means that the planning and control processes are constantly adjusted to match the actual situation, which needs to be supported by factors such as closer integration, higher levels of visibility, and automated adjustments of planning and execution of operations. The main prerequisite of a dynamic MPCE system becomes the ability to integrate the system from the top planning level (ERP) to the shop floor execution level, where information is able to flow effortlessly in both directions.

5.2 IoT-enabled MPCE Conceptual System

In this section, the defined high-level requirements will be put into the development of a revised To-Be MPCE conceptual system, which also incorporates the scope of Industry 4.0.

The conceptual system is mainly based on the framework/system architecture developed by Arica and Powell (2014), which has been considered as the most relevant pre-Industry 4.0 MPC system architecture. The MPCE system architecture developed has been named the IoT-enabled MPCE, where IoT is included as a result of its core enabling role in the system, and "Execution" is added to MPC to include the emphasis on not only planning and control, but also on the execution of the planned activities, which is an aspect that is of high relevance within he scope of Industry 4.0.

5.2.1 System Architecture

Figure 38 shows the system architecture of the revised IoT-enabled MPCE which has been developed by incorporating the relevant technologies and concepts form Industry 4.0 with the framework developed by Arica and Powell (2014). As can be seen, the overall systematic approach/architecture is quite similar to the RFID-enabled real-time PPC/MPC by Arica and Powell, which entails that the changes in the developed system architecture lies more in the system components rather that in the system architecture.

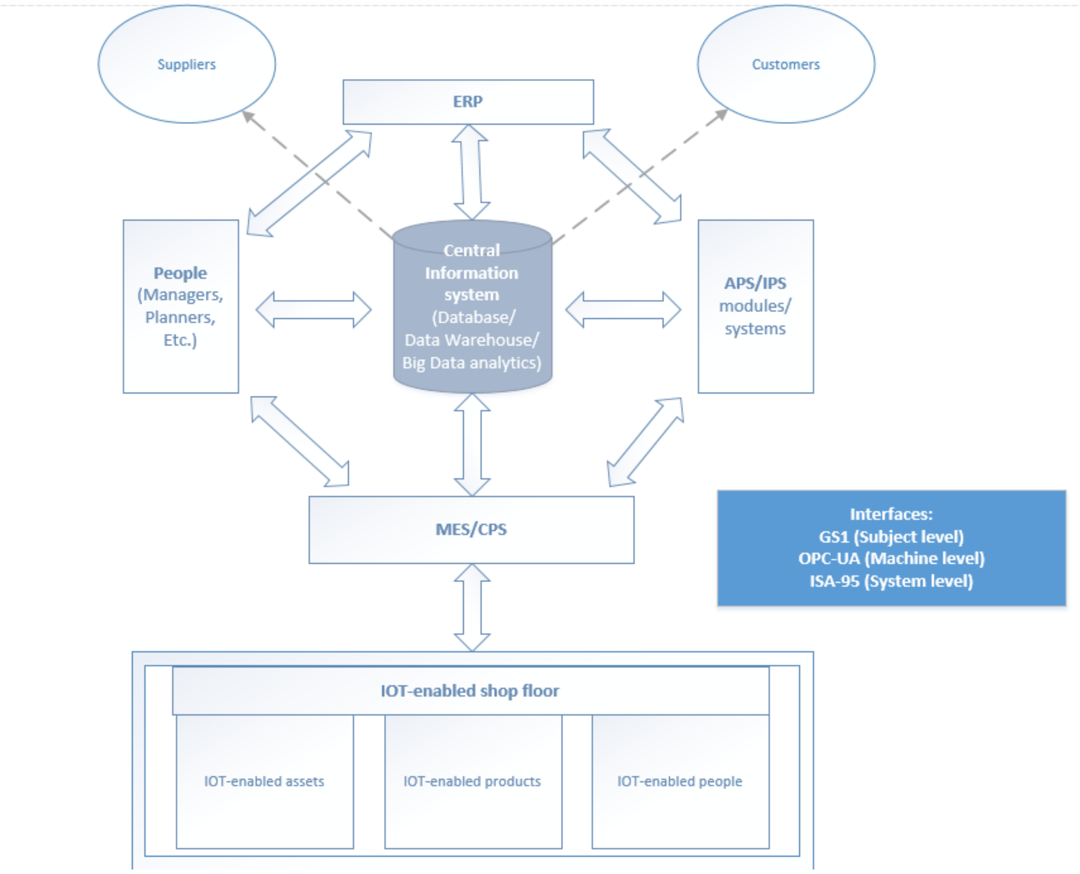


Figure 38. IoT-enabled MPCE, To-Be system architecture.

5.2.2 System Components

This section provides the description to each of the system components and their role in the overall system architecture.

5.2.2.1 ERP

Located at the top of level of the system architecture, the ERP system still remain as an important tool for the planning and scheduling of the manufacturing operations, as well as for capturing important business events related to the control of planned operations. The core logic behind planning in the ERP system is based on the MRP logic, which is centered on planning manufacturing operations from the top and down, meaning that manufacturing operation are planned ahead of time and then execution as scheduled as the shop floor. Findings from the case study supports that the ERP system is an important tool that supports planning and control the Plan-to-Machine business process at Brunvoll. As long as no process dynamic occur, this approach such yield sustainable and stable manufacturing processes, that is as long as no process dynamics occur. Once it does occur, the demand for responsiveness and flexibility in terms of making dynamic adjustments and changes to the scheduled operations becomes present. What is meant by this in the scope of the IoT-enabled MPCE is the occurrence of process dynamics will require the planning and control system to adjust itself from the bottom, i.e. the shop floor level, which is where the process dynamics factors occur, to the top level where schedules are maintained.

5.2.2.2 Advanced, Intelligent and dynamic planning system (APS/IPS)

The lacking ability of ERP systems to handle process dynamics in a responsive, dynamics and flexible manner has given rise to systems such as the Advanced Planning and Scheduling (APS), which takes some of the responsibility for handling re-scheduling and adjustments of the planned manufacturing operations in the occurrence of process dynamics. The system does this by leveraging data from the physical world, i.e. the shop floor processes, with data in the ERP system in order to provide dynamic planning capabilities for dynamic environments.

In the context of Industry 4.0, the developments in computational power has enabled systems to analyze and process vast amounts of data collected from the physical world. The speed and ability to handle large sets of data is one of the core prerequisites of the modern APS system, where the dynamic response of the system should ideally be as close to the occurring dynamics as possible. In addition, the developments within the field of artificial intelligence shows the potential to create intelligent systems that might make decisions with as good as or better decisions making capabilities than people, meaning that the system is able to handle process dynamics factors better and faster than humans and in an autonomous manner. This also means that such systems could be intelligent enough to predict the occurrence of dynamic and automatically safeguard against them in both a preemptive and reactive manner. The vision behind the Advanced, Intelligent and dynamic planning systems thus becomes the ability to both predict and handle the occurrence of process dynamics in a dynamic and flexible manner. This is especially relevant for the Plan-to-Machine business process at Brunvoll, where the planner often lack the time and resources to handle all the process dynamic occurring, which lead to type 1 and 2 process dynamics outcomes.

5.2.2.3 Central Information System

In the context of Industry 4.0, one key concepts for data and information management is Big Data analytics. IoT-enabled manufacturing environments will generate vast amounts of data compared to the traditional manufacturing environment, and the ability to capture and transform this data into valuable information will be a source of competitive advantage. In the context of the Plan-to-Machine business process, this implies going from only capturing historic transaction data for selected business events, to the real-time monitoring and capturing of business events on a much more granular level, including not only subjects, but also people and machines, which in turn reflect the real world, real time process. In addition, relevant information from the physical things in the manufacturing environment such as status and sensor information can be collected and analyzed as a result of the embedded capabilities of the IoT related technologies. All this data has to be has to be leveraged across all the value dimensions of Big Data (DHL, 2013), in order to increase operational efficiency, improve customer experiences, and create new business model possibilities, which are the some of the drivers for competitiveness and profitability. The power and possibilities provided by information thus becomes an important competitive factor in 4.0 industries.

The conceptual model for the IOT-enabled MPCE is mainly based on leveraging the information from the physical and digital world across the different things and systems that make up the conceptual system. This means that all the information captured from physical Things and other system components should be collected and stored in a central information system, where the information can be consolidated, processed, leveraged, and extracted for further processing by stakeholders, things, and the overall systems. In addition, the information can be shared with suppliers and customers within the scope of improving the supply chain performance and customer satisfaction. One such use of sharing information could be to provide customers with detailed information about the status of their orders, where the information can add value to both the company and the customers, achieved by increasing the customer satisfaction and the chances of customer retention. Another use of the information is related to the more traditional information sharing with the upstream supply chain actors, where the sharing of information can enable closer supply chain integration with suppliers and subsequent potential increase in supply chain performance. Since the information is already captured internally, there should be no reason why this information should not be shared externally across the supply chain. This will however require information to be managed in such a way that the information is of an adequate quality, as well as protecting concerns regarding sensitive information.

5.2.2.4 Humans

Although the frequent mentions of smart factories teeming with intelligent robotics and systems within Industry 4.0, humans still play an important role in manufacturing environments, at least as long as humans possess the capabilities that machines do not possess. The humans within the IoT-enabled MPCE are the people involved with the tasks of planning, controlling and executing the manufacturing operations. The role of these people is quite important as they provide input to the planning and control systems, interpret information, and make decisions based on information leveraged from multiple sources, things, and systems. There are two main pitfalls with regards to the tasks performed by humans. The first is the risk of humans making errors, which off course is both a natural and unavoidable part of human nature. As we have seen from the analysis of the process dynamics factors in the Plan-to-Machine business process, most human errors manifests itself through the violation of process procedures, which again lead to process dynamics. The second pitfall is the limited capacity of humans, reflected in the person’s ability to handle large amounts of data and the ability to take actions and measures in against the occurrence of process dynamics. Therefore, the key objective of the human component of the conceptual system is support the overall system with the decision-making capabilities that cannot be directly supported and performed by the ICT based system components.

Otherwise, it is the objective of the overall system to provide humans with the support they need to be efficient components of the overall system.

5.2.2.5 MES/CPS

As described before, the main objective of a Manufacturing execution system (MES) is to aid in the monitoring of the manufacturing processes and the execution of operations within those processes. The way the MES is positioned in the IOT-enabled MPCE (Figure 38) means that is acts as the central hub of the overall system as is connects the IOT-enabled shop floor to the above planning systems and components, and vice versa. This inherently means that information can flow effortlessly from both the top-down and from the bottom-up in the system architecture, which really is the key prerequisite for dynamic planning. What is meant by this is that the system collects all the information form the physical world enabled by the IOT-enriched shop floor, which then can be leveraged between and across planners, managers, planning and information systems in order to ensure that planning, control and execution is based on real world visibility and real time information. As we move towards the visions of Industry 4.0, one can see that an MES share many similarities with what will be the Cyber physical systems (CPS), where the physical manufacturing environment is integrated completely with the cyber related planning, control and execution systems.

5.2.2.6 IoT-enabled shop floor

As have been discussed, the IoT is the key enabler for the level of integration envisioned in the scope of CPS and Industry 4.0. Each of the high-level requirement listed builds on the ability to achieve connectivity and integration between the physical and digital world. As have been defined, the IoT is merely a network of physical objects (things), where the objectives have the capability to communicate, sense, and interact with each other and to the external environment, but its potential is often described as truly revolutionary, which is also an indication of its key role in Industry 4.0.

The capabilities and benefits provided by the IoT-enabled MPCE system is based on the ability to integrate the physical shop floor environment with the other system components. This inherently means that the overall MPCE system is dependent on the capabilities provided by the IoT, but the capabilities in themselves do not provide any value before they are utilized within the capabilities of the whole system. This in turn enable real world, real time informant to flow from both the top-down and bottom-up in the system architecture so that the information can be captured and leveraged between the other system components.

The IoT-enabled shop floors are built on the use of embedded and wireless technologies that enable physical things to become interconnected. In the scope of the physical shop floor environment within the IoT-enabled MPCE system, the Things have been classified as the following three:

IoT-enabled Products: Connecting products, components, subjects, etc. using embedded and wireless technologies within the scope of supply chain visibility has been widely adopted in logistics since the introduction of barcodes, RFID and other Auto-ID technologies. These technologies have predominately been used to increase visibility and efficiency by enabling automatic identifications of the products as they flow through the supply chain, and where the capturing and reporting of major business events could be automated as a result of the capabilities provided by the technologies. In the context of the case study findings, the use of embedded identifiers could yield several benefits and eliminate some of the factors that cause or contribute to the occurrence of process dynamics. By automating identification, the business events related to manual reporting could now the captured automatically by the system, which would ensure that the information captured consists of input quality and timeliness that reflect the actual situation in real time, which would improve the level of information quality and visibility within the system. This would also enable the possibility to capture more business events, which would create more visibility into the flow and location of products, meaning that less subjects would be missing/unavailable when they are needed.

IoT-enabled Assets: Connecting machines, robots, conveyors, and other assets within the physical manufacturing environment further extends the potential of the overall IoT-enabled MPCE system. Only when Products and Assets are integrated through the IoT and CPS that the capabilities of SMART factories within the scope of Industry 4.0 can be accomplished, where products and machines have the ability to communicate directly with each other to make autonomous decisions and actions. To provide an example within the context of the case study findings, this could for instance be the ability for the M53 machining center to capture the identity of the inbound subject and automatically selected the machining program based on the virtual information stored about the subject, i.e. the work order. Such integration and communication is governed through the overall MPCE system, which leverages and distributes information to where it is needed. Furthermore, integrating assets could provide additional information into the state and performance of the assets, which could provide valuable information to be leveraged within the overall system.

IoT-enabled People: In most manufacturing processes, people play an important role in the execution of tasks and operations. By integrating the shop floor workers within the overall system, the risk of human errors could be reduced or eliminated by providing intelligent support within the execution of these tasks. Furthermore, the close integration between products, assets, and people within the scope of IoT and CPS enables the system to closely monitor all activities performed, which could identity errors and procedural deviations as they occur and increase the overall responsiveness of the planning, control and execution processes.

5.2.3 System Interfaces

Interfaces and global standards play an important role in creating integrated, interoperable and connected manufacturing environments. In the context of the IoT-enabled MPCE, there are three levels that must be integrated for the entire system to work, namely the object/ level (subjects in case study), the machine level, and the system level.

At the object level, the main prerequisite is to be able to uniquely identify all things that make up the IoT, not only internally in the manufacturing process, but also when things move across the supply chain. With this comes the possibilities to follow the component or product until it reaches the customer and even after the customer has started using the product. Here, standards such as GS1 provide identifications schemes than can be used to identify a wide range of objects. Furthermore, the “identify”, “capture”, “share”, and “use” logic behind the GS1 standards become highly relevant in the scope of building automated, connected, and interoperable manufacturing environments. In the traditional sense, the focus of the GS1 logic has been to increase visibility across the supply chain. However, the same information can for instance also be used as input that enable automated execution of tasks within manufacturing processes, supported by capabilities such as product-to-machine communication and machine-to-machine communication. One thing that is certain is that the “Use” dimension of the GS1 logic is far extended in terms of potential and possibilities within the scope of Industry 4.0. One core aspect of this in the scope of the IoT and CPS is that the system is not only capable of capturing major business events, but captures all relevant events within the physical space.

At the machine level, machines needs to speak the same language if they are to become integrated and interoperable. Standards such as the OPC UA provide interoperability standards that enable secure and reliable exchange of data, which is independent of hardware and software platforms, which in turn enables the integration of heterogeneous manufacturing environments.

The system level lies at the same level as the overall MPCE system architecture. As explained before, the ability to leverage information between the system components is a key prerequisite for the system to operate as envisioned. This requires a certain degree of integration between the different system components at the different levels (Figure 11 and 13). Standards such as the ISA-95 standard was developed to enable the efficient sharing and coordination of information across the different levels by uniquely describing the information exchanged, including the interrelationships between the different types of information.

5.3 Potential Implications

This section provides a discussion as to the potential implications that such a proposed To-Be system could have on the occurrence of process dynamics, the Value Chain, and the strategic areas within ETO manufacturing, which is related to answering the fourth research question:

RQ4: What are the potential implications of an Industry 4.0 enriched MPCE system on the value chain and some of the strategic areas within ETO manufacturing?

5.3.1 Potential Implications on Process Dynamics

The potential implications of the IoT-enabled MPCE on process dynamics has already been discussed through the high-level requirements and system architecture, which are built around either handling, reducing, or eliminating the underlying factors that contribute to the occurrence of process dynamics. These capabilities can be summarized as the following.

- Real world, real time information that is captured and leveraged between the system components, so that the overall MPCE system is always provided with the right information, at the right time, and in the right quality. Another important aspect of this is the ability for information to flow from both the top-down and the bottom-up. What is meant by this is under normal circumstances, planning and control is predominately based on the top-down approach, where operations are scheduled ahead of time from the ERP to the shop floor. Here, the only bottom-up flow is the control aspect where the conformance to the scheduled operations are captured through predefined business events. On the other hand, the bottom up capabilities is vital whenever process dynamics occur, which then requires that all relevant information with regards to the event that causes the process dynamics is captured. This information has to be captured and leveraged in order for the system to achieve the requirement of dynamic/responsive planning and assisted/automatic decision-making.

- Automated and/or assisted decision-making is primarily achieved through the integration between the psychical environments and the system components, which in turn might enable human performed tasks to be automated or receive support from the overall system.
- Interoperable manufacturing environments is archived as a result of the overall MPCE systematic approach enabled by the integration between the physical manufacturing environment and the cyber related components.

5.3.2 Potential Implications on Strategic Areas

This section provides a brief discussion on the potential implication of the IoT-enabled MCPE on some of the strategic areas of ETO manufacturing identified by Gosling and Naim (2009), and presented under section 2.2.4.1.

5.3.2.1 Information management

The case study findings support the fact that the traditional transaction based control is highly inefficient when disruptions occur as according to Karkkainen et al. (2003). In addition, challenged related to low informant quality have been identified as a source of process dynamics. The proposed system architecture emphasizes the importance of identifying, capturing, sharing and using/leveraging the information at the individual product level between the system components in order to achieve the overall benefits of the systematic approach. This is mainly supported by the close integration between the physical and digital components that is enabled by key interfaces and standards along with embedded and wireless technologies.

5.3.2.2 Supply Chain Integration

Although Hicks et al. (2000) find that there has been a trend among ETO companies to move towards more vertical disintegration partly driven by the financial pressure and the need to reduce cost, the capabilities of the IoT-enabled MPCE could enable closer integration with suppliers and suppliers. This is mainly supported by the high level of integration and information management capabilities that the system provides internally within the company, which through the use of global standards such as the GS1 could be aligned with the overall supply chain. Furthermore, information stored centrally could easily be shared with both suppliers and customers, as illustrated in the system architecture (Figure 38), which would support closer integration, for instance through providing suppliers with important demand information and customers with order status information such as customer order milestone reporting.

5.3.2.3 Business system-/process re-engineering

Since the IoT-enabled MPCE builds on several Industry 4.0 ICT-based concepts and technologies, this would certainly support the re-engineering from what could be considered pre-Industry 4.0 manufacturing processes. Furthermore, the integrated, flexible, and automated nature of the system should also be able to adapt to changes in customer demand/requirements in a responsive manner.

As mentioned, an important aspect of system engineering is that the factors that might influence the process ability to meet the cost, performance and schedule objectives must be taken into consideration in terms of integration them into the business system/process design. The case study analysis has identified some of the factors that are currently contributing to the occurrence of process dynamics at Brunvoll, which in turn are either handled, reduced or eliminated though the conformance to the high level requirements that the IoT-enabled MPCE system builds on.

5.3.2.4 Flexibility

As mentioned, the role of flexibility in ETO related processes and supply chains are shared among many researchers as an important competitive factor (Gosling et al. 2013, Gosling and Naim 2009). As the case study findings suggest, there is a need for flexibility in the MPCE processes whenever process dynamics occur, both in terms of agility in response to specific events and uncertainties, and in the capabilities of handling product and process variability. The proposed IoT-enabled MPCE supports increased flexibility by providing dynamic and responsive planning that aim to eliminate or handle the occurrence of process dynamics in the most optimal way. Furthermore, the interoperable and automated capabilities of the system also enable tasks such product and machine changeovers to more efficient and/or automated.

5.3.2.5 Time compression

From the perspective of the total cycle time (TCT) paradigm (Towill, 2003), the goal is to reduce the time taken to execute a business process from the perception of customer need to the satisfying of that need. Although the main objective of the IoT-enabled MPCE is not focused on reducing cycle times, it might still be a fortunate bi-product of the overall system and the capabilities provided by technological concepts and technologies. It is widely known that integrated and automated manufacturing environments has the potential to be far more efficient that similar environments dominated by human performed tasks. This implies that the IoT-enabled MPCE has the potential to reduce cycle times by performing tasks more efficiently through automation, as well as reducing waste in terms of human errors and events where important information is missing as input/signals.

5.3.3 Potential Implications on the Value Chain

According the research model hierarchy (Figure 23), the scope of this thesis has been to investigate MPC within the context of Brunvoll’s Value Chain, and more specifically within primary activity Operations (Figure 14). As have been discussed, the capabilities of the IoT-enabled MCPE has the potential to increase the performance of companies within the ETO sector through the various strategic areas. First and foremost, this implies that the primary activity Operation in Porters Value Chain is provided with improved margins by increasing the overall efficiency and performance of the MPCE system and associated processes. Furthermore, the technological developments added by such a system might support other primary activities as an important support activity.

Currently, this research has arrived at the bottom of the research model hierarchy, which means that the implications of the developed system architecture can only be discussed with regards to its potential implications. Therefore, the actual implications on the strategic areas and value chain can only be investigated further when the research model hierarchy is inverted, i.e. the capabilities of the model is tested. This will be discussed more in the further studies section.

6.0 Conclusion

The first part the case study consisted of describing and mapping the current approach to MPCE at the Plan-to-Machine business process level in order to gain insight into how the intended processes and systematic approach to MPCE is performed currently at Brunvoll. This formed the basis for the second part of the case study, which consisted of comparing the intended processes with what is observed as the actual processes in order to identify current challenges within these processes. Here, the objective was to investigate the occurrence of what was defined as process dynamics, which is the deviation between the intended and the actual process, which then could be further analyzed in order to investigate the underlying factors behind these deviations. The main takeaway from this analysis is that process dynamics occur in several situational events within the Plan-to-Machine business process, and where several factors have been identified as underlying factors behind these events and deviations. However, no strong conclusions could be drawn as to actual causation between these underlying factors and the specific occurrence of process dynamics. This is mainly a result of the complex nature of process dynamics which are likely to be composed of several underlying factors including those who have identified in the case study and those not yet identified. Furthermore, the ability to identify and analyze these underlying factors was limited to the information provided by the key informants and the M3 ERP system, both sources of information that can be considered as incomplete compared to the information that would describe the actual event. What is meant by this is that the key informants only have the ability to describe these underlying factors on a general basis based on their experience of which factors are the most predominant. However, the quantitative analysis of process dynamics have been identified at the individual work order level, which meant that each occurrence of process dynamics at the individual work order level could potentially be composed of a unique set of underlying factors. Furthermore, the findings support that the capabilities of the M3 ERP system to capture information related to process dynamic and underlying factors is quite limited, which further challenged the objective of identifying underlying factors given the research design. However, these factors still provided valuable insight into factors that on a high level systematic approach to MPCE could become key requirements that could be used to create a To-Be systematic approach to MPCE.

The first and second part of the case study represents the current approach to MPCE at Brunvoll and the key challenges within these processes. As a concluding remark to these, the findings suggest that the current systematic approach taken towards MPCE, mainly supported by the M3 ERP system, lacks some of the capabilities in light of the level of process dynamics occurring and in the scope of Industry 4.0. In the occurrence of process dynamics, the support from the M3 ERP system is considered as lacking because of factors such as limited visibility, flexibility, integration between the system and the physical machining process, which in turn puts the responsibility of handling the process dynamics in hands of the production planner or other human stakeholders.

The third part of the case study was concerned with developing a To-Be systematic approach to MPCE within the scope of the previous case study findings and Industry 4.0. The main objective behind this was that by handling, reducing, or eliminating the underlying factors, the overall occurrence of process dynamics could be reduced, which would subsequently improve the performance of the MPCE related processes. The concluding remarks for the developed IoT-enabled MPCE system architecture is that the system, 1. Supports the handling, reduction, or elimination of the factors identified, 2. Adds supplementary capabilities that the ERP system lacks within the scope of MPCE and process dynamics, and 3. Creates a relevant approach to the future of MPCE within the scope of Industry 4.0.

However, implementing such an extensive system in a real world scenario would require significant efforts and investments. More realistically, such a system would gradually be developed and implemented over time. The IoT-maturity assessment by Bø and Wiig (2016, Figure 10) shows that companies such as Brunvoll still have a long way to go before reaching the scope and level of Industry 4.0, which is where the capabilities of the proposed system architecture would operate at.

7.0 Limitations and Further Studies

This thesis aimed at analyzing the current situation and challenges for the manufacturing planning, control, and execution processes at Brunvoll and then put these findings into the scope of Industry 4.0. Due to the limitations of a Master thesis and the scope and objectives of the research undertaken, the unit of analysis had to be delimited to one node in the manufacturing process and the machining of one component type. This means that findings towards the approach to MPCE at Brunvoll is only based on a limited part of the overall manufacturing process, which as a whole could potentially provide slightly different findings. Furthermore, the case study tried to explain the relationship between the process dynamics and the underlying factors that were identified. However, due to the research design and the available information provided by the key informants and the M3 ERP system, no strong conclusions could be drawn with regard to this. One important aspect of this is the capabilities of ERP system within such environments as have been analyzed in this case study, where the findings suggest the support from ERP system in terms of dynamic planning and process dynamics is somewhat lacking. The limiting factor behind such a conclusion is based on the fact that the ERP system analyzed within this case study is in fact only one system from one vendor. Since the level of integration and capabilities of ERP systems can vary a lot, such a conclusion might not be very generalizable. Another limitation within this thesis lies in the visionary nature of Industry 4.0, which at this stage does not exactly lack visions of great potential, but somewhat lacks strong scientific exploration. Another limiting factors with regards the underlying factors is the fact that the second method of data collection from the M3 ERP system was not applied to the case study analysis as a result of the time and scope limitations of a master thesis. This method was developed to capture the information with regards to process dynamics that the M3 ERP system did not capture.

This study has mostly been an exploratory study that has given valuable insight into the current situation and challenges within MPCE at Brunvoll and how Industry 4.0 related concepts and technologies might be used within such environments. In light of this, further studies should be aimed at further investigating each of the situational events in more detail by collecting more complete information that could explain the relationship between the process dynamics and the underlying factors. Furthermore, the case study should be extended to other manufacturing nodes and products types in order to investigate the overall approach to MPCE and the occurrence of process dynamics and underlying factors at Brunvoll. Even further ahead, such system architecture might be furthered developed at a more detailed level. Once this is accomplished the research model hierarchy (Figure 23) developed within this thesis might be inverted as the actual implications of such a system could be tested from the specific processes and process dynamics to the value chain level.

REFRENCES

Aberdeen Group. 2013. *Supply Chain Visibility: A Critical Strategy to Optimize Cost and Service*. http://www.gs1.org/docs/visibility/Supply_Chain_Visibility_Aberdeen_Report.pdf (Accessed 06.02.2017)

Ackoff, R.L. 1989. *From data to wisdom*. Journal of Applied Systems Analysis 16 (1989) 3–9.

Adonis:CE. BPMN tool. http://en.adonis-community.com/.

Arica, Emrah., Powell, Daryl J. 2014. *A framework for ICT-enabled real-time production planning and control*. Advances in Manufacturing, 2014, Vol.2(2), pp.158-164.

Aslan, Bulut., Stevenson, Mark., Hendry, Linda C. 2012. *Enterprise Resource Planning systems: An assessment of applicability to Make-To-Order companies*. Computers in Industry, September 2012, Vol.63(7), pp.692-705

Avison, David., Fitzgerald, Guy. 2006. *Information systems development: methodologies, techniques & tools*. 4th edition, McGraw-Hill Education.

Barratt, M., Oke, A., 2007. *Antecedents of supply chain visibility in retail supply chains: A resource-based theory perspective*. Journal of Operations Management Volume 25, Issue 6, November 2007, Pages 1217–1233.

Berner, Martin., Augustine, Jino., Maedche, Alexander. 2016. *The impact of Process Visibility on Process Performance*. A Mulitple Case Study of Operations Control Centers IN ITSM. Bus Inf Syst Eng 58(1): 31-42.

Bø, Agnethe., Wiig, Heidi. 2016. *IoT-Technological Maturity Model Development and Maturity Assessment of Norwegian Manufacturing Companies.* Master Thesis, Molde University College.

Businessdictionary. *Information definition*. http://www.businessdictionary.com/definition/information.html (Accessed 30.03.2017)

Businessdictionary. *System engineering definition*. http://www.businessdictionary.com/definition/system-engineering.html (Accessed 23.01.2017)

Cameron, N.S., Braiden, P.M., 2004. *Using business process re-engineering for the development of production efficiency in companies making engineered to order products.* International Journal of Production Economics 89 (3), 261–273.

Caridi, Maria, Antonella Moretto, Alessandro Perego, and Angela Tumino. 2014. *The benefits of supply chain visibility: A value assessment model*. International Journal Production Economics 151 (2014): 1-19.

Childerhouse, P., Lewis, J., Naim, M., Towill, D.R., 2003. *Re-engineering a construction supply chain: a material flow control approach*. Supply Chain Management 8 (3/4), 395–406.

Choo, C.W. (1995). *Information Management for the Intelligent Organization: Roles and Implications for the Information Professions*, 1995 Digital Libraries Conference (March 27-30, 1995; Proceedings p. 81-99). Singapore: National Computer Board of Singapore.

Christopher, Martin. 2000. *The Agile Supply Chain: Competing in Volatile Markets*. Industrial Marketing Management, Vol 29., No. 1., 2000. Pg 37-44

Christopher, Martin. 2011. *Logistics and Supply Chain Management*. 4th edition, Pearson Education limited. Prentice Hall.

Cscmp. *Supply Chain management definition*. Council of Supply Chain Management Professionals. http://cscmp.org/imis0/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588-f65f-4ab5-8c4b-6878815ef921 (Accessed 15.01.2017)

Davenport, T.H., Harris, J.G., Cantrell, S. 2004. *Enterprise systems and ongoing process change.* Business Process Management Journal 10 (1) (2004) 16–26.

De Bernardini, Luigi. 2015. *Industry 4.0 or Industrial Internet of Things—What's Your Preference?* https://www.automationworld.com/industry-40-or-industrial-internet-things-whats-your-preference (Accessed 15.02.2017)

De Ugarte BS, Artiba A, Pellerin R (2009) *Manufacturing execution system—a literature review*. Prod Plan Control 20:525–539

DHL. 2013. BIG DATA IN LOGISTICS. DHL Trend Research. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/bigdata.html#.WSA9cMYlH4E (Accessed 01.04.2017)

DHL. 2015. *INTERNET OF THINGS IN LOGISTICS*. DHL Trend research. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/internet_of_things.html#.WSA6dsYlH4F (Accessed 26.02.2017)

DHL. 2016. *LOGISTICS TREND RADAR*. DHL Trend Research. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/trendradar.html#.WSA1y8YlH4E (Accessed 15.02.2017)

Donselaar, K.V., Kopczak, L.R., Wouters, M., 2001. *The use of advance demand information in a project-based supply chain*. European Journal of Operational Research 130 (3), 519–538.

Ellram, Lisa. 1996. *The use of the case study method in logistics research.* Journal of Business Logistics, 1996, Vol.17(2), pp.93-138

EPRS. 2015. Industry 4.0: Digitalisation for productivity and growth. European Parliament research service. PE 568.337. http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf (Accessed 15.02.2017)

Francis, Vernon. 2008. *Supply chain visibility: lost in translation*. Supply Chain Management: An International Journal 13/3 (2008): 180-184.

Gabbai, Arik. 2015. *Kevin Ashton Describes "the Internet of Things".* Smithsonian Magazine. http://www.smithsonianmag.com/innovation/kevin-ashton-describes-the-internet-of-things-180953749/ (Accessed 02.01.2017)

Gantz, John., Reinsel, David. 2013. *The digital universe in 2020: Big Data, bigger digital shadows, and biggest growth in the far east* – United States. IDC country brief. https://www.emc.com/collateral/analyst-reports/idc-digital-universe-united-states.pdf (Accessed 31.03.2017)

Gartner. Internet of Things Defined. http://www.gartner.com/it-glossary/internet-of-things/ (Accessed 17.02.2017)

Gerwin, Donald. 1993. *Manufacturing Flexibility: A Strategic Perspective*. Management Science, 1 April 1993, Vol.39(4), pp.395-410

Goh, Mark, Robert De souza, Allan N. Zhang, Wei He, & Tan P.S. 2009. *Supply Chain Visibility: A decision making perspective*. Industrial Electronics and Applications (4th IEEE Conference on Digital Object Identifier: ICIEA) Pages: 2546-2551

Golafshani, N. 2003. "*Understanding Reliability and Validity in Qualitative Research*".The Qualitative Report. Volume 8 (4) p. 597-607.

Gosling, J., Purvis, L., and Naim, M.M., 2010. *Supply chain flexibility as a determinant of supplier selection*. International journal of production economics, 128 (1) 11-21.

Gosling, Jonathan., Naim, Mohamed M. 2009. *Engineer-to-order supply chain management: A literature review and research agenda.* International Journal of Production Economics, 2009, Vol.122(2), pp.741-754

GS1. *Global Language of Business*.

http://www.gs1.org/standards http://www.gs1.org/company-prefix

http://www.gs1.org/id-keys

http://www.gs1.org/how-gs1-standards-work

http://www.gs1.org/about

http://www.gs1.org/about/what-we-do

http://www.gs1.org/sites/default/files/docs/architecture/AG_Flyer_final.pdf

http://www.gs1.org/standards/internet-of-things

http://www.gs1.org/sites/default/files/docs/architecture/GS1_System_Architecture.pdf

http://www.gs1.org/sites/default/files/images/standards/internet-of-things/gs1-and-the-internet-of-things-IoT.pdf (All Accessed 8.2.2017)

GTAI. 2014. *INDUSTRIE 4.0: Smart Manufacturing for the Future*. German Trade and Invest. https://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Brochures/Industries/industrie4.0-smart-manufacturing-for-the-future-en.pdf (Accessed 27.02.2017)

Harrison, Alan., Van Hoek, Remko. 2011. Logistics Management & Strategy, Competing Through the Supply Chain. Prentice Hall.

Hicks, C., McGovern, T., Earl, C.F., 2000. *Supply chain management: a strategic issue in engineer to order manufacturing*. International Journal of Production Economics 65 (2), 179–190.

HiMolde. Master Thesis. http://www.himolde.no/studier/MasterofScienceinLogistics/Sider/side.aspx (Accessed 20.03.2017)

ISA. *About ISA.* https://www.isa.org/about-isa/ (Accessed 28.04.2017)

ISO. *The main benefits of ISO standards*. https://www.iso.org/benefits-of-standards.html (Accessed 15.04.2017)

ITU-T Y.2060. 2012. *Overview of the Internet of things*. ITU Telecommunication Standardization Sector. http://www.itu.int/ITU-T/recommendations/rec.aspx?rec=y.2060 *(Accessed 06.02.2017)*

Karkkainen, M.,Holmstrom,J.,Framling,K.,Artto,K.,2003.*Intelligent products—a step towards a more effective project delivery chain*. Computers in Industry 50(2),141–151.

Kletti, J. 2007. *Manufacturing execution systems (MES*). Springer, Berlin.

Lambert, Douglas M; Cooper, Martha C; Pagh, Janus D. 1998. "*Supply Chain Management: Implementation Issues and Research Opportunities*", The International Journal of Logistics Management, Vol. 9 Iss 2 pp. 1 – 20

Pama. *Speedmat 3*. http://en.pama.it/prodotti/speedmat/ (Accessed 15.03.2017)

Lee, J., Bagheri , B., Kao, H-A., 2014. *A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems.* NSF Industry/University Cooperative Research Center on Intelligent Maintenance Systems (IMS), University of Cincinnati, Cincinnati, OH, United States.

Löffler, Markus., Tschiesner, Andreas. 2013. *The Internet of Things and the future of manufacturing.* Mckinsey. http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-and-the-future-of-manufacturing (Accessed 26.02.2017)

Mangan, John., Lalwani, Chandra., Butcher, Tim., Javadpour, Roya. 2011. *Global Logistics & Supply Chain Management*. 2nd edition. 2012 John Wiley & Sons Ltd.

McGowan, A. 1998. *Perceived benefits of ABCM implementation*. Accounting Horizons, 12 (1) (1998), pp. 31–50

McKinsey. 2013. *Disruptive technologies: Advances that will transform life, business, and the global economy*. http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/disruptive-technologies (Accessed 17.02.2017)

Merriam-Webster. Research Definition. https://www.merriam-webster.com/dictionary/research (Accessed 20.03.2017)

Oakland, John S. 2003. *Total Quality Management*. Text with cases.

Olhager ,J., 2003. *Strategic positioning of the order penetration point*. International Journal of production Economics 85.

OMG. BPNM 2.0. Object management Group. http://www.omg.org/spec/BPMN/2.0/ (Accessed 01.03.2017)

OPC. 2013. *ISA95*. OPC-foundation. https://opcfoundation.org/developer-tools/specifications-unified-architecture/isa-95-common-object-model. Permission to use granted by Mr. Michael Bryant, Administrative Director at the OPC Foundation (20.03.2017).

OPC. *Unified Architecture*. OPC-foundation. https://opcfoundation.org/developer-tools/specifications-unified-architecture. Permission to use granted by Mr. Michael Bryant, Administrative Director at the OPC Foundation (20.03.2017).

Porter, M.E., 1985. Competitive Advantage. The Free Press.

Porter, M.E., Millar, V.E., 1985. *How Information gives you competitive advantage*. Harvard Business Review. July-August 1985. No. 85415.

Porter, M.E. Heppelmann, J.E. 2014. *How Smart, Connected Products are Transforming Competition.* Harvard Business Review. NOVEMBER 2014 ISSUE.

Rahman, A., Rahim, A., Shariff, M., Baksh, N., 2003. *The need for a new product development framework for engineer-to-order products*. European Journal of Innovation Management 6 (3), 182–196.

Salvador, F., Rungtusanatham, M., Forza, C., Trentin, A., 2007. *Mix flexibility and volume flexibility in a build-to-order environment*. International Journal of Operations & Production Management 27 (11), 1173–1191.

Seborg, Dale E., Mellichamp, Duncan A., Edgar, Thomas F., Doyle III, Francis J. 2010. *Process Dynamics and Control*. 3rd Edition, Wiley.

Sintef. *Internet of Things and Cyber-Physical Systems*. http://www.sintef.no/en/information-and-communication-technology-ict/communication-systems/internet-of-things-and-cyber-physical-systems/ (Accessed 31.03.2017)

Sundmaeker, H., Guillemin, P., Friess, P., Woelfflé, S. 2010. "*Vision and Challenges for Realizing the Internet of Things*", Cluster of European Research Projects on the Internet of Things (CERP-IOT). [Online]. http://www.internet-of-things-research.eu/pdf/IoT_Clusterbook_March_2010.pdf (Accessed 01.02.2017)

Techopedia. *Artificial Intelligence (AI)* https://www.techopedia.com/definition/190/artificial-intelligence-ai (Accessed 02.04.2017)

Tenhiälä, Antti., Helkiö, Pekka. 2015. *Performance effects of using an ERP system for manufacturing planning and control under dynamic market requirements*. Journal of Operations Management 36 (2015) 147–164.

Towill, D., 2003. *Construction and the time compression paradigm*. Construction Management and Economics 21 (6), 581–591.

UCS Library Research guide. *Research design*. University of Southern Carolina. http://libguides.usc.edu/writingguide/researchdesigns (opened 20.03.2017)

Vokurka, R., Lummus, R. 2003. *A conceptual model of Supply Chain flexibility*. Industrial management & data systems.

Vollmann, T. E., Berry, W. L., Whybark, D. C. & Jacobs, R. F. 2005. *Manufacturing Planning and Control for Supply Chain Management*. McGraw-Hill, Boston.

Wilhjelm, Richard. 2013. *Revisiting the 3Vs of Supply Chain: Visibility, Variation and Velocity*. Supply Chain Digest. http://www.scdigest.com/experts/ComplianceNetworks_13-10-17.php?cid=7489 Accessed (06.02.2017)

Womack, James P., and Daniel T. Jones. 2003. *Lean thinking: Banish waste and create wealth in your cooperation*. London: Simon & Schuster.

Yin, Robert K. 2009. *Case study research : design and methods.* Applied social research methods series vol. 5

Zhou, H; Benton, W.C. 2007. *Supply chain practice and information sharing.* Journal of Operations Management, 2007, Vol.25(6), pp.1348-1365

Zumbach. *OPC UA – Overview.* *http://www.zumbach.com/products/product-finder/opc-ua/opc-ua-overwiew.html (Accessed 02.03.2017)*

APPENDICES

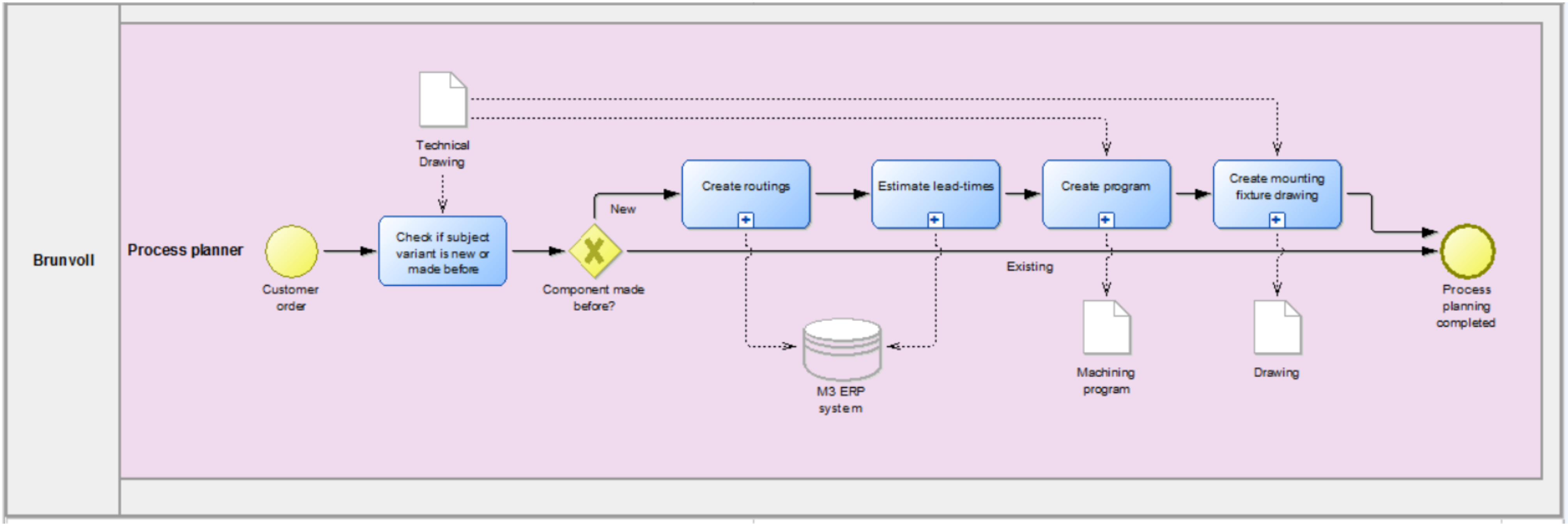
Appendix A.

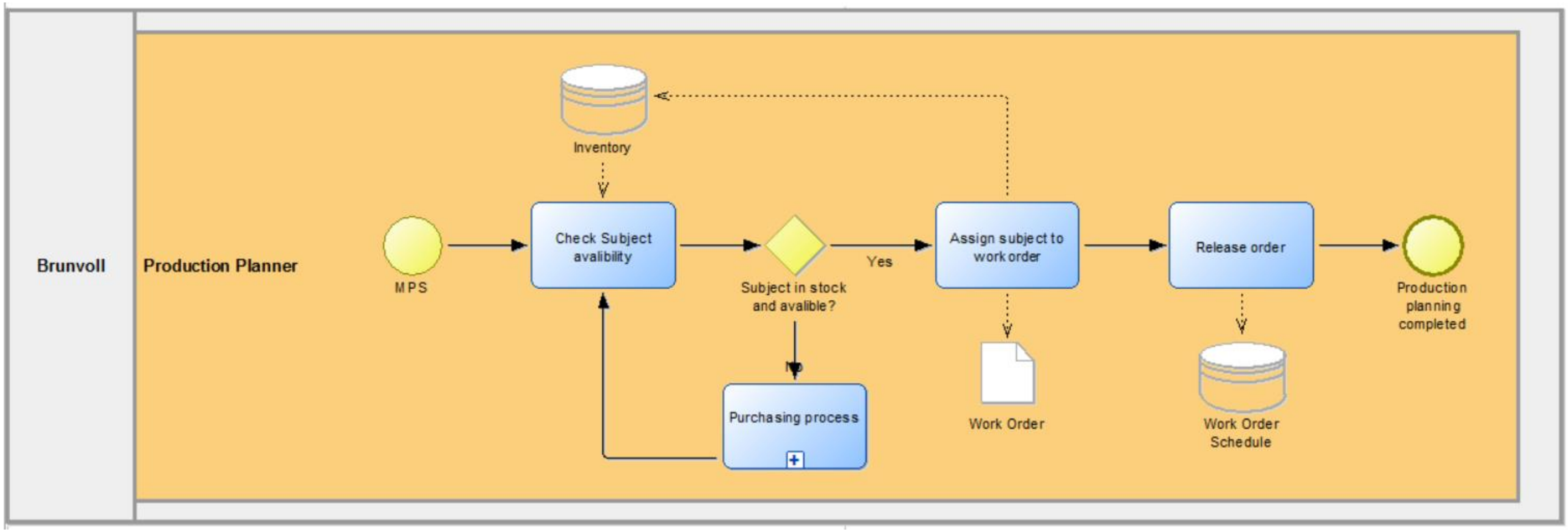
Case study translation table.

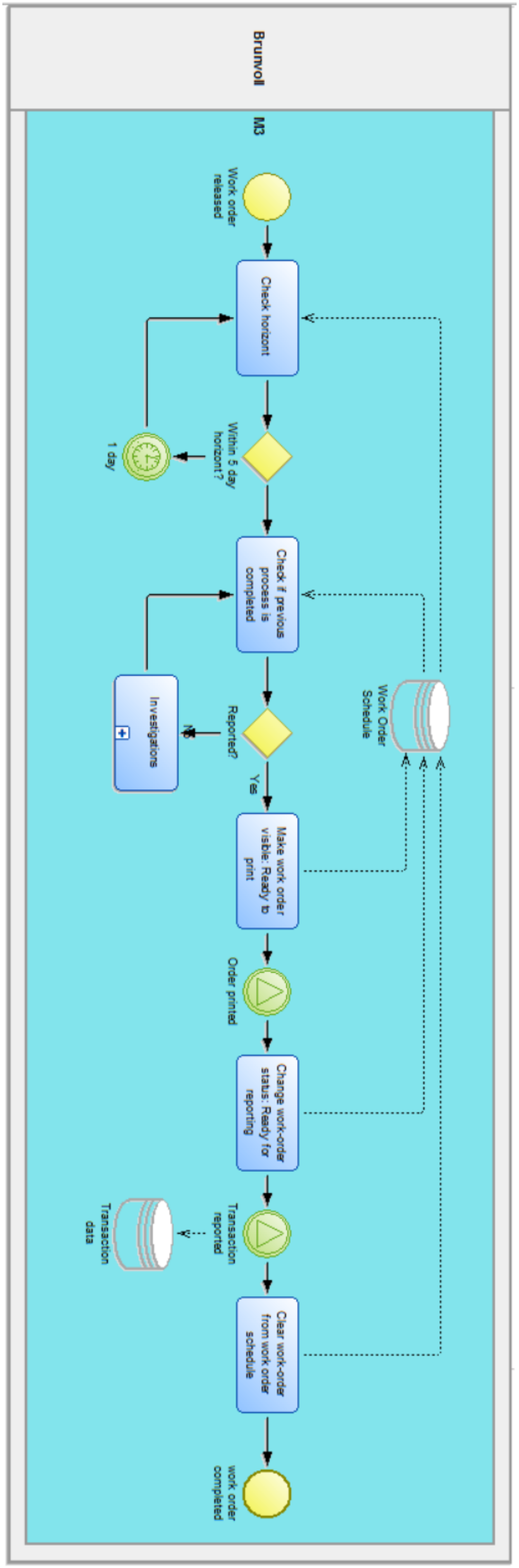
Norwegian	English
Emne	Subject
Kjøreplan	Work Order Schedule
Arbeidsordre	Work Order
Artikkelnummer	Item number

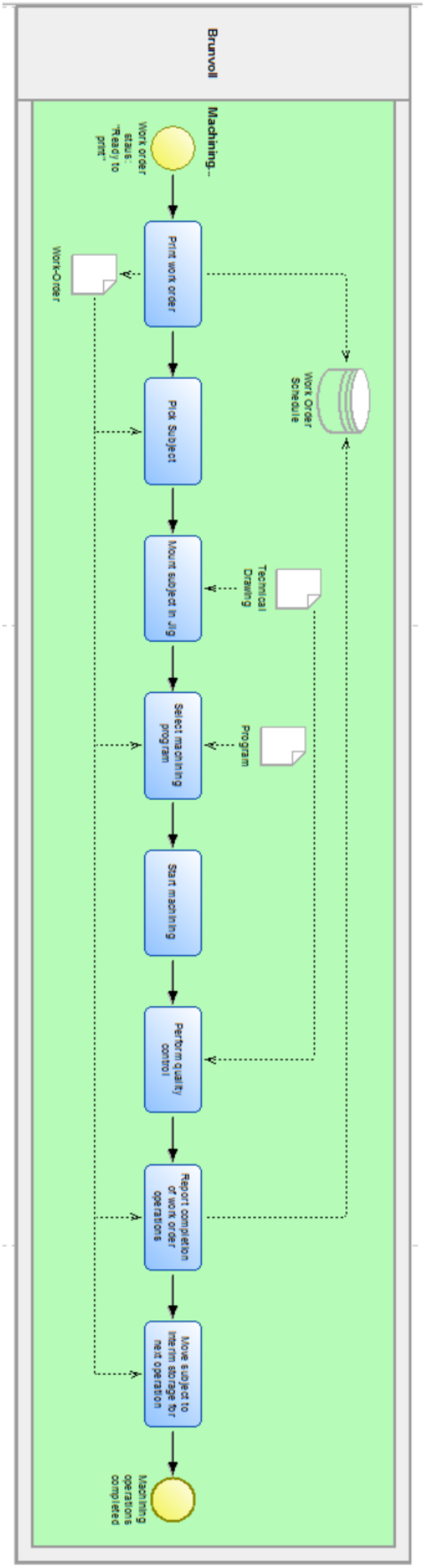
Appendix B.

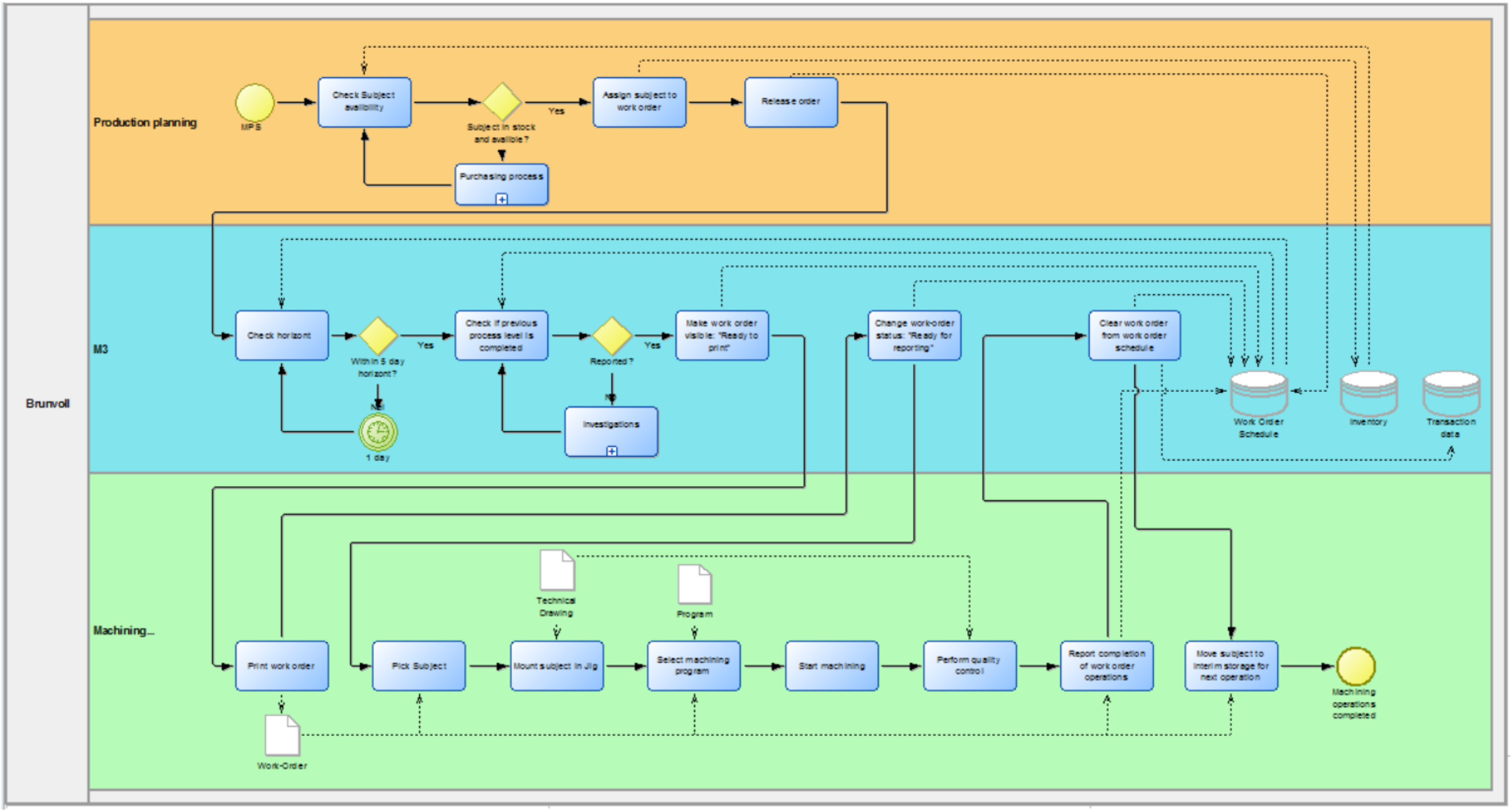
BPMN models (Large format).


Brunvoll
Process planner
Customer order
Technical Drawing
Check if subject variant is new or made before
Component made before?
New
Existing
Create routings
Estimate lead-times
Create program
Create mounting fixture drawing
M3 ERP system
Machining program
Drawing
Process planning completed


Brunvoll
Production Planner
MPS
Inventory
Check Subject avalibility
Subject in stock and avalible?
No
Purchasing process
Yes
Assign subject to work order
Work Order
Release order
Work Order Schedule
Production planning completed

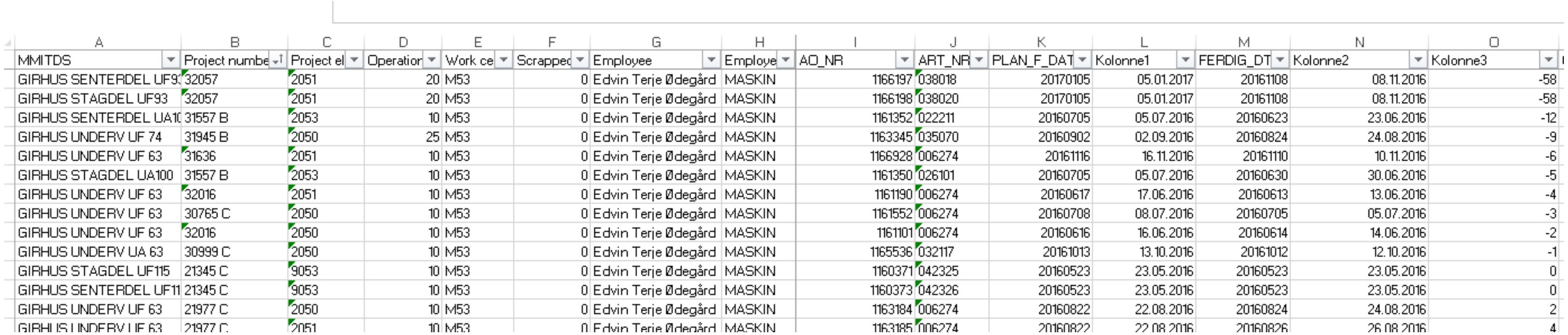

Brunvoll
M3
Work order released
Check horizont
Within 5 day horizont?
1 day
Check if previous process is completed
Work Order Schedule
Reported?
No
Yes
Investigations
Make work order visible: Ready to print
Order printed
Change work-order status: Ready for reporting
Transaction reported
Transaction data
Clear work-order from work order schedule
work order completed


Brunvoll
Machining...
Work order status: "Ready to print"
Print work order
Work-Order
Work Order Schedule
Pick Subject
Mount subject in Jig
Technical Drawing
Select machining program
Program
Start machining
Perform quality control
Report completion of work order operations
Move subject to interim storage for next operation
Machining operations completed


Brunvoll
Production planning
MPS
Check Subject availibility
Subject in stock and availible?
Yes
Purchasing process
Assign subject to work order
Release order
M3
Check horizont
Within 5 day horizont?
Nei
1 day
Yes
Check if previous process level is completed
Reported?
No
Investigations
Yes
Make work order visible: "Ready to print"
Change work-order status: "Ready for reporting"
Clear work order from work order schedule
Work Order Schedule
Inventory
Transaction data
Machining...
Print work order
Work-Order
Pick Subject
Mount subject in Jig
Technical Drawing
Select machining program
Program
Start machining
Perform quality control
Report completion of work order operations
Move subject to interim storage for next operation
Machining operations completed

Appendix C.

Excerpt from the SQL queries in Excel.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
MMITDS	Project numbe	Project el	Operatior	Work ce	Scrappec	Employee	Employe	AO_NR	ART_NR	PLAN_F_DAT	Kolonne1	FERDIG_DT	Kolonne2	Kolonne3
GIRHUS SENTERDEL UF93	32057	2051	20	M53	0	Edvin Terje Ødegård	MASKIN	1166197	038018	20170105	05.01.2017	20161108	08.11.2016	-58
GIRHUS STAGDEL UF93	32057	2051	20	M53	0	Edvin Terje Ødegård	MASKIN	1166198	038020	20170105	05.01.2017	20161108	08.11.2016	-58
GIRHUS SENTERDEL UA1(	31557 B	2053	10	M53	0	Edvin Terje Ødegård	MASKIN	1161352	022211	20160705	05.07.2016	20160623	23.06.2016	-12
GIRHUS UNDERV UF 74	31945 B	2050	25	M53	0	Edvin Terje Ødegård	MASKIN	1163345	035070	20160902	02.09.2016	20160824	24.08.2016	-9
GIRHUS UNDERV UF 63	31636	2051	10	M53	0	Edvin Terje Ødegård	MASKIN	1166928	006274	20161116	16.11.2016	20161110	10.11.2016	-6
GIRHUS STAGDEL UA100	31557 B	2053	10	M53	0	Edvin Terje Ødegård	MASKIN	1161350	026101	20160705	05.07.2016	20160630	30.06.2016	-5
GIRHUS UNDERV UF 63	32016	2051	10	M53	0	Edvin Terje Ødegård	MASKIN	1161190	006274	20160617	17.06.2016	20160613	13.06.2016	-4
GIRHUS UNDERV UF 63	30765 C	2050	10	M53	0	Edvin Terje Ødegård	MASKIN	1161552	006274	20160708	08.07.2016	20160705	05.07.2016	-3
GIRHUS UNDERV UF 63	32016	2050	10	M53	0	Edvin Terje Ødegård	MASKIN	1161101	006274	20160616	16.06.2016	20160614	14.06.2016	-2
GIRHUS UNDERV UA 63	30999 C	2050	10	M53	0	Edvin Terje Ødegård	MASKIN	1165536	032117	20161013	13.10.2016	20161012	12.10.2016	-1
GIRHUS STAGDEL UF115	21345 C	9053	10	M53	0	Edvin Terje Ødegård	MASKIN	1160371	042325	20160523	23.05.2016	20160523	23.05.2016	0
GIRHUS SENTERDEL UF11	21345 C	9053	10	M53	0	Edvin Terje Ødegård	MASKIN	1160373	042326	20160523	23.05.2016	20160523	23.05.2016	0
GIRHUS UNDERV UF 63	21977 C	2050	10	M53	0	Edvin Terje Ødegård	MASKIN	1163184	006274	20160822	22.08.2016	20160824	24.08.2016	2
GIRHUS UNDERV UF 63	21977 C	2051	10	M53	0	Edvin Terje Ødegård	MASKIN	1163185	006274	20160822	22.08.2016	20160826	26.08.2016	4

Appendix D.

Interview guide.

The interviews with the key informant where based on a semi-structured approach, where question where based around two main steps/topics. Since each informant belonged to a separate process, this meant that the questions was adapted to each informant/process. The two main steps of the qualitative data collection was thus the following:

Step 1:

Describe the As-Is process in detail (Prerequisites, sequences, tasks, information flow)

Step 2:

Describe situations where deviations occur i.e the actual process deviated from the intended process, and what are the underlying factors behind these events?