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Gunnleiv Dahl

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**NTNU**
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Department of Mechanical and Industrial Engineering

Gunnleiv Dahl

# Mitigating Delays Through Identifying and Addressing the Underlying Factors: A Framework Proposal

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# Mitigating Delays Through Identifying and Addressing the Underlying Factors: A Framework Proposal

**Gunnleiv Dahl**

Global Manufacturing Management
Submission date: June 2019
Supervisor: Erlend Alfnes
Co-supervisor: Swapnil Bhalla

Norwegian University of Science and Technology
Department of Mechanical and Industrial Engineering

# Abstract

**Keywords:** Manufacturing Delays, Mitigating Delays, ETO Manufacturing, Lead Time Reduction.

**Background:** In ETO manufacturing there are many different factors that can cause delays. Some of these are a natural part of the trade-offs of having an ETO manufacturing strategy and are difficult to mitigate without affecting factors that are desirable to keep as they are. Still, many factors do not necessarily have to cause delays and could be eliminated or mitigated. Literature covers many factors and many solutions, but no holistic framework has been constructed for identifying and mitigating delays. The research is focused towards ETO environments with high variations in product specifications and demand at manufacturers with long production lead times and suppliers with long delivery lead times, with special focus on the manufacturing processes.

**Objective:** The objective of this research was to identify the possible factors causing delay in ETO through literature and empirical investigations through investigating the solutions proposed in literature and test towards the ETO environment in a case study. Based on this a robust framework for decision support in ETO manufacturing environments was constructed.

**Methodology:** It was important that the research was robust and replicable, as it can be beneficial to make further investigations for other, similar environments and further test and expand the framework and increase generalizability of application. The research methodology was well documented to facilitate replicability and robustness, so that it can be repeated to refine the results and final framework.

**Results:** This research identified an extensive list of possible factors that can lead to delays in manufacturing processes and fitting solution proposals to mitigate the effect of these factors in various manufacturing environments with similar characteristics to ETO. It identifies that ETO has several environmental characteristics to MTO, construction and NPD and that some solutions might be applicable across these environments.

**Limitations of research:** This research focused on a single case which is a benefit that allowed it to go in depth. On the other side, establishing a framework could benefit from investigating problems and solutions at multiple cases in order to increase generalization. Through setting boundaries for the literature search in the methodology, there is always a chance that relevant literature is left out. These are identified as possible improvements to generalize the results and framework further.

**Contribution:** This thesis makes a contribution towards both research and industry through constructing a new framework for decision support based on characteristics of factors, manufacturing environments and solution, the framework proposes which factors can be addressed by which solution and indicates appropriateness in ETO. In order to develop this framework a methodology was designed which could be used to do the same research for other environments in order to develop similar frameworks or to strengthen the framework proposed by this research. It also contributes by identifying and analyzing an extensive list of factors causing delays based on literature and empirical data.

# Sammendrag

**Nøkkelord:** Produksjonsforsinkelser, Begrense forsinkelser, ETO produksjon, Ledetids reduksjon.

**Bakgrunn**: I ETO-produksjon er det mange ulike faktorer som kan forårsake forsinkelser. Noen av disse er en naturlig del av avviket med å ha en ETO-produksjonsstrategi, og er vanskelig å redusere uten å påvirke faktorer som er ønskelige å beholde som de er. Likevel er det mange faktorer som skaper forsinkelse som ikke trenger å ha innvirkning på produksjonen gjennom å begrenses, eller elimineres. Litteraturen dekker mange årsaker og mange løsninger, men det er ikke laget noen helhetlige rammeverk for å identifisere og redusere forsinkelser. Forskningen er fokusert på ETO-miljøer med høye variasjoner i produkt speasifikasjon og etterspørsel hos produsenter med lange produksjonsledetider og leverandører med lange leveransetidstider, med særlig fokus på produksjonsprosessene.

**Mål**: Målet med dette forskningsprosjektet var å identifisere mulige faktorer som forårsaker forsinkelse i ETO gjennom litteratur og empiriske undersøkelser ved å undersøke de foreslåtte løsningene i litteratur og test mot ETO-miljøet i en case-studie. Basert på dette ble det bygget et robust rammeverk for beslutningsstøtte i ETO-produksjonsmiljøer.

**Metodikk**: Det var viktig at forskningen var robust og replikerbar, da det kan være gunstig å foreta videre undersøkelser for andre lignende miljøer og videre teste og utvide rammen og øke generaliserbarheten av søknaden. Forskningsmetodikken var godt dokumentert for å legge til rette for replikabilitet og robusthet, slik at det kan gjentas for å finjustere resultatene og det endelige rammebetinget.

**Resultater**: Denne forskningen presenterer en omfattende liste over mulige faktorer som kan føre til forsinkelser i produksjonsprosesser. Passende løsninger for å redusere effekten av disse faktorene i ulike produksjonsmiljøer med lignende kjennetegn til ETO. Det er identifisert at ETO har flere miljøegenskaper for MTO, konstruksjon og NPD, og at noen løsninger kan gjelde på tvers av disse miljøene.

**Forskningsbegrensninger**: Denne forskningen fokuserte på en enkelt case som er en fordel som lar forskningen gå i dybden. På den andre siden har etableringen av et rammeverk kan dra fordel av å undersøke problemer og løsninger i flere caser og gjøre rammeverket mer generaliserbart. Gjennom å sette grenser for litteratursøk i metodikken, er det alltid en sjanse for at relevant litteratur blir utelatt. Disse er identifisert som mulige forbedringer for å generalisere resultatene og rammeverket ytterligere.

**Bidrag**: Denne oppgaven bidrar både til forskning og industri gjennom å bygge et nytt rammeverk for beslutningsstøtte basert på egenskaper, faktorer, produksjonsmiljøer og løsningsforslag. Det foreslåtte rammeverket foreslår hvilken faktor som kan løses ved hvilken løsning og angir mulighet for implementering i ETO. For å utvikle dette rammeprogrammet ble det utviklet en metodikk som kunne brukes til å gjøre samme forskning for andre miljøer for å utvikle lignende rammer eller for å styrke rammen foreslått av denne forskningen. Det bidrar også ved å identifisere og analysere en omfattende liste over faktorer som forårsaker forsinkelser basert på litteratur og empiriske data.

# Preface

This master's thesis is the final part of the Master of Science degree in Global Manufacturing Management at the Department of Mechanical and Industrial Engineering at NTNU. This thesis investigates the factors causing delays in ETO manufacturing environments and proposes a decision support framework.

I would like to thank my supervisor, Erlend Alfnes, for his guidance and feedbacks. I would also like to thank my co-supervisor, Swapnil Bhalla, for his encouragement, constructive feedback, valuable ideas to my thesis, and for being available when needed.

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# Abbreviations

| | |
|---|---|
| ATO | Assemble-to-Order |
| BOM | Bill-of-Materials |
| CE | Concurrent Engineering |
| CODP | Customer Order Decoupling Point |
| ETO | Engineer-to-Order |
| JIT | Just-in-Time |
| LPS | Last Planner System |
| MTO | Make-to-Order |
| MTS | Make-to-Stock |
| NPD | New Product Development |
| PPC | Production Planning and Control |
| PV | Pressure Vessel |
| RQ | Research Question |
| WIP | Work-in-Progress |

# 1 Introduction

The introduction of this master thesis is an explanation of the existing knowledge on factors causing delays in the Engineer-to-Order (ETO) manufacturing and why it is important to do research in this area. The chapter describes the objectives of the research and the research questions that were answered in through the research. At the end, an outline of the thesis is presented.

When talking about factors and causes in this research; factor refers to the origin of the delay, cause is how it leads to a delay.

## 1.1 Background for Research

For manufacturing companies, there is an increased demand for customized products, which are produced at a low volume (Gosling and Naim, 2009). At the same time the customers want the product with a shorter delivery time and at a lower cost (Gosling and Naim, 2009). Manufacturing of highly customized products at low volumes are typical for the ETO manufacturing environment (Gosling and Naim, 2009). Traditionally for customized products, fast delivery at a lower cost with high quality has been a trade-off, you would have to choose one or the other and ETO products have previously operated with very long lead times and it has since become crucial for ETO companies to reduce their lead times in order to stay competitive (Hyer and Wemmerlöw, 2002, Slomp et al., 2009). In order to get the product by the time it was needed, the customers often had to purchase from local manufacturers, rather than from the international market (Sriram and Alfnes, 2014). This has led to that the last years, ETO manufacturers in Norway has shifted their focus to improve their efficiency in order to maintain the advantage of geographical proximity (Sriram and Alfnes, 2014). To achieve this, many actors in the ETO environment has looked to mass production and Lean manufacturing methods and has implemented tools and measures from these industries into their own environments (Matt and Rauch, 2014).

In ETO challenges are often related to uncertainty of demand and product mix. For some companies this means that they have difficulty in planning their inventory and are unable to reduce delivery lead time by ordering materials in advance (Amrani et al., 2010). For these it means that the manufacturers has to reduce their internal manufacturing lead times to stay competitive. A natural part of this will be to make an effort to mitigate or eliminate delays in the internal supply chain (Stefansson et al., 2009).

Delays in manufacturing are defined by Arunagiri and Babu (2013) as "to stop, detain, or hinder for a time; to move or act slowly; to cause to be late or behind in movement or progress", the Oxford Dictionaries (2019) define delay as "to make something happen at a later time than originally planned or expected", and Kumar and Raj (2015) describes delay to be an activity taking longer than planned. In this research the definition for delay is to do or deliver something later than planned or agreed and for an operation to use more time than planned, even if it is delivered on time. The consequences of delivering later than agreed could be losing a customer for the manufacturers and spending more hours and over time will reduce the profitability for the manufacturer, which are the main motivations for ensuring efficient processes and reducing lead times (Kumar and Raj, 2015). An efficient way of reducing these lead times is amongst others, improve progress analysis, implementing new manufacturing policies, planning methods or tools from Lean manufacturing with the intention to reduce waste of time and resources and to mitigate delays in the manufacturing processes to eliminate or mitigate the factors that cause delays (Matt and Rauch, 2014).

The works of Abotaleb and El-adaway (2018) and (Adaku et al., 2018) describe the factors that cause delays as endogenous and exogenous, or in and out of the manufacturers control. Since there are so many factors, there are also many different solutions proposals as to how to mitigate the effect caused by these factors, and it is widely accepted that there is no **one** solution that will fit all contexts within a certain manufacturing strategy (Shenhar et al., 2002, Beck et al., 2012).

Much of the literature for reducing delay is focused on improving processes, and a popular topic is Lean manufacturing. Lean has shown great improvements in mass production and many companies from the ETO sector are looking to implement Lean tools in their processes (Papadopoulou, 2013). However, the Lean processes are not exclusively applicable in the ETO context (Stefansson et al., 2009). For instance, Kanban, one of the most well-known Lean tools is very efficient in standardized components and products, but as it, in its original form, is based on standardized cards describing the different process steps for each part or product, it has been considered unfitting in the ETO environment which is characterized by a high degree of variation (Matt and Rauch, 2014), low production volumes and there is a lot of uncertainty related to product mix, product volumes and the availability of raw material (Adrodegari et al., 2015). This makes it difficult to make accurate plans and achieve a well-coordinated manufacturing process (Wikner et al., 2007, Stefansson et al., 2009, Mello et al., 2015).

The existing literature related to the subject often discusses how solutions can be implemented to mitigate a problem leading to delays in this context, but among the literature that has been found does not investigate the underlying factors. Some articles explained what factors can be handled using certain tools, but all underlying factors have not been identified and collectively addressed in literature. Which can be very useful as often there are sets of multiple factors causing an observed delay that a given measure is supposed to handle but might magnify one of the factors that are not addressed by this solution, and there is a gap in literature that describes what solutions are available for an extensive list of factors causing delays in ETO manufacturing.

There is a need to further investigate the delays experienced in the ETO industry, to identify where and why the delays occur, what factors cause these delays and if and how this can be mitigated considering the characteristics of the ETO environment. This research focuses on factors causing delays in the ETO industry through analyzing existing literature and through empirical research to map the possible factors causing delays in this environment, describing the characteristics of these factors for the environment they are found in and further set a guideline for how to make decisions for which solutions can be implemented to mitigate delays.

## 1.2 Research Question and Objectives

***What are the solution proposals for addressing factors causing delays in ETO manufacturing, and do they sufficiently address these factors?***

This Research Question (RQ) is answered through a thorough mapping of potential delaying factors described in literature and through empirical research. The research should identify and categorize factors which can cause delays based on research from various manufacturing environments. Further an investigation of what potential solutions exist and where they can fit in the context of ETO manufacturing of customized steel products which have long lead times in production and for material supply.

The research adds to the existing knowledge by identifying and systematically analyzing the factors described in theory, as well as additional factors discovered through the empirical research in a context where this has not been formerly described by literature. The most important characteristics that differentiates this context are that no material can be ordered until the initial design has been approved and that there are few suppliers capable of delivering according to the required specifications, leading to long purchasing lead times for material and critical parts and that there is no chance to make any predictions to the design. This research commits to identify solution proposals for the identified factors for manufacturing in this environment based on the available literature and contextualizing these to examine the fit to the investigated case. An analysis of factors and solution proposal for this context adds to the body of knowledge by systematically presenting existing knowledge with new findings. The objective was to produce a decision support framework that can aid in identifying factors and solution proposals in order to mitigate delays and in turn the manufacturing lead times.

## 1.3 Scope of Research

The scope of this research is directed towards ETO manufacturing focusing on the production processes of ETO, rather than design phase, aware that design and engineering changes have a large effect on manufacturing but is not considered for the scope of this research. The research is done for manufacturers that have several ongoing projects of different sizes at once using the same facilities. The study is done for manufacturing environments where there is strong dependency towards a few suppliers with long delivery lead times and, where material has to be ordered after a customer order has been received and design has been approved. The research focuses on endogenous factors, factors that the manufacturer can do something to mitigate or eliminate and factors that occur in a manufacturing facility for production of parts and components, supplying an assembly station. This excludes factors from outside the manufacturer's fabrication facilities, and factors occurring at the assembly stations. Focusing on what can be done to mitigate impact of factors causing delay internally. Through this the manufacturer can achieve higher performance and in turn increase their reliability to their customers and maintain their advantage in the market (Sriram and Alfnes, 2014, Kumar and Raj, 2015). Some factors are characteristic to the ETO and related to flexibility and concurrent changes (Vaagen et al., 2017). These are a part of the strategic choice of the manufacturer in going into ETO and solution proposals for these will not be addressed in the framework, as that would be a trade-off for important factors for customers and manufacturers in the ETO environment, especially concerning concurrent changes. Cultural factors causing delays will not be part of this research, as cultural factors can be very local and difficult to generalize and can be a study of its own (Masovic, 2018).

## 1.4 Outline

Table giving an overview of the thesis. Short description of what is found in each of the chapters.

| | | |
|---|---|---|
| Chapter 1 | Introduction | The introduction gives an overview of the current situation in general for the literature on ETO manufacturing and how factors causing delays are addressed and how solutions are proposed. It identifies the gap in theory that this research has attempted to cover. |
| Chapter 2 | Methodology | A presentation of the research methodology where the research approach and use of the selected methods are explained and justified for researching this area of Operations Management. |
| Chapter 3 | Theoretical Background | The theory chapter is important for the reader and researcher to gain a firm understanding of the characteristics and challenges of the ETO manufacturing environment. It gives a brief insight into potential solutions that are known to mitigate delays that fit with the characteristics of the relevant manufacturing environments in literature and case research. |
| Chapter 4 | Literature Search | Presents the theoretical research process and results identifying factors causing delay and solution proposals that form the foundation for constructing a framework as part of the results from this research. |

| | | |
|---|---|---|
| Chapter 5 | Case Research | The empirical research was done to test and refine the findings from the literature search and to expand the knowledge on factors causing delays as well as solution proposals. The research identified factors that were not mentioned in the studied literature and resulted in expanding the framework with factors and solution proposals that could be fitting in the ETO manufacturing environment. |
| Chapter 6 | Discussion | The discussions directed towards constructing the framework. Firstly, based on literature and then refined for fit to ETO through case research. The discussion highlights strengths and weaknesses of the research and the application area of the framework. |
| Chapter 7 | Conclusion | The conclusion is describing how the research answered the research questions and reached its objectives. It highlights the limitations and future works recommended based on this research. |

**Table 1.1 Thesis outline**

# 2 Methodology

Research is defined as "The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions (Oxford Dictionaries, 2019)". Research is done to improve knowledge and to improve understanding of events in various contexts through describing these by using a set of methods to gather information, analyze and discuss the findings leading to creating new or testing existing knowledge (Matthews and Ross, 2010).

When doing research, it is important that the research can be validated. Research should be based on a firm methodology making the research replicable so that someone can do the same research to either strength or weaken the hypothesis of the research (Matthews and Ross, 2010). For this research it has been found important to further investigate existing knowledge and also make a contribution to theory by covering a gap of knowledge in literature, since through the pre-study, little research material was found on which factors cause delays in ETO manufacturing environment described. Literature on related topics and from related context was found, but covered a few factors, but no holistic view on how to mitigate delays. Rather than explaining why a certain solution could mitigate delays in certain areas for certain factors and among the literature, the research was not identified where the majority of manufacturing is done at a single facility, but with a large portion of outsourcing focusing on assembly operations, which is only a small portion of the operations for many manufacturers.

In order to design a methodology for research it is necessary to understand the Engineer-to-Order context and the occurrence of delays both from understanding the practical challenges and leading causes and existing literature on related topics, including what is still not described in order to expand the understanding based on either qualitative or quantitative data (Croom, 2009).

The phenomenon and context in research here are of such a nature, that within the scope set for this research, it is challenging to make quantitative measurements. This is mainly due to variations and concurrent changes. Because of little literature discovered on this exact topic, a qualitative research is found to be a good fit as per Flick (2009). In qualitative research existing literature as well as case research is valuable (Flick, 2009). Therefore, this research is designed around a structured literature search from various relevant contexts, and a case study is used to validate the theory for the ETO manufacturing environment. As Yin (2009) stated, the existing literature is fitting to answer "what" questions which is the research question here. At the same time the case research, is a good tool for answering the "how" questions, which is essential for establishing new knowledge, not just collecting existing knowledge. The goal was to investigate the presence of the discovered factors in another environment than where they were described in literature, and to expand the existing knowledge by adding more possible factors. And in the process of doing this it is necessary to ask "what" and "how" questions as part of answering the RQ. The theory was a crucial part of the empirical study, as it guided in determining what is useful to test and how to build new theory on existing knowledge (Yin, 2009).

A literature study was done to map existing literature on factors causing delays for manufacturers in various manufacturing environments and what solutions can be implemented to eliminate or mitigate these. This also led to gaining a deeper understanding of how to identify these factors and on what basis a mitigating or eliminating solution can be proposed to solve the problem in an ETO manufacturing environment. The literature is used as a reference point to other contexts which is tested through empirical data from a case research which investigates the presence of the identified factors for other contexts than where literature describes the factor and through this making the theory more generalizable and could also expand knowledge on the area of delays in ETO manufacturing (Yin, 2009).

After gathering all the data, a discussion was made comparing empirical findings from the case study to the findings from literature, discussing the presence of theory in empirical data and move on to construct a framework based on empirical and theoretical findings, making it a robust framework that could be applicable to several environments.

## 2.1 Literature Search

To make a reliable research it should be transparent, objective, replicable and systematic (Siddaway, 2014). Therefore, it was important for this research to clearly show how the literature research was conducted, including search phrases, databases and finally the findings of the research and processes were well documented. That way, the research can be replicate and other researchers should find the same results, given that the structure of the research is followed, and that objectivity is held by the researchers.

### 2.1.1 Literature Reviewing Technique

When designing the literature search, firstly the research questions were broken down into individual concepts to find synonyms, and identifying both broader and more narrow terms for the search phrase sets (Siddaway, 2014).

The first round was a theoretical pre-study. For this, a random keyword search using Scopus, since Scopus has a large database and an efficient and it is easy to keep track of previous searches and it handles truncations and Boolean operators well in order to find as many relevant articles as possible. This was done to include as many relevant articles as possible. All searches were done for title, abstract and keyword section of the literature. When selecting articles for the pre-study, the literature searched for was towards the ETO manufacturing environments, preferably with a similar scope on manufacturing environmental characteristics as for this research. This led to studying research from ETO and Make-to-Order (MTO) companies with long internal and external lead times. The research found was used for developing a structured literature search. This method for doing research through literature studies is based on the works of Croom (2009) and Siddaway (2014). Text books on research in operations management and systematic literature reviews.

The structured literature search was done using the search phrases found while studying the literature described above and was done using multiple databases with the capabilities of using Boolean operators, truncation and could handle the number of search phrases identified. The databases used were then Scopus, ProQuest and Web of Science.

All articles found were initially included and since studied for applicability to the research and scope. First any duplicate literature, then based on that the article was either published as a book section, an article in a journal or a conference paper that was available in English and that the full-text of the article was published online or in libraries the researcher had access to.
Further the number of articles abstracts were read and relevance to this research evaluated and articles with relevance to the research were included in the final review of the literature. The articles included somehow described one or more factors causing delays in manufacturing, processing or construction in several contexts. Even though the product and environment characteristics are different, still many factors are the same in different areas.

All factors that were identified were since categorized and defined in the context of the literature describing them. The literature proposes solutions to the majority of these factors, and the solutions were systematically analyzed to identify what factors they address and in what characteristics manufacturing environment they have a proven effect.

## 2.2 Empirical Research

In order to answer the research question posed in the introduction, it is important to fully understand the challenges that are common to the ETO environment. In order to gain understanding of the processes it was beneficial to make an in-depth study of the processes through a case study (Dul and Hak, 2008). To be able to make a detailed study it is beneficial to go into the details of the empirical data. In the early phases of the research it was found that there were a large number of potential factors to investigate, as well as the same factors reoccurring at several stages of the processes and because of the time constraint for this research, it was decided to do a single case study for this research. A single case allows the research to be thorough and to go into the details of things and gain a large understanding of the phenomenon (Yin, 2009). but at the same time, data from a single case can be more difficult to generalize, and must be taken into consideration (Dul and Hak, 2008, Yin, 2009). The objective of the case study is to test the theory based on various manufacturing environments towards the ETO environment, investigate the presence of the factors causing delays identified through literature and to check for feasibility of implementing solution proposals as proposed by the studied literature in an ETO manufacturing environment.

For the case study it was important to avoid bias and to gather as much objective information as possible. To ensure this it is necessary to gather data in several ways and achieve a triangulation of the phenomenon studied, since the data collected from case studies has many variables and can be difficult to read and findings in interviews and from observations could be biased (Yin, 2009). The research was conducted through observation of operations at the case company, collection of historical data from various data bases and from interviews with key personnel regarding the processes studied to ensure objectivity of the research.

### 2.2.1 Single Case Study

The reason for selecting a single case study in this research is the opportunity to go in depth in the challenges and understand the consequences and following consequences because of the interdependencies. To understand where a factor causes a delay, and where it is made visible in the processes. Single case studies are according to Voss (2009) strong tools to test and refine theory, which in this research will be done by studying theory and then refine it through studying the case. Based on this the discussion is made and the goal is to find what theory is available from other contexts and validate it for ETO. This way the research also could identify new variables and factors that were not described in theory. The data from case study compared to literature will form the foundation for constructing a generalized framework. Through doing the same research at several contexts can further strengthen the research at a later stage, which emphasizes the importance of a replicability and robustness of this research.

#### 2.2.1.1 Selection Criteria

For this research it was necessary to find a case company which had certain characteristics as described in the scope of this research, and the following criteria were posed:

- ETO manufacturer with a high portion of internally made parts
- Multiple ongoing projects with a great variation in manufacturing lead times
- Long material delivery lead times
- Looking to improve manufacturing performance

In addition, it was useful for the researcher to find a case company from a familiar manufacturing setting, and a Norwegian manufacturer supplying the offshore industry was preferred because of familiarity with rules and regulations.

#### 2.2.1.2 Data Acquisition

The data collected was collected from the researcher's observations through several individual guided tours with relevant persons at the case company, through semi-structured interviews with key personnel for the production processes at the case company, and finally through collecting historical data from the company's databases.

The data was collected from the planning tool where data on actual work start and completion compared to plan was extracted, budgeted versus actual hours from the clocking system and from the case company's own investigation of why they experience delays.

#### 2.2.1.3 Interviews

When conducting an interview, it is important to avoid preconceptions and be unbiased, to be a good listener and to be aware of what is being left unsaid as much as what is being said to ensure objective data. (Voss et al., 2002). The interview method used was semi-structured interviews as this lets the interviewees share their knowledge on the area through open questions where they are given the opportunity in answering the questions to spontaneously provide information not asked for that can be valuable for research. This has been seen as a recommended method when interviewing people with a high competency in their field like many of the employees at the case company (Flick, 2009, Matthews and Ross, 2010).

Interviewees at the case company were General Manager, Production Manager, Project Manager, Purchaser Planner, Engineering Manager and Supervisor of Prefabrication.

The interviews followed an interview guide and if the same person was interviewed on multiple occasions the same questions were asked again to see if the answers were consistent or if anything had changed since the last time as the changes are fairly recent. The findings in these interviews were used to increase understanding of processes at the case company and to highlight challenges in manufacturing and what might be the factors causing delays. The findings from interviews are presented in the results section of the report and interview guide can be found in Appendix A.

Because of sensitivity of data from case study, only the results from studying them are included, and raw data and interview reports are not enclosed.

#### 2.2.1.4 Summary of Case Research Conducted

The case company was visited over a 3-day period which was found to be sufficient, as the researcher was well familiar with the processes and had a firm understanding of their challenges based on previous research including the case company. During these three days the interviews were conducted. Only two people were interviewed twice, the Supervisor of Prefabrication and the Planner. The others were interviewed once during this time. After the visit the researcher had frequent contact with the Planner and Production Manager for clarification on several subjects and to acquire larger volumes of data. An agreement of this was made during the visit.

## 2.3 Analysis

Creswell (2014) states that research is not just collecting data, but how it is done, and further how it is analyzed and used to make theory and Eisenhardt (1989) describes the analysis as the theory-building part of any research. That is why it is crucial to conduct a proper methodical analysis of data, comparing the empirical observations to existing theory and through this strengthen and expand the knowledge on the area.

### 2.3.1 Literature

The articles from the structured literature search were systematically studied, and all factors causing delays described were identified and sorted into groups based on where in the manufacturing process they were described as most likely to occur and the manufacturing environment where they were studied. These findings were presented in tables presented in the Literature Search chapter.

For identifying possible solution proposals for mitigating or eliminating the factors causing delay, the articles found through the literature search identified solution proposals that were found effective in the context of the articles research. The fit of these to ETO environment was later discussed based on the potential fit in ETO as compared to where the case research had found a match for this measure.

To be able to discuss the presence of factors causing delays in this context, it is important to first understand the context and a theoretical description of the characteristics of the ETO strategy was done. The strategy involves some choices that introduces factors that can cause delays and are to be expected in the environment. This worked as the foundation for a discussion of which factors are possible to mitigate and how they can be mitigated or eliminated.

### 2.3.2 Case Research

For analyzing the empirical data, an acknowledged method for investigating factors in manufacturing with the intent to mitigate delays is desirable. Saad et al. (2013) describes the A3 to investigate and solve problems in developing Lean processes, which focuses on removing waste. Among the wastes described is time waste, including delays. The tool is a systematic approach to describing problems with the intent to find root causes, propose what the desired future condition of the observed problem is and further make a plan for eliminating or mitigating the problem with a proposal of countermeasures, a plan for implementation and how to follow up the development. A3 is an iterative process, where after implementation the follow-up will consist of repeating the process in order to find if the countermeasures implementation were able to eliminate or mitigate the problem to the lowest possible impact (Saad et al., 2013). This is not feasible in the scope of this research which will present a framework for step 5, selecting the appropriate solution proposal.

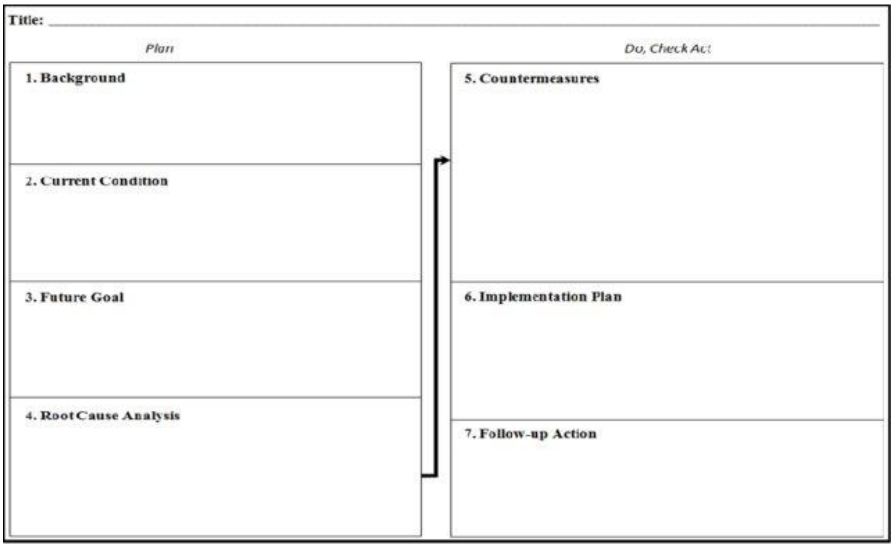


**Figure 1 A3 template (Saad et al., 2013)**

The analysis of the empirical findings is done through the following steps:

1. Background
    - What are the problems identified at the case company and why is that a problem? Describing the situation of the case study, what their activities are and what are the characteristics of the environment where they operate.
2. Current Condition
    - Empirical research describes what is the status at the case company and why it is interesting to investigate the factors causing delay there.

3. Future Goal
    - What the desired future state of the case company's manufacturing processes is.
4. Root Cause Analysis
    - Empirical research and literature search describe the factors that occur in the manufacturing environment. The objective was to identify the factors causing delays in the case environment.
5. Countermeasures
    - Solution proposals to what can mitigate the effect of the problem that is studied in the ETO manufacturing environment through applying the proposed framework.

The most contributing steps for this research is step four; Root Cause Analysis and step five; Countermeasures. These present the findings from the case study and compares findings to the existing literature, investigating the presence in the case company's environment and to propose solutions that are fitting for that environment, which corresponds to the scope of this research. Those steps are used to validate the findings from literature on multiple manufacturing environments in the ETO environment described. In order to understand and describe the current condition and find all the factors at the root of the problem, the findings from acquired data, observations and interviews were used in triangulation to gain an objective understanding of the situation and challenges.

For the empirical research, only the first five steps of the A3 model is possible to perform within the scope of this research. It is not possible to do the last steps of the A3 in the time frame of this research.

## 2.4 Developing Framework

Based on the factors and solution proposals from literature, validated in the empirical study and literature study, a decision support framework was developed. This framework identifies what measures can mitigate delay in the ETO environment based on the fit with characteristics of ETO compared to the characteristics of where these measures have been implemented and which factors are the cause for the delay. As part of this analysis, the factors not relevant to the scope of the research were removed from the framework, as the framework is directed towards the internal production processes. For the case research, this refers to the fifth step of the A3 method for refinement of the framework and validation for applicability in ETO.

The framework was constructed initially based on the existing literature and identifying which factors can be solved through implementing certain solutions proposed by the literature. The solution proposals were rated as Verified Fit (++) for where the solution has been proven in ETO environments with similar characteristics and Conceptual Fit (+) for where a solution has been proven to work in a manufacturing environment outside of ETO, but with similar characteristics. The literature found in the literature, did not propose solutions to all factors, nor did all solution proposals indicate a conceptual fit for the ETO environment and some gaps for solution proposals were identified.

In order to test the completeness, validate and refine the framework towards the ETO environment researched, the framework was applied to the case company. The framework was validated for presence of the factors causing delay that were mentioned in theory, investigate if there are factors not described by literature, test feasibility of solution implementation, as well as investigating what other solutions were possible to implement in this environment that were not mentioned by literature. The solution proposals originated in solutions that had been tested at the case company, and proposals discussed during the interviews, that has a proven record in ETO from literature not identified using this methodology.

## 2.5 Strengths and Weaknesses of This Methodology

The strengths of doing this research is that it has been documented and through this made replicable, leading to that other researches could do the same research and find the same results. This means that the theory could be tested for other environments to further build and strengthen the framework. The application of a single case study and a structured literature search allows the researcher to go in depth and gain a firm understanding challenges and potential for solutions.

Using a single case has some challenges: The observations can be biased, and the interviews could be biased based on the interviewers understanding and pre-conception of the problem. This is why it was important to interview several people in the organization, make observations in several rounds and to acquire unbiased data to achieve an objective triangulation.

# 3 Theoretical Background

This is the theoretical section of this research. It introduces a background on manufacturing strategies and environments and goes into detail on the ETO environment and its characteristics. The theory is important for understanding the issues that are researched, why it is necessary to conduct and how research benefits science and industry.

## 3.1 Manufacturing Environments

An important aspect of the manufacturing environments is the set of product and process characteristics which are present and contributes towards selecting a manufacturing and supply chain strategy. One way of describing these strategies is based on customer involvement, identified by the Customer Order Decoupling Point (CODP), as described by Olhager (2003), (2010) and Hoekstra and Romme (1992). The CODP is where customer involvement starts, and an order is made. Production is then linked to a specific customer. The earlier in the process the CODP is located, the longer lead- times and more a higher degree of customization for each order and less room for forecast based and speculation is used for production planning. The most commonly used classifications are ETO, MTO Assemble-to-order (ATO) and Make-to-stock (MTS) (Rudberg and Wikner, 2004). This research focused on ETO, and investigating factors in MTO and ATO, as well as in New Products Development (NPD) and Construction projects, which characteristics are described alter in this chapter.

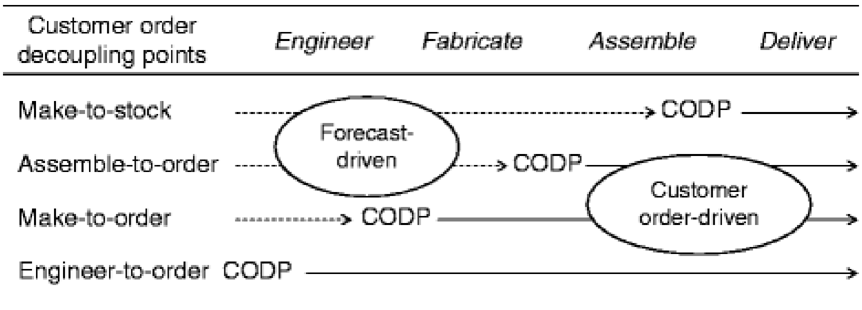


**Figure 2 Customer Order Decoupling Point (Olhager, 2010)**

### 3.1.1 Engineer-to-Order

This research was conducted for an ETO manufacturing environment. The ETO environment is characterized by a high variety of the products and a low production volume (Matt and Rauch, 2014). In literature the definition of "low volume" varies, but in this research the number has been set to less than 100 total units annually, and each product is produced in quantities less than 5 equal units. The products are ordered with specific requirements and specifications and will need some degree of engineering work, whether it is adjustments of physical dimensions or designing a new part from scratch (Sriram and Alfnes, 2014). In ETO manufacturing uncertainty as described by Vaagen et al. (2017) is another challenge facing ETO manufacturers, leading to a large risk by doing any sort of work on a project before an order is received, as changes are likely, and it is difficult to predict timing and specifications of orders. This can often lead to prolonged lead times, especially in the cases where material and purchased parts cannot be ordered until design and specifications are confirmed and where supplier's capacities and material availability are scarce (Amrani et al., 2010). Another challenge ETO manufacturers are faced with on a regular basis is engineering changes, forcing rework in design and in many cases production (Vaagen et al., 2017).

There are many definitions of what ETO is, but most of them somehow describe customer involvement and CODP (Lampel and Mintzberg, 1996, Olhager, 2003, Stevenson et al., 2005, Wikner and Rudberg, 2005, Olhager, 2010). This research refers to the definition by (Wikner and Rudberg, 2005), stating that ETO is a manufacturing environment were engineering means the development of a completely new product or modifying existing designs as it best covers the environment of the environment the research was done towards.

Among the characteristics of ETO manufacturing is the complexity of the product and supply chain (Bertrand and Muntslag, 1993, Hicks et al., 2001, Mello et al., 2015). Complexity concerning products is because of the number of different parts, deep product structures and variation in design, interdependencies in manufacturing processes and concurrent design ang engineering work. Uncertainty levels contribute in making the processes in ETO more complex. As mentioned, ETO environment is characterized by high variations in product specifications and low volumes, the effect on manufacturing is that a flexible and cross-trained work force (Mello et al., 2015). ETO products are characterized by a low degree of standardization, and many parts are used only once, and for some parts, if the same design is used again it can often be years between each time it is used (Hicks et al., 2001). This means there is a lot of engineering work required for each project, even though parts can be similar, some degree of customization is often required (Bertrand and Muntslag, 1993).

For ETO projects the typical flow of processes are Tendering, Engineering and Design, Production, Assembly and Final Assembly or Installation (Bertrand and Muntslag, 1993, Hicks et al., 2000). As the below figure by Bertrand and Muntslag (1993) shows, there is a certain order each step has to happen in. Because of the large risk of starting any work before a design is final, with rework or scrapping of parts as a possible result if any manufacturing starts before design is final and approved by the customer (Stefansson et al., 2009). It is not described by the figure, but the processes in ETO are characterized by a high frequency of concurrent changes that affects the ongoing, or past activities, leading to a lot of rework for engineering and design, as well as the manufacturing where there is the added risk of having to scrap part and then have to order new material (Adaku et al., 2018). The coordination of the processes is one of the main challenges for the manufacturers; to plan depending on interdependency and critically of each process, allowing concurrent processes which reduces lead times (Kwon et al., 2004, Mello et al., 2015).

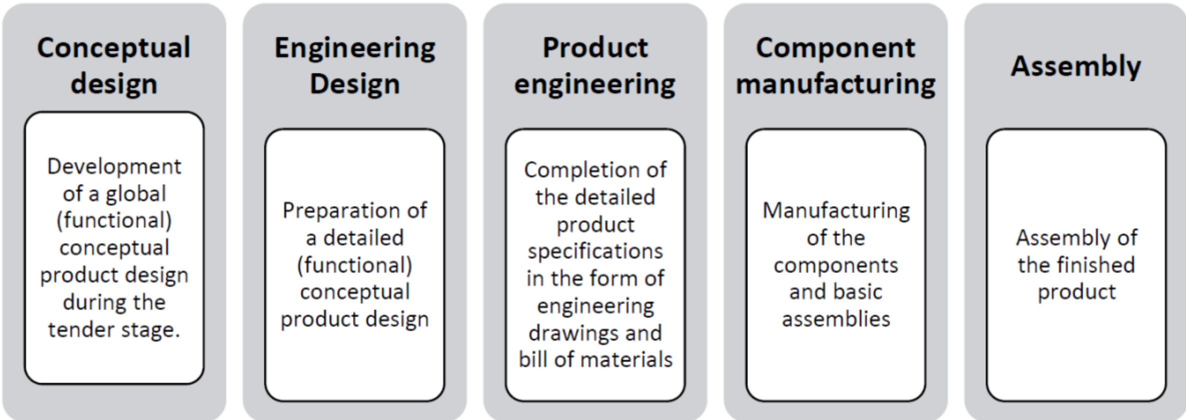


**Figure 3 Phases of the ETO manufacturing process (Bertrand and Muntslag, 1993)**

All of the above characteristics lead to difficult planning, extended lead times compared to where there is a higher degree of standardization and demand can be forecasted (Bertrand and Muntslag, 1993, Stefansson et al., 2009). Other factors that add on to this is the material availability, suppliers delivery lead times, availability of special or hired laborers, and the facility limitations (Kingsman et al., 1993, Kwon et al., 2004, Elstner and Krause, 2014).

### 3.1.2 Make-to-Order

Just like ETO, MTO is a manufacturing environment characterized by high levels of variations and low production volumes (Manzini and Urgo, 2018). This means that in this environment, material and parts has to be ordered after a customer order has been received and planning can start after that (Kingsman et al., 1993). Where the manufacturer is dependent on a few suppliers that operate with long lead times, which is the environment being studied, the manufacturers can usually only reduce their internal lead times. Compared to ETO, MTO does not need engineering work for each project and products are to a larger extent standardized (Olhager, 2010). This makes the risk of ordering material early lower and reduces chances for errors in the design phase, but still changes can happen to and order as in ETO (Manzini and Urgo, 2018).

### 3.1.3 Assemble-to-Order

The ATO manufacturing environment uses already produced or purchased parts and sub-assemblies in order to make up customized products after customer specifications within consisting of the parts the manufacturer is able to supply (Wemmerlöw, 1984). The parts are standardized, but it is difficult to forecast which parts are needed when, and inventory management can be very challenging (Wemmerlöw, 1984). Here, as in ETO, changes can happen during the manufacturing process, and disrupt the flow in and between the work stations (DeCroix et al., 2009).

### 3.1.4 New Products Development

NPD is the process of developing new products and prototypes for various manufacturing environments. NPD follows many of the same processes as for ETO, as production often starts before design is finished in order to be first to market, which is an especially important factor for mass production, where the first product of its kind, often will grab the largest market share (Filippini et al., 2004). Often this leads to concurrent changes and rework, which disrupts the flow in the manufacturing process and delays market release (Elstner and Krause, 2014). This often means that there is a high degree of variation and low volumes for the innovative process of NPD (Filippini et al., 2004).

### 3.1.5 Construction Projects

Construction projects and ETO have many of the same characteristics mentioned above. They are project focused, as each product in the ETO environment is treated like a project due to its uniqueness (Dallasega and Rauch, 2017). There are many concurrent changes and parallel processes in the manufacturing and the products are usually one-of-a-kind (Motawa et al., 2007). It is just as challenging to forecast what is needed, and planning and material orders are done after an order has been received (Abotaleb and El-adaway, 2018).

## 3.2 Manufacturing Delays

Manufacturing delays have been defined as “to make something happen at a later time than originally planned or expected” (Oxford Dictionaries, 2019), and Kumar and Raj (2015) also describes delay to be an activity taking longer than planned. In this research delay refers to doing or delivering something later than planned or agreed and for an operation to spend more time than planned, even if it is delivered on time.

In manufacturing environments where multiple activities using the same equipment for different processes, such as in ETO, and passing through the same bottlenecks can be more prone to delays than for other manufacturing environments (Dallasega and Rauch, 2017), because of the complexity and more factors that could lead to a delay (Adaku et al., 2018). One of the main factors causing delay is changes to a project, and in ETO changes are a natural part of the manufacturing process (Arunagiri and Babu, 2013). Usually because of specification changes from the customers (Motawa et al., 2007).

## 3.3 Improvements in ETO Environment to Mitigate Delays

In the recent years, ETO manufacturers have started to take measures to improve on their internal production processes in order to cope with their customers’ requirements of a reduced delivery lead time, lowered cost and at the same quality (Hyer and Wemmerlöw, 2002, Gosling and Naim, 2009, Slomp et al., 2009). Much of the inspiration comes from mass production, where these improvements have been a natural part of the industry for a long time now (Amrani et al., 2010). Due to the difference in characteristics in the production environments and that mass production has a large degree of forecastability and standardization, not all of the measures found there are directly applicable, but still there has been a large development of these measures to implement them in ETO (Amrani et al., 2010, Matt and Rauch, 2014). When improving the supply chain for manufacturers in the ETO environment that are strongly dependent on a few suppliers with long delivery lead times for parts and material and demanding engineering work that require a lot of work and many revisions it becomes important to control the internal production processes that can and reduce lead times in those processes (Amrani et al., 2010). This can be done in many ways, amongst them are the implementation of Lean tools in order to reduce waste in the processes, the implementation of Concurrent Engineering (CE), Production Planning and Control (PPC), Last Planner System (LPS), and through having efficient feeding systems with an efficient material flow with few disruptions (Slomp et al., 2009, Caputo and Pelagagge, 2010, Papadopoulou, 2013, Powell et al., 2014, Kjersem et al., 2015, Kjersem and Jünge, 2016).

### 3.3.1 Concurrent Engineering

CE is a method where production processes start based on partial designs while the continuation of design processes are done in parallel with the production (Wognum et al., 2006). Its goal is to reduce lead time and cost of manufacturing, but includes a risk of identifying later in the design process that changes to what has been produced must be made (Wognum et al., 2006).

### 3.3.2 Feeding Policies

The work of Caputo and Pelagagge (2010) described several options for feeding policies. The article presented three options depending on the characteristics of parts or sub-assemblies which can take different forms based on environment. They divide into Just-in-Time (JIT), Kitting, and Line stocking. Where JIT was proposed for larger parts with high variations, meaning that the part would be finished just before it was needed to arrive at the point it was needed, Kanban was used as an example, but is not found to be an appropriate tool in its original form for ETO, due to high levels of customization, by Matt and Rauch (2014). Kitting was proposed where batches of the same or similar small or medium sized parts needed at the same time was made when possible and stored in a box or trolley and supplied in the sequence they were planned to be assembled. Line stocking was proposed for standard components and means that the parts are stored at the assembly station for quick access for frequently used parts or material.

### 3.3.3 Last Planner System

LPS is designed to have a control component close to the execution of tasks through transforming what should be done to what could be done (Ballard, 2000). Through creating weekly plans the LPS creates a commitment to achieve what is planned by giving the authority to a foreman at the production facility (Ballard, 2000). This is believed to enhance flow of work, build trust in an organization and improve performance (Ballard, 2000).

### 3.3.4 Lean Manufacturing

Lean Manufacturing or Lean production is both a toolbox of solutions that could be implemented in manufacturing facilities and processes as well as a mindset of eliminating waste from the manufacturing processes (Powell et al., 2014). The most commonly used tools are 5S, which is a systematic approach for improving processes at the workplace (Pasale and Bagi, 2013), Kanban, a card based system focusing on controlling work in progress (WIP) and flow of goods through the manufacturing facilities (Takahashi et al., 2005). Kanban is strongly dependent on a certain level of standardization of components, which does not fit well in the ETO environment characterized my high variations (Powell, 2018). However, as per the article by Powell (2018), the most basic principles of Kanban can be applicable. The article proposed to implement the use of the Kanban signboard in environments with high variety and low volumes of manufacturing. The board is designed to control flow, share information and control level of WIP. An important part for utilizing the signboard is daily stand up meetings and the tool is efficient in controlling and visualizing the work flow and has the potential to increase capacity utilization. There are many other tools and mindsets in Lean, among them LPS and principles in feeding policies as described above, but not all are relevant to this research.

### 3.3.5 Production Planning and Control

PPC refers to planning methods that determine how planning should be done for a given context. It consists of various methods, many of them can be found in the “Lean toolbox” (Sriram et al., 2012). Sriram et al. (2012) presented a selection of PPC methods in relation to ETO manufacturing of varying complexity and comprehensiveness, from simple control principles to complete systems controlling and planning processes on a detailed level, concluding that ETO manufacturers should develop their PPC methods towards an Enterprise Resource Planning (ERP) system.

# 4 Literature Search

For this research, studying literature was very important. And to ensure the quality of it, it has to be replicable. As part of this, it is essential to know which literature was used. To make it replicable the process was well documented.

## 4.1 Factors Causing Delays

This research was designed based on a pre-study of the topic. This formed the foundation for the structured literature search keywords. In addition to the terms used in the studied literature, synonyms were used leading to the following search words.

| Context | Problem | Reason |
|---|---|---|
| | and | and |
| Engineer-to-Order/ ETO | Delay | Reason* |
| or | or | or |
| Make-to-Order/ MTO | Time overrun | Factor* |
| or | or | or |
| One-of-a-Kind | After schedule | Source* |
| or | or | or |
| Design-to-Order/ DTO | Time exceeded | Variable* |
| or | or | or |
| Concurrent engineering | Not meeting deadline | Disrupt* |
| or | or | or |
| Concurrent development | Late delivery | Driver* |
| or | | or |
| New product development | | Trigger* |

**Table 4.1 Search words for structured literature search on delays**

This search was done in 3 databases, Scopus, Web of Science and ProQuest. The reason for this is that they have the desired capabilities and manageable databases within the scope. The same search in Google Scholar gave 428 total results, which are too many to study for the scope of this research. The databases allowed to use Boolean operators "AND" and "OR", truncation "*" for open endings for search terms, to be able to easily to do replicable and iterative database searches. The searches were conducted for literature available in English published as journal papers, books or conference papers in the fields of business, engineering, operations management, decision making and material to limit the results to include relevant literature.

| Database | Results | Duplicates |
|---|---|---|
| Scopus | 38 | 18 |
| ProQuest | 7 | 4 |
| Web of Science | 21 | 14 |
| Total | 67 | |

**Table 4.2 Results from structured literature search on delays**

The literature search resulted in finding **67** articles in these databases. 18 were duplicates, among these, two articles were found in all 3 databases, reducing total articles to **49**. After this, the literature included was to be found available as full-text in available databases from the NTNU server. This further reduced the number of articles to **38**. After this, abstracts were read in order to identify which articles were relevant to the research, literature with abstracts describing theory considered to be remotely relevant were included for this part, resulting in **26** articles. By skimming through introductions and conclusions of this literature. By doing this, another **11** articles were excluded, as they did not describe any factors causing delays, but discussing delays as a problem in manufacturing without discussing why or proposing solutions to avoid delays in general without going into which factors that could be eliminated or mitigated. Finally, **15** articles were included in the literature study.

The articles included were systematically studied for which delay causing factors they described, which context the research was conducted in and what solutions they proposed to eliminate or mitigate these factors. This will be highlighted in a later section.

The literature included described a large variety of projects experiencing delays in projects from construction, NPD ATO, MTO and ETO projects describing numerous underlying factors. These were studied and categorized. Synonymous terms were used in the literature, and among those with the same meaning, only one of the synonymous terms were used in this report. All of the factors were then categorized into relevant topics. Some were represented in several topics, but the topic where the factor was found most repeatedly is presented.  A summary of what the literature describes follows on the next pages.

| | Delay causing factors | Manufacturing environment | Proposed solution |
|---|---|---|---|
| (Li et al., 2017) | Work force skill, Work force availability, Capacity, Production planning, Supplier capabilities, Wrong estimates, Connectivity of work stations | MTO | Production planning, Capacity planning, JIT planning, Technological improvements, Work force training |
| (Manzini and Urgo, 2018) | Missing components, Supplier reliability, Facility physical limitation, Component supply method | MTO | Feeding policies, Inventory policies, Coordination of processes, Process synchronization |
| (Motawa et al., 2007) | Specification changes, Design errors | Construction | Information sharing, Plan for change |
| (Mello et al., 2015) | Specification changes, information sharing, Connectivity of work stations, Coordination of processes, Interdependencies between engineering and production, Work force skill, Work force experience | ETO | Concurrent engineering, Coordination of processes, Information sharing, Process synchronization |
| (Wemmerlöw, 1984) | Product complexity, Inventory control, Material availability, Unachievable deadlines | ATO | Process evaluation, Inventory policies, Process synchronization, Production planning |
| (Adaku et al., 2018) | Waiting for inspection/test results, Specification changes, Information sharing, Human error, Capacity, Coordination of processes, Managerial | NPD | Coordinating processes |

| | | | |
|---|---|---|---|
| | abilities, Concurrent projects interfering, Work force skill, Work force experience, Priority in production | | |
| (Ansah and Sorooshian, 2017) | Information sharing, Waiting for inspection/test results, Work force availability, Coordination of processes | Construction | Concurrent Engineering, Last Planner System, Coordination of processes, Process evaluation, Standardizing processes |
| (Abotaleb and El-adaway, 2018) | Out-of-sequence work, Work force skill, Interdependency of work stations | Construction | None |
| (Kingsman et al., 1993) | Unachievable deadlines, Wrong estimates, Information sharing | MTO | Master data improvements, Capacity planning, Information sharing |
| (Elstner and Krause, 2014) | Specification changes, Product complexity, New parts, New material, Level of vertical integration, Connectivity of work stations, Supplier reliability | NPD | Process evaluation |
| (Stefansson et al., 2009) | Production planning, Material availability, Equipment failure, Wrong estimates, Capacity, Human error, Design error, Supplier reliability, Power outages | MTO | Forecasting |

| | | | |
|---|---|---|---|
| (Filippini et al., 2004) | Work force skill, Specification changes, Vague customer requirements | NPD | None |
| (Yongjin et al., 2004) | Manufacturing feasibility, Design errors | ETO/ MTO | Automating processes |
| (Williams et al., 1995) | Information sharing, Connectivity of work stations, Feedback from customer, Interdependencies between engineering and production | MTO | None |
| (Owens, 2007) | Vague customer requirements, Material availability, Capacity | NPD | None |

**Table 4.3 Summary of literature search**

## 4.2 Factors Causing Delay in Manufacturing

| No. | Delaying factor | Category |
|---|---|---|
| 1 | Specification changes | Engineering |
| 2 | Design errors | Engineering |
| 3 | Vague customer requirements | Engineering |
| 4 | Work force skill | Work Force |
| 5 | Workforce availability | Work Force |
| 6 | Workforce experience | Work Force |
| 7 | Human error | Work Force |
| 8 | Facility physical limitations | Facilities |
| 9 | Capacity | Facilities |
| 10 | Connectivity of work stations | Facilities |
| 11 | Interdependency of work stations | Facilities |
| 12 | Manufacturing feasibility | Facilities |
| 13 | Power outage | Facilities |
| 14 | Equipment failure | Facilities |
| 15 | Production planning | Manufacturing management |
| 16 | Unachievable deadlines | Manufacturing management |
| 17 | Wrong estimates | Manufacturing management |
| 18 | Coordination of processes | Manufacturing management |
| 19 | Concurrent projects interfering | Manufacturing management |
| 20 | Component supply method | Manufacturing management |
| 21 | Out-of-sequence work | Manufacturing management |
| 22 | Managerial abilities | Manufacturing management |
| 23 | Priority in production | Manufacturing management |
| 24 | Level of vertical integration | Manufacturing management |
| 25 | Information sharing | Manufacturing management |
| 26 | Supplier ability | Supplier related |
| 27 | Supplier reliability | Supplier related |
| 28 | Missing components | Inventory management |
| 29 | Material availability | Inventory management |
| 30 | Inventory control | Inventory management |
| 31 | Product complexity | Complexity |
| 32 | New parts | Complexity |
| 33 | New materials | Complexity |
| 34 | Feedback from customer | Waiting |
| 35 | Waiting for inspection/test results | Waiting |
| 36 | Interdependencies between engineering and production | Waiting |

**Table 4.4 Identified factors causing delay from literature**

Table 4.4 shows all identified factors causing delay in the literature from the structured search. An explanation of each factor and the categories in the following tables.

### 4.2.1 Definition of Factors

**Engineering**

In ETO, there is always some degree of engineering work performed. For the literature that was from ETO contexts (Gosling and Naim, 2009). The articles described the challenges related to engineering work, with focus on engineering changes related to errors, specification changes or misunderstood requirements.

| Factor | Definition | Literature |
|---|---|---|
| Specification changes | When the customers specifications change during the manufacturing processes in such a manner that it requires rework or material from the engineers to manufacturing are delayed. | (Filippini et al., 2004, Motawa et al., 2007, Elstner and Krause, 2014, Mello et al., 2015, Adaku et al., 2018) |
| Design errors | Human errors or misunderstandings in the design phase causing rework for engineers and/or manufacturing, leading to delayed deliveries of parts, assemblies or finished products. | (Stefansson et al., 2009, Manzini and Urgo, 2018) |
| Vague requirements | Requirements specifications from customers that are difficult to understand can cause delayed production start. | (Filippini et al., 2004, Owens, 2007) |

**Table 4.5 Engineering related factors**

**Work Force**

Factors related to work force causing delays in the manufacturing processes.

| Factor | Definition | Literature |
|---|---|---|
| Work force skill | When the work force does not have the right training, certification or abilities to do the work fast enough or with the right quality. This can lead to operations taking longer than planned or rework required due to poor quality. | (Filippini et al., 2004, Mello et al., 2015, Li et al., 2017, Abotaleb and El-adaway, 2018, Adaku et al., 2018) |
| Workforce availability | Lack of hired staff, key personnel allocated to tasks so that they cannot be where they are needed. Can be contractor that cannot deliver the right people when they are needed. This can many times lead to delays. | (Ansah and Sorooshian, 2017, Li et al., 2017) |
| Workforce experience | Experienced personnel need less time understanding and performing familiar tasks with new variations. They can more easily detect errors in drawing and required material. Without the right experience workers can cause delays compared to plan, even if they make their best efforts | (Mello et al., 2015, Adaku et al., 2018) |
| Human error | Mistakes are a part of any work place and can happen to anyone at any point. In manufacturing it can be related to performing a job without the right training or experience, it could be because of accidents. Errors are difficult to predict and sometimes detect and can have varying degree of impact to delay. | (Stefansson et al., 2009, Adaku et al., 2018) |

**Table 4.6 Work force related factors**

**Facilities**

In manufacturing where there is a large product and product mix variation the manufacturers facilities should accommodate variation through having flexible equipment that can be used to produce a large variation of parts and products (Stefansson et al., 2009).

| Factor | Definition | Literature |
|---|---|---|
| Facility physical limitations | Some products require a lot of space. There are many reasons, but in ETO products they can often be large products that consist of many parts. These will require a lot of storage space, large machinery and require large assembly areas. This leads to challenges when moving parts or products around in the assembly area, and often machines and material is brought to the product. This can be time consuming, and without the proper planning it can require a lot of unplanned time consumption that can lead to delays. | (Manzini and Urgo, 2018) |
| Capacity | Capacity is the amount a machine or facility is able to produce in a certain time frame. With many parts or products requiring the same machines, but with varying demands it is a difficult process to make a good flow without some parts or products having to wait for available capacity, as this could lead to delays. | (Stefansson et al., 2009, Li et al., 2017, Adaku et al., 2018) |
| Connectivity of work stations | How material moves and how information is communicated between work stations can make a large difference in time spent waiting for each station. A lot of time can be spent moving parts unnecessarily far or often because of how work stations are located according to the sequence of operations and priorities at each station can be affected by how information is shared. All time wasted on these things can add up to cause delays. | (Williams et al., 1995, Elstner and Krause, 2014, Mello et al., 2015, Li et al., 2017) |
| Interdependency of work stations | Where one station depends on another, bottlenecks can easily occur and cause parts or products line up waiting at one station to be able to carry on. Some of the work station can share equipment and/or operators and if one of these are required at the same place at once, one will have to wait. These things can lead to operations happening later than scheduled. | (Abotaleb and El-adaway, 2018) |

| | | |
|---|---|---|
| Manufacturing feasibility | Sometimes in ETO manufacturing an order is made with certain specifications that a facility cannot handle. This can be because of several of the above-mentioned factors | (Kwon et al., 2004) |
| Power outage | Power outages are usually factors that typically are factors one cannot control but can have a large impact on all operations in modern manufacturing. | (Stefansson et al., 2009) |
| Equipment failure | Equipment fail for numerous reasons. It can be related to maintenance, worn out equipment, wrong equipment for the job or, an equipment manufacturing error leading to failure. The implications can be small, if it is a piece of equipment that is easily replaced, or it can take a long time to fix or get replacement equipment. Any time equipment fails it has the potential to delay the manufacturing process. | (Stefansson et al., 2009) |

**Table 4.7 Facility related factors**

**Manufacturing Management**

Because of the uncertainties and variations in ETO manufacturing, it is a very difficult environment to manage (Adrodegari et al., 2015). Projects rarely look the same, and changes happen during the project that can affect the entire supply chain (Adrodegari et al., 2015). With one solution being the right in one project, it may not be the right solution for the next and management has to be a flexible process (Mello et al., 2015).

| Factor | Definition | Literature |
|---|---|---|
| Production planning | With a high amount of uncertainty in ETO manufacturing, it is difficult to make accurate plans. In addition, the plans need to accommodate for possible and likely changes. Plans can be proactive or reactive. A reactive plan means the problem has occurred, and planning happens late, which can cause delays. | (Stefansson et al., 2009, Li et al., 2017) |
| Unachievable deadlines | For some cases it has been discovered that the deadlines set in order to deliver as promised to a customer by a sales representative are not possible to reach. This can be because the sales representative is not able to calculate an accurate time estimate, has not included representants from production or engineering in the sales process, or reduced the delivery lead time to win the contract. This means that because of a too early deadline, the delivery will be late. | (Wemmerlöw, 1984, Kingsman et al., 1993) |
| Wrong estimates | Estimates used in planning and/ or sales is based on data from earlier projects and can be based on a software's master data. If the data used does not represent the reality either because it was used wrong or is inaccurate, it can both lead to the product being finished early, and more commonly; late. | (Kingsman et al., 1993, Stefansson et al., 2009, Li et al., 2017) |

| | | |
|---|---|---|
| Coordination of processes | With a large variety and manufacturing products with a large number of parts, that are dependent on each other, for several projects at one time which all need to utilize the same work force and facilities. There will often times be overlaps where activities need to happen at the same work station, or with the same equipment at the same time. Some activities need to be finished by a certain time for another to be able to start. When processes are not properly coordinated, and some processes will have to wait for another to finish and could fall behind schedule. | (Mello et al., 2015, Adaku et al., 2018, Ansah and Sorooshian, 2017) |
| Concurrent projects interfering | For manufacturers with several ongoing projects in the same production facility, using the same work stations and equipment can often be in the way of one and other and require the same equipment and area at the same time. When that happens, either extra time is used to find a contingency or one of the projects will have to wait for the other. When these things happen, delays can occur for one or more projects. | (Adaku et al., 2018) |
| Component supply method | How, when and where parts are supplied can make a difference regarding the time consumed. This literature describes parts that need to be supplied earlier than when they are needed for assembly because of space limitations blocking the part from being supplied at a later stage. If the part was not supplied early, a lot of delay causing rework would have to be done. | (Manzini and Urgo, 2018) |
| Out-of-sequence work | Operations that happen at a point when it was not supposed to due to unforeseen events. This can interrupt other operations and occupy scheduled capacity at a work station and have a strong impact towards delays. | (Abotaleb and El-adaway, 2018) |
| Managerial abilities | Adaku et al. (2018) claim that all delays have managerial abilities at its root and refers to upper level management. Meaning that delays can be prevented through proper management of processes in innovative products. | (Owens, 2007, Adaku et al., 2018) |

| | | |
|---|---|---|
| Priority in production | How products are prioritized going in and out of work stations can be done in several ways, similarity, urgency or first come, first served are examples. If this is not managed properly, it can lead to long waiting times for critical components and cause delays in other areas as a consequence. | (Adaku et al., 2018) |
| Level of vertical integration | The more activities are done “in house”, the more control the manufacturer have over these processes. Being dependent on suppliers or contractors can lead to delays depending on their capabilities, capacity and reliability. | (Elstner and Krause, 2014) |
| Information sharing | Information sharing is a very important part of the flexible and changing manufacturing environment of ETO manufacturing. It is important throughout the project. From the bidding process, through engineering and manufacturing to commissioning. Especially when changes occur, it is vital that all affected by the change are informed, so that these changes can be implemented as quickly as possible, trying to avoid delays. Information flow can be internal at the manufacturing facility and across the supply chain. | (Kingsman et al., 1993, Williams et al., 1995, Mello et al., 2015, Ansah and Sorooshian, 2017, Adaku et al., 2018) |

**Table 4.8 Manufacturing management related factors**

**Suppliers**

As in most supply chains manufacturers are dependent on suppliers of raw material and/or components (Dallasega and Rauch, 2017).

| Factor | Definition | Literature |
| --- | --- | --- |
| Supplier ability | With a high degree of variation, often unique parts are required, which a manufacturer does not have the capabilities to deliver. Many manufacturers use the same supplier for similar parts or materials, so when a unique part or material is demanded which none of the current suppliers can supply it can be a time-consuming process to find new suppliers. Spending time on finding a new supplier or an existing supplier finding a way of delivering what is demanded will often lead to delays. | (Li et al., 2017) |
| Supplier reliability | When planning a manufacturing process, it is important to know when parts or material arrive, and work can start. If a supplier is late, it can delay the entire project. | (Stefansson et al., 2009, Elstner and Krause, 2014, Manzini and Urgo, 2018) |

**Table 4.9 Supplier related factors**

**Inventory Management**

In ETO it is not common to carry a lot of inventory of material because of the variations and uncertainties the manufacturers have to deal with, and it is desirable to have material available when it is needed, not earlier (Kjersem et al., 2015).

| Factor | Definition | Literature |
|---|---|---|
| Missing components | If a component is missing when it is needed it can take a long time to get a new one, especially if it is a customized part, as it often is for ETO manufacturing. | (Manzini and Urgo, 2018) |
| Material availability | For some materials or parts, there is a limited supply. This could for instance be that there are few suppliers, or it is a scarce natural resource. This could mean that lead times can be longer with seasonal variations, and parts or material arrive later than planned, causing delays. | (Owens, 2007, Stefansson et al., 2009) |
| Inventory control | It can happen that there is an error in the inventory management system, this could lead to a wrong part being used, or that one part is believed to be available, but is not, and must be acquired. Depending on the part, it will affect the severity of the delay caused. | (Wemmerlöw, 1984) |

**Table 4.10 Inventory related factors**

**Complexity**

One of the characteristics of ETO products and supply chains is complexity (Bertrand and Muntslag, 1993). This is related to the high degree of variations and customized solutions. This complexity leads to a set of challenges that, if not properly handled can lead to delays (Elstner and Krause, 2014).

| Factor | Definition | Literature |
|---|---|---|
| Product complexity | Products with deep Bill-of-Material structures and large variations, as ETO products are, are more vulnerable to change as customized parts can often take longer to acquire and if a change happens deep into the product structure it makes a large impact on rework having to be done. This will often lead to delays. | (Wemmerlöw, 1984, Elstner and Krause, 2014) |
| New parts | Making and designing entirely new parts can often take more time than for modified parts. In production, an operator will usually do the work faster for a familiar design and is more likely to do mistakes on a new design. | (Elstner and Krause, 2014) |
| New materials | Same as for new parts. In addition, a new material is more difficult to predict the new material will behave in the different processes as compared to a material that has been used before. | (Elstner and Krause, 2014) |

**Table 4.11 Complexity related factors**

**Waiting**

When one process depends on another in order to carry on.

| Factor | Definition | Literature |
|---|---|---|
| Feedback from customer | Some processes such as design changes need approval from the customer before moving on to the next step. If this takes too much time, a delay can potentially occur. | (Williams et al., 1995) |
| Waiting for inspection/test results | In ETO environment and for new products it is important to test each product as compared to mass production where one can do sample tests. These often has to be approved by an external certified company. Often it can take a long time to get these tests results, and there can be a great risk to move forward before getting it approved. If a manufacturer has to wait, it could potentially cause a delay. | (Ansah and Sorooshian, 2017, Adaku et al., 2018) |
| Interdependencies engineering and production | The engineering and production departments often need confirmation from each other before moving on. It could be that engineers need confirmation on that a part or product is feasible to manufacture, or it could be that a drawing is late from the engineers, due to changes or priorities that misalign with manufacturing sequence. | (Williams et al., 1995, Mello et al., 2015) |

**Table 4.12 Waiting related factors**

### 4.2.2 Solution Proposals to Mitigate or Eliminate Factors Causing Delay

Table 4.13 is a visual presentation of solution proposals to mitigate factors causing delay, with a more detailed explanation to follow.

| | Automating Processes | Capacity Planning | Concurrent Engineering | Coordination of Processes | Feeding Policies | Forecasting | Manufacturing Information | Inventory Policies | JIT planning | Master Data Improvements | Plan for Change | Process Evaluation | Process Synchronization | Production Planning | Standardizing Processes | Technological | Last Planner System | Work Force Training |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(Li et al., 2017)** | | X | | | | | | | X | | | | | X | | X | | X |
| **(Manzini and Urgo, 2018)** | | | | X | X | | | X | | | | | X | | | | | |
| **(Motawa et al., 2007)** | | | X | | | | X | | | | X | | | X | | | | |
| **(Mello et al., 2015)** | | | X | X | | | X | | | | | | X | | | | | |
| **(Wemmerlöw, 1984)** | | | | | | | | X | | | | X | X | X | | | | |
| **(Adaku et al., 2018)** | | | | | | | | | | | | | | | | | | |
| **(Ansah and Sorooshian, 2017)** | | | | | | | | | | | | X | X | | X | | X | |
| **(Abotaleb and El-adaway, 2018)** | | | | | | | | | | | | | | | | | | |
| **(Kingsman et al., 1993)** | | X | | | | | X | | | X | | | | | | | | |
| **(Elstner and Krause, 2014)** | | | | | | | | | | | | X | | | | | | |
| **(Stefansson et al., 2009)** | | | | | | X | | | | | | | | | | | | |
| **(Filippini et al., 2004)** | | | | | | | | | | | | | | | | | | |
| **(Kwon et al., 2004)** | X | | | | | | | | | | | | | | | | | |
| **(Williams et al., 1995)** | | | | | | | | | | | | | | | | | | |
| **(Owens, 2007)** | | | | | | | | | | | | | | | | | | |

**Table 4.13 Literature describing different solution proposals for mitigating or eliminating factors causing delay from structured literature search**

Table 4.14 presents the manufacturing environments where the solution proposal has a proven effect.

| Solution proposal | Environments where effect has been proven | Articles |
|---|---|---|
| Automating Processes | ETO Engineering | (Kwon et al., 2004) |
| Implement Capacity Planning | MTO manufacturing management | (Kingsman et al., 1993, Li et al., 2017) |
| Adjust use of Concurrent Engineering | ETO and Construction engineering | (Motawa et al., 2007, Mello et al., 2015, Ansah and Sorooshian, 2017) |
| Coordinating Processes | ETO and MTO manufacturing management | (Mello et al., 2015, Manzini and Urgo, 2018) |
| Implement Feeding Policies | MTO manufacturing management | (Manzini and Urgo, 2018) |
| Forecasting Based Planning | MTO and NPD manufacturing management | (Stefansson et al., 2009, Filippini et al., 2004) |
| Implement Manufacturing Information Systems | ETO, MTO and construction manufacturing management | (Kingsman et al., 1993, Motawa et al., 2007, Mello et al., 2015) |
| Improve Inventory Control | MTO manufacturing management | (Manzini and Urgo, 2018) |
| Implement JIT Planning | MTO manufacturing management | (Li et al., 2017) |
| Master Data Improvements | MTO manufacturing management | (Kingsman et al., 1993) |
| Plan for Change | Construction engineering | (Motawa et al., 2007) |
| Process Evaluation for Continuous Improvement | ETO, NPD and construction manufacturing management and ATO inventory management | (Ansah and Sorooshian, 2017, Elstner and Krause, 2014) |
| Improve Process Synchronization | ETO and construction manufacturing management | (Mello et al., 2015, Ansah and Sorooshian, 2017, Manzini and Urgo, 2018) |
| Implement Fitting Production Planning Methods | Construction engineering and MTO manufacturing management | (Wemmerlöw, 1984, Motawa et al., 2007, Li et al., 2017) |
| Standardizing Processes | Construction manufacturing management | (Ansah and Sorooshian, 2017) |
| Technological Improvements | MTO manufacturing management | (Li et al., 2017) |
| Implement Last Planner System | Construction manufacturing management | (Ansah and Sorooshian, 2017) |
| Work Force Training | MTO manufacturing management | (Li et al., 2017) |

**Table 4.14 Solution proposals for mitigating or eliminating factors causing delays from literature search**

### 4.2.3 Explanation of Solution Proposals

The solution proposals listed in Table 4.14 were found based on the articles included in the literature search. They describe the proposed solutions in varying degree, so for some proposals definitions and explanations had to be found from additional sources. Characteristics to utilizing the proposed solution in ETO is highlighted.

**Automating Processes**

The literature does not provide a definition of automation, so the definition by Lindström and Winroth (2010) is used: "Automation is the application of machines to tasks once performed by human beings or, increasingly, to tasks that would otherwise be impossible." Kwon et al. (2004) suggests using automation through utilizing software in the design process of CE projects to greatly reduce time in this phase so that changes will cause less delay.

**Implement Capacity Planning**

The capacity of a manufacturing facility is often a factor causing delays, especially with several ongoing projects utilizing the same equipment, area and personnel (Li et al., 2017). One of the challenges relevant to the ETO environment is that planning usually happens close to execution, as planning happens after an order has been placed and efficient planning becomes all the more important (Kingsman et al., 1993). Using input and output control is an efficient way of mitigating delays, and according to Kingsman et al. (1993), once the capacity is known it is important to not accept more work than the facility can handle so that the processes can be finished on time.

**Adjust use of Concurrent Engineering**

CE is when the manufacturing process starts before the design process is finished (Ansah and Sorooshian, 2017). Manufacturing starts for what has been finished from the engineering department with the intention to reduce the manufacturing lead time, with the risk of changes occurring causing rework and potential delays and can be a threat to performance even though the intention was to mitigate delays, it can in some cases cause delays (Williams et al., 1995, Mello et al., 2015).

**Coordinating Processes**

In order to reduce lead times in ETO it is important that the processes are aligned to achieve a common goal, rather than just focusing on a single process finishing as fast as possible (Mello et al., 2015). This is particularly relevant where there are several ongoing projects with interdependent processes in order to reduce lead times (Manzini and Urgo, 2018).

**Implement Feeding Policies**

Manzini and Urgo (2018) proposes policies for making sure the right part is at the assembly station at the right time as a solution to mitigate delays but does not describe any of these policies. An introduction to feeding policies was given in the Theoretical Background.

**Forecasting Based Planning**

Stefansson et al. (2009) proposes forecasting techniques in order to reduce the lead time after an order has been placed by already having reached a certain stage. This has a large risk, especially for ETO environments where changes are frequent, and variations and any work done before an order is placed and design has been approved has the risk of being wasted time and material.

**Implement Manufacturing Information Systems**

To have a system where the relevant people can find relevant and accurate information and information is shared with those who need it rather than everyone having all the information can lead to each process being done in a more accurate manner and avoid processes causing delays for each other (Kingsman et al., 1993). With everyone having new information as early as possible, this could further mitigate rework and delays (Motawa et al., 2007), even if the information is incomplete at first (Mello et al., 2015). Kuang and Gao (2007) explains Manufacturing Information Systems as database systems where information from each process can be shared efficiently with those who need it to ensure up to date information, from and to everyone involved, including suppliers and customers. The most common software for this purpose is ERP systems.

**Improve Inventory Control**

Manzini and Urgo (2018), Wemmerlöw (1984) proposes that an implementation of inventory control systems can lead to mitigating delays. They do not go in detail on exact proposals, but indicates that inventory should be pushed back as much as possible, and in ETO it is not common to carry a lot of inventory (Hicks et al., 2001).

**Implement JIT planning**

Li et al. (2017) proposes prioritizing production so that everything can be finished when it is needed and keep spare capacity available. An introduction to JIT planning was given in the Theoretical Background.

**Master Data Improvements**

Kingsman et al. (1993) stresses the importance of having accurate and up to date data, especially for estimating plans and in the bidding processes. They state that the data should be easily accessible and easy to keep updated.

**Plan for Change**

Motawa et al. (2007) proposes to plan to have a buffer of time available for when changes occur in manufacturing environments where changes are likely to occur after production has started.

**Process Evaluation for Continuous Improvement**

As Mello et al. (2015) states, there is no one size fits all when it comes to solving problems in a manufacturing environment characterized by high variations, even for one manufacturer the solution that fit one project does not necessarily have the same effect for the next. Elstner and Krause (2014) says that a risk assessment is to be performed for process improvements to analyze trade-offs to identify whether the solution give a total positive effect in light of the manufacturing strategy. Especially for ETO, some solutions can make the processes less flexible to accommodate changes during the project (Matt and Rauch, 2014).

**Improve Process Synchronization**

With a high level of interdependent processes in products with deep BOM structures it is essential that all parts that are required simultaneously are available at the same time, as a delay at one stage gets a large consequence, the deeper in the BOM the delay occurs with a higher criticality to accurate delivery (Manzini and Urgo, 2018, Wemmerlöw, 1984).

What distinguishes synchronization from coordination is that coordination is meant for the facilities to handle several ongoing projects to flow through the same stations, while synchronization is for a project to ensure that parallel processes are performed so that no processes has to wait for another to be finished and in turn reduce lead time.

**Implement Fitting Production Planning Methods**

Wemmerlöw (1984) proposes to use the Bill-of-Materials (BOM) as a basis for planning to make sure processes are synchronized, Li et al. (2017) proposes to utilize mathematical models to ensure on time delivery of customized products, and (Motawa et al., 2007) states that a flexible plan is essential to handle the variations that occur when manufacturing custom products.

None of these propose one exact method to be implemented, but a mindset of planning that can be applicable in several manufacturing environments.

**Standardizing Processes**

Ansah and Sorooshian (2017) suggests that to standardize work processes can increase efficiency, which is well known. However, it can reduce flexibility for an ETO manufacturer (Gepp et al., 2016).

**Technological Improvements**

Li et al. (2017) proposes to invest in new more efficient technology to improve efficiency, increase capacity and reduce errors.

**Implement Last Planner System**

Ansah and Sorooshian (2017) identifies LPS as one of the best solutions to mitigate delays in manufacturing environments with a high degree of variations and concurrent changes. An introduction to LPS was given in the Theoretical Background.

**Work Force Training**

Well trained, experienced personnel are less likely to cause delays and can improve on efficiency and detect production or engineering errors earlier (Li et al., 2017).

# 5 Case Research

## 5.1 Case Selection

The case company selected is a Norwegian manufacturer of highly specialized and customized Pressure Vessels (PV)s for the oil industry. Depending on demand, which typical for the manufacturing environment it is in can be very fluctuating, but the number of products through the factory has never exceeded 50, so it is a low volume manufacturer. The manufacturer usually has multiple projects going on, and during the research period more than 10 different projects were going on in assembly and parts fabrication. The most common variations are physical dimensions and complexity of outfitting of the pressure vessels. The lead times are long and from order to delivery it could go from about half a year to more than a year for the largest and most complex projects. The projects studied for this research lasted approximately 50 weeks from order was placed until completion. This because the production itself is time and labor intensive and because of long lead times from suppliers of raw material because of a low number of capable suppliers.

## 5.2 Case Description

Step one of the case analysis is understanding the background of the issue and a detailed explanation of the environment of the research is to follow.

These PVs are made after specific requirements varying with its application, meaning that only a few PVs are the same, but usually the products are on-of-a-kind, making each project engineered to customer requirements. Their main customers are operators on the Norwegian Continental Shelf. Since the NORSOK standards (Standard.no, 2019) give specific requirements for equipment, only a few companies can supply PVs according to these requirements. The case company is the only Norwegian supplier that can satisfy these requirements for the largest PVs made from stainless steel. In recent time the company have made decisions and taken actions to make manufacturing more efficient. The customers are involved from the design stage and the CODP as presented by Olhager (2003) is set at the beginning of the manufacturing process. The case company has a low volume of products with a high variability. No work is being started before an order is placed because of the importance of exact specifications before procuring raw material and parts for each project and a low level of standardization. After procurement, changes to this will be very costly and potentially cause major delays and complex rescheduling in the factory. The remaining engineering work will continue during the lead-time of raw material and the complete design will often only be finished before the PV is assembled at the line. Most of the parts the manufacture has to go through Non-Destructive Testing (NDT), for most components this is x-ray and stress test for some parts with special requirements, before the can get the certificates approved for the PV to be used at the Norwegian Continental Shelf, approved according to NORSOK-standard (Standard.no, 2019).

For planning the manufacturing Primavera is used. It splits down projects to each activity to a specific level for assembly and a general level for prefabrication. This planning system was implemented in the second quarter of 2018 and the factory workers and supervisors are still getting used to a structured planning system leading to some challenges where the plan cannot be followed exactly causing delays in all manufacturing. They are making adjustments to how they plan and what data is used in planning. This can be because of shortage of work force and materials, missing drawings and causes that cannot be controlled. Plans are based on lead times, experience in the company and estimates for each project with some slack intentionally kept in the implementation phase. The measurement of progress in this environment with the level of variations is difficult to measure and report. Progress is reported manually in a database, with the hours spent for each step is registered. The steps are quite vague, and include many operations, often for many parts.

The products made by the case company are highly customized pressure vessels for the offshore industry and no parts for the PVs are made before an order has been placed, and before procuring any raw material or parts made by suppliers, the initial design including dimensions of the vessel have to be confirmed with customer. Each of these are made from sheet metal that is made specifically for each PV with variations in material properties, and dimensions. In general terms the manufacturing operations are three-fold: prefabrication, assembly and commissioning. Sheet metal plates are rolled and welded into shell strakes, these are welded together, and end-caps are welded on to each end to form the PV. These end-caps are made casted by a supplier. The PV is equipped with nozzles, brackets, lifting ears, internal measurement equipment etc. After the assembly the PVs are pressure tested, sand blasted and painted before installing internal equipment, that is purchased and installed by the case company before shipping to customer.

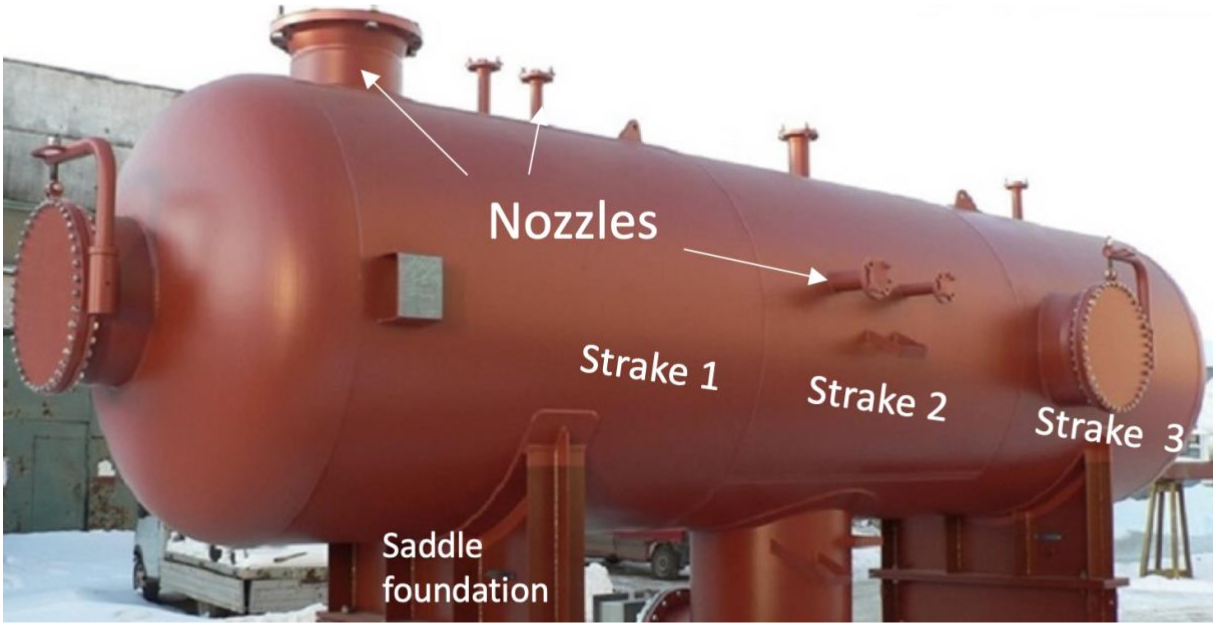


**Figure 4 Large Pressure Vessel with indications to the parts that go into it.**

Most components are made at internally either my making from sheet metal or purchased parts like metal pipe and flanges that has to be machined to exact measurements, a capability that the case company does not have. The sheet metal and end-caps have long lead-times and the case company has no impact on this part of the supply chain since there is a limited number of suppliers with many customers. However, their realization is that they can reduce the lead times by reducing their manufacturing lead times in their own facility.

The manufacturer is mainly struggling with one operation in assembly, which is the marking of the PVs and cutting holes for installing nozzles and other equipment. In parts fabrication there are delays in several steps and for various reasons. This will be the main part of the empirical research; to investigate what are the factors causing delays in parts production at this PV manufacturer.

## 5.3 Delays at the Case Company

The second step of the analysis is to describe the current condition; hence a description of what the manufacturer experiences related to delays as per today.

Per the definition of delays used in this research, it does not only refer to late delivery to customer, as this is rarely an issue. If the manufacturing is running late, they can use overtime and hire more temporary workers to ensure timely delivery, but that will reduce the profit. For some operations they use more than the three times more than the budgeted hours and some operations were finished up to 30 days after schedule where the schedule said the total process was to be finished within 18 days. An entire project consumed in total 50% more man hours than budgeted and was behind schedule for 80% of the project's duration, but still they were able to deliver the product to the customer as agreed.

It is not common that deliveries are late from suppliers and if there are delays, they are for parts of the delivery and a rescheduling in manufacturing can ensure completion as planned, so the delays are in general from specification changes or because of factors from the design or manufacturing processes.

## 5.4 Improvements to Mitigate Delay Tested by Case Company

Step three of the analysis is to describe the future goal, and for the manufacturer it is to reduce lead times in order to increase capacity and win more contracts by delivering the high quality required at a shorter time and lower cost.

The challenges related to production at the case company are that there is a low volume and high variety in the products they make. The varieties are in dimensions of the PV (diameter, length, curve of end caps and hull thickness), which material is used and the complexity of outfitting (number and dimensions of nozzles, internal equipment, etc.).

As part of increasing efficiency and reducing production lead time is reorganizing the assembly of the PVs. The biggest change in this has been reorganizing from a fixed position assembly to an assembly line with takt. There are three lines with different takt times, this is to take into consideration size and complexity of the PVs and the goal is to assemble the PVs from prefabricated parts in 6, 16 and 21 weeks, which earlier took up to 45 weeks. The prefabrication area has only had minor changes, but investments in new equipment has increased the capabilities of this part of the factory, but it has been noticed that there are operations in parts fabrication that take longer than planned, and delays are experienced for each project.

The number of vessels produced at one time is limited by takt stations to 13, unless more than one is being produced at the same takt location which can happen when the physical dimensions and complexity allows it. Other challenges that are distinctive for metal work is that some work has to wait because of heat-treated material needs cooling before the next step of work can be done. This is accounted for in production plan and is a natural part of the processes.

## 5.5 Factors Causing Delay

The fourth step of the analysis is the root cause analysis. It has been identified that there is a struggle with delays in parts fabrication of the PV manufacturer. The manufacturer has started some work to identify where these are, and based on data, observations and interviews these delays have been identified. In addition to this, interviews and observations by the researcher are inputs to this analysis.

The root cause analysis is done by investigating where a delay is found, factors causing delay and how they can be mitigated. Some of these factors are natural results of being an agile manufacturer as can a part of the ETO manufacturing strategy (Adrodegari et al., 2015).

Based on the findings in literature a comparison of what causes have been identified to be likely to occur is made to identify what factors exist at the ETO case company and to investigate if there are factors that were not addressed in literature. This list includes only the factors that are in the scope.

| # | Factor causing delay | Literature | | | | | Case research in ETO | Comments |
|---|---|---|---|---|---|---|---|---|
| | | NPD | Construction | ATO | MTO | ETO | | |
| 1 | Work force skill | X | X | | X | X | X | |
| 2 | Workforce availability | | X | | X | | X | |
| 3 | Workforce experience | X | | | | X | X | |
| 4 | Human error | X | | | | | X | |
| 5 | Capacity | X | | | X | | X | |
| 6 | Connectivity of work stations | X | | | X | X | X | |
| 7 | Interdependency of work stations | | X | | | X | X | |
| 8 | Manufacturing feasibility | | | | X | X | | Limitations for products they can manufacture are clearly defined |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | Equipment failure | | | | X | | X | |
| 10 | Production planning | | | | X | X | X | Factors not accounted for in planning |
| 11 | Wrong estimates | | | | X | | X | Sales calculus is based on historical data, and the sales calculus is what they use for planning |
| 12 | Coordination of processes | X | X | | | | X | |
| 13 | Concurrent projects interfering | X | | | | | X | |
| 14 | Component supply method | | | | X | | X | |
| 15 | Priority in production | X | | | | | X | |
| 16 | Level of vertical integration | X | | | | | | |
| 17 | Information sharing | X | X | | X | X | X | |
| 18 | Missing components | | | | X | | X | |
| 19 | Inventory control | | | X | | | X | |
| 20 | Feedback from customer | | | | X | | X | |
| 21 | Waiting for inspection/test results | X | X | | | | X | |
| 22 | Interdependencies between engineering and production | | | | X | X | X | |
| | Factors not covered by literature, but found in case | | | | | | | Poor housekeeping<br><br>Assumptions<br><br>Outdated equipment |

**Table 5.1 Factors causing delay identified at the case company**

Three factors were identified at the case company that were not identified in literature. They are described in the following section.

**Poor Housekeeping**

The facilities are to some degree unorganized and lack proper storage for finished components, this is mainly due to a reorganization process ongoing while keeping production going and because of a lack of housekeeping rules and systems. This has been identified and there is an ongoing process to find and implement a fitting solution to this.

**Assumptions**

It was highlighted through the interviews that many delays could be avoided if assumptions were eliminated. The assumption that material was available or that a process or delivery lead time was shorter has led to delays which could have been avoided if decisions were made based on accurate information rather than assumptions. These factors falls under the information sharing factor.

**Outdated Equipment**

With several delays related to equipment failing and processes taking longer than they were expected to can in some cases be related to that equipment is not of today's standard and cause delays by making processes more time intensive. This was reported to be related to maintenance, capacity and breakdowns, which are factors that were mentioned in literature.

## 5.6 Solution Proposals

Step five of the analysis is to propose solutions to mitigate delays. During the interviews, it was discussed what could be done to achieve this and what had been done and what how it had worked. The following solutions proposals were the following.

**Improve accuracy of historical data**

Through improving the quality of the data used for calculations in bidding process and planning. There are concerns from several of the interviewees that these numbers are not accurate enough for these calculations and that what is sold to the customer is not attainable. As proposed by Kingsman et al. (1993), what is communicated to potential customers could be done to win orders, and not necessarily represent accurately how the work is to be performed or within their capabilities. However, the "sold hours" is what the case company uses for planning the projects. The proposal is to implement technology that allows for easy digital tracking of progress, rather than manual progress reporting after a process has been completed. This solution can address the delays related to wrong estimates, as these are based on historical data. This solution was proposed by literature as well.

**Invest in new technology**

With a need to increase capacity to be able to manage an expected increase in demand and to achieve their goals of lead time reduction it has been agreed to invest in new, more efficient equipment to reduce lead times and reduce overconsumption of hours in manufacturing. It has been found that old equipment has resulted in welding repairs being required, and a plan for acquiring new equipment has been made to avoid this. This solution can address delays related to outdated equipment, equipment failure, capacity and human error, as the technology can reduce the potential for error and have a higher capacity. This solution was proposed by literature as well.

**Signboards**

The case company are considering implementing a signboard to coordinate the manufacturing and assembly processes. A good example of this that has been proven to have a positive effect in the ETO environment is a signboard based on Kanban and CONWIP (Powell, 2018). This solution can address the delays related to assumptions, capacity, production planning, coordinating processes, concurrent projects interfering, component supply, priority in production and information sharing, as it visualizes to everyone what is going on where at any time and knows what they need to do related to the subsequent process.

**5S housekeeping rules**

The company has identified that implementing the 5S housekeeping policy from Lean manufacturing. The 5S's are: Sort, Set in Order, Shine, Standardize and Sustain and refers to how the work place is organized and made more efficient through simple housekeeping (Rose et al., 2011). This solution can address delays related to poor housekeeping and missing components as the factors are direct results from this.

**Standardizing parts**

Standardizing parts is not a part of 5S, which refers to the work place itself. To standardize parts means that there are less variations and work can start earlier in order to mitigate delays and reduce lead time. It was found that only around 1% of the number of parts could be standardize and that these parts are rarely delayed, are not labor intensive and that standardizing other parts could lead to large material wastes and large inventory build ups of parts that is impossible to predict when will be used. This solution can address delays related to the engineering process, and complexity. This solution was proposed by literature as well.

**JIT parts manufacturing**

Considered ideal for flow of goods and inventory reduction, but leads to large work load variations, and will be difficult to achieve. Some jobs, the manufacturer is benefited with doing while other, more time-consuming processes are ongoing, and the workers otherwise would have to wait for these to finish. This solution can address delays related to synchronization and missing components, as it forces the processes to start just in time to finish when they are needed. This solution was proposed by literature as well.

**Carry out work while waiting for feedback**

The case company has tested with starting processes before confirmation from tests and customers that a design is approved or that a part satisfies the requirements. For well-known processes, where the tests are been approved each time the recent years, they send test material and carry on working expecting the test to be approved. This has led to a great lead time reduction and rarely any rework. By carrying out work before a change is approved has been considered a great risk and often leads to major rework. This solution can address delays related to waiting for customer feedback and test results.

# 6 Discussion

This section of the thesis evaluates the research, through discussing the results from the literature search and case research to how they were found and analyzed. Further, the relevance to answering research question and solve problem stated is discussed. This section highlights the quality of the research, the robustness and applicability of the constructed framework and improvements the framework could benefit from.

This was done to be able to investigate the factors that can cause manufacturing delays in the ETO environment. With the objective to identify as many as possible, and the evaluate which were relevant to the scope of this research, in order to propose solutions to guide ETO manufacturers towards a solution in handling the challenge of reducing their internal lead times through mitigating delays.

A common question to ask before conducting any research after defining a problem and investigate existing literature and finding a gap is “why has this not been done before?” There could be various reasons for that. It could be the lack of literature on the topic not allowing a thorough mapping of factors, or that it was believed that the relevance from other environments is not sufficient to solve problems in one exact environment. This research was therefore done with the intention to investigating possibility to solve problems through evaluating the fit of solution proposals.

## 6.1 Analyzing Results

The literature was systematically analyzed with the objective of identifying all factors and solution proposals from various environments relevant when investigating ETO manufacturing. The important considerations for the analysis was the possibility of compliance between the environment where the factor or solution was described and the ETO environment.

Through this research it was identified that on the background of similar environmental characteristics it is possible that a solution with proven effect for production processes in MTO, NPD and construction environments can have a similar effect for manufacturers operating in the ETO manufacturing environment, and on this background these solutions were given a conceptual fit in the framework, while for ATO it was found that the characteristics were not similar enough to propose a solution solely based on environmental characteristics.

For analyzing the case company, the A3 analysis was used for inspiration to structure the analysis of the empirical research based on that it is commonly used in process improvement in Lean manufacturing and follow relevant steps for identifying the actual problem that would lead to the unwanted result. Delay in this case. It was found to be an efficient and precise method for approaching the problem researched as it gave a structure that was easy to follow and addressed the steps necessary to make a thorough investigation of the challenges the case company experiences, what should be the goal to remain in a strong competitive position, what factors that cause delays for the case company and how they should be addressed to mitigate them in order to reach their goals.

An additional area of application of the analysis methodology for the case research is that it can be used for manufacturing companies in order to investigate the factors causing delay in their processes and use the framework to identify potential solutions.

## 6.2 Literature Search

The structured literature search was designed to identify factors that can cause delays based on literature from various, but similar manufacturing environments, which is reflected in the search phrases used for identifying the literature used. Most of the literature had the objective of solving issues rather than describing the factors. These factors solution proposals formed the basis for developing the framework. The literature found included little literature specifically towards the ETO manufacturing environment, which strengthens the need of doing this research. The literature revealed gaps towards solving all identified factors, and further research had to be done to fill these and to validate the relevance towards ETO.

Based on the factors found and described in chapter 4.1. The analysis evaluated that the following factors were outside the scope of this research:

- Engineering work is considered to be an external factor for the production processes, and none of these will be included in the final framework.
- Among the facility related factors power outage was excluded because it is a random event and facility physical limitations, as expanding the manufacturing facilities is assumed to be a decision made on an upper level management.
- Manufacturing management factors: Unachievable deadlines is considered to be an external factor, as it is either based on customer requirement, or sales representatives overselling the production capabilities. Wrong estimates can be both internal and external and is included in this research with a focus on the part of is related to inaccurate reporting from production processes. Out-of-sequence work can be traced to changes or supplier related factors and is not considered part of the scope of this research. Level of vertical Integration is assumed to be a strategic choice made by top management and, Managerial abilities refers to upper level management and is not considered to be a part of production processes.
- The suppliers are assumed to not be selected by or affected by production processes and is considered to be an external factor in this research.
- Inventory management is related to the processes in the production facility and is relevant to this research. Material availability refers to how material is ordered from suppliers and is not part of the scope and will not be further addressed.
- Complexity is a natural part of operating in the ETO environment and is one of the strategic choices the manufacturers make, aware of these challenges, and will not be further addressed in this research (Adrodegari et al., 2015).
- The factors related to waiting refers to waiting for external feedback, but the manufacturer is responsible for what this waiting time is used for, and it is included in this framework.

### 6.2.1 Factors Included in the Framework

After excluding the factors that are outside of the scope of this research, the following list of factors causing delays were implemented in the framework:

| No. | Delaying factor | Category |
|---|---|---|
| **1** | Work force skill | Work Force |
| **2** | Workforce availability | Work Force |
| **3** | Workforce experience | Work Force |
| **4** | Human error | Work Force |
| **5** | Capacity | Facilities |
| **6** | Connectivity of work stations | Facilities |
| **7** | Interdependency of work stations | Facilities |
| **8** | Manufacturing feasibility | Facilities |
| **9** | Equipment failure | Facilities |
| **10** | Production planning | Manufacturing management |
| **11** | Wrong estimates | Manufacturing management |
| **12** | Coordination of processes | Manufacturing management |
| **13** | Concurrent projects interfering | Manufacturing management |
| **14** | Component supply method | Manufacturing management |
| **15** | Priority in production | Manufacturing management |
| **16** | Information sharing | Manufacturing management |
| **17** | Missing components | Inventory management |
| **18** | Inventory control | Inventory management |
| **19** | Feedback from customer | Waiting |
| **20** | Waiting for inspection/test results | Waiting |
| **21** | Interdependencies between engineering and production | Waiting |

Table 6.1 Factors causing delay in ETO manufacturing.

### 6.2.2 Framework Based on Literature

The methodology refers to the A3 model for problem solving and has introduced the fifth step to be the development of a framework proposing solutions for mitigating delays based on an extensive set of factors. This chapter is titled discussion and shows how the results from studying literature and the case can be used to develop a framework for this manufacturing environment.

The initial framework is based on theory from various manufacturing environments, including ETO. For solution proposals that that have been proven in ETO manufacturing these have a strong, empirical match as solution proposals in the ETO environment and a for solutions that have been proven to work in other manufacturing environments with characteristics that are similar to ETO, these are awarded a conceptual match as potential solution.

Only solution approaches that are addressing the relevant factors for the scope of this research are included in the initial framework, and solutions that address the same factor that was found in manufacturing environments with similar characteristics as ETO for that kind of operations. Hence, all proposals that are related to engineering are discarded. Also, for a conceptual match, the solution is not considered to be an appropriate solution only on the background of being proven in ATO, as the manufacturing processes are too different with regards to standardization of components, while the characteristics of MTO, NPD and construction projects have many of the same characteristics. On these grounds, "Concurrent Engineering", "Plan for Change", "Automating Processes" and "Standardizing Processes" were eliminated from the framework.
For a strong match, based on that it has been identified as a fitting solution in ETO, these solution proposals are matched with "++" and is considered a verified fit for ETO, Conceptual fits are marked with "+", indicating that because of characteristic similarities between ETO and environments where the solution has been verified as a fitting solution it indicates that it could be a fit in ETO.

| Delaying factor | Capacity Planning | Coordinating Processes | Feeding Policies | Forecasting | Manufacturing Information | Inventory Policies | JIT Planning | Last planner System | Master Data Improvements | Process Evaluation | Process Synchronization | Production Planning | Technological Improvements | Work Force Training |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Capacity** | + | | | + | | | | | | | | | + | |
| **Component supply system** | | | + | | | | | | | | | | | |
| **Concurrent projects interfering** | | + | | | | | | | | | | | | |
| **Connectivity of work stations** | | ++ | | | | | | | | ++ | ++ | | | |
| **Coordination of processes** | | ++ | | | | | | + | | ++ | ++ | | | |
| **Equipment failure** | | | | | | | | | | | | | | |
| **Feedback from customer** | | | | | | | | | | | | | | |
| **Human error** | | | | | | | | | | | | | | |
| **Information sharing** | | | | | ++ | | | | | | | | | |
| **Interdependencies between engineering and production** | | ++ | | | ++ | | | | | | ++ | | | |
| **Interdependency of work stations** | | | | | | | | | | | | | | |
| **Manufacturing feasibility** | | | | | | | | | | | | | | |
| **Missing components** | | | | | | + | | | | | | | | |
| **Priority in production** | | + | | | | | | | | | | + | | |
| **Production planning** | | | | + | | | + | | | | | + | | |
| **Waiting for inspection/test results** | | | | | | | | | | | | | | |
| **Work force skill** | | | | | | | | | | | | | | + |
| **Workforce availability** | + | | | | | | | | | | | | | |
| **Workforce experience** | | | | | | | | | | | | | | + |
| **Wrong estimates/ master data** | | | | | | | | | + | | | | | |

**Table 6.2 Framework for decision support based on literature**

The framework purely based on literature in Table 6.2 has several solution proposals to many of the factors identified, some of these are verified fits, while others are conceptual fits. The next step in the process of constructing the framework is to test the framework for completeness towards empirical data from a case research in order to validate that it is applicable, to investigate if there are factors not identified in the literature search, to test feasibility of solution proposals in order to strengthen or refute the solution proposals feasibility in the ETO manufacturing environment.

## 6.3 Case Study

As part of this research, it was identified that since the majority of the research came from manufacturing environments outside ETO, it was beneficial for the robustness of the research and framework to validate the findings in literature towards the ETO environment. An additional reason was to investigate if literature covered all the factors that could be found. The case research identified solutions that were considered to be implemented in this environment that literature did not cover. This contributed to expanding the framework and to validate and refute the existence of the factors identified in literature in the ETO environment and to investigate feasibility of implementing the proposed solutions in ETO, refining the framework to be more fitting for ETO. It was not specified in literature, but the availability of hired staff from contractors is not addressed, as it is considered to be an external factor, but work force availability of permanent hires the factor “Work Force Availability” is addressed. Based on the discoveries in the case study and literature combined.

### 6.3.1 Development of Framework Based on Case Research Results

Based on the case research, one more factor has been added to the framework, “Poor Housekeeping”. Since the case company clearly states their manufacturing limitations, and these are related to physical limitations, there should be no challenges related to manufacturing feasibility, as they only accept projects, they know they can carry out. The case research identified several solution proposals, mainly through interviews and discussions based on knowledge on the area amongst the researcher and employees at the case company and based on observations and historical data from the manufacturer. The solutions with proven effect at the case company are verified fits and is marked “++”, while the speculated solutions, which have not been tested at the case company, but are considered viable options are considered to be conceptual fit with a “+”. The contributions based on the case research, that theory did not mention as well as those that were strengthened through the case research are highlighted with a superscript C in the framework on the next page.

Considering the framework, the solution proposals were discussed with the case company to identify feasibility for implementation in the ETO environment. This led to identifying JIT planning as a challenge, as there were several smaller jobs that could be done in between major processes, while there was waiting time, in order to have a high work force utilization, and JIT was considered to have a higher cost than benefit for this environment, and was removed from the framework. It was clearly stated that based on the ETO strategy it becomes near impossible to forecast demand, variations, or product mix, hence forecasting was removed as solution proposal in the framework.

The case company managers that were interviewed strongly agrees with that there is a need to improve on historical data, and there are plans to improve this data collection through implementing new technology. As part of their improvement processes, the case company has used elements of LPS with great success in the areas of coordination of processes. Based on the above mentioned, the framework was refined to the final framework.

## 6.4 Final Framework

| Delaying factor | 5S Housekeeping Rules C | Capacity Planning | Coordinating Processes | Feeding Policies | Manufacturing Information | Inventory Policies | Last planner System | Master Data Improvements | Process Evaluation | Process Synchronization | Production Planning | Signboards C | Technological Improvements | Work Force Training | Work While Waiting C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity | | + | | | | | | | | | | + | + | | |
| Component supply system | | | | + | | | | | | | | + | | | |
| Concurrent projects interfering | | | + | | | | | | | | | + | | | |
| Connectivity of work stations | | | ++ | | | | | | ++ | ++ | | | | | |
| Coordination of processes | | | ++ | | | | ++ | | ++ | ++ | | | | | |
| Equipment failure | | | | | | | | | | | | | +C | | |
| Feedback from customer | | | | | | | | | | | | | | | + |
| Human error | | | | | | | | | | | | | +C | | |
| Information sharing | | | | | ++ | | | | | | | + | | | |
| Interdependencies between engineering and production | | | ++ | | ++ | | | | | ++ | | | | | |
| Interdependency of work stations | | | | | | | | | | | | | | | |
| Missing components | | | | | | + | | | | | | | | | |
| Poor Housekeeping C | + | | | | | | | | | | | | | | |
| Priority in production | | | + | | | | | | | | + | + | | | |
| Production planning | | | | | | | | | | | + | | | | |
| Waiting for inspection/test results | | | | | | | | | | | | | | | + |
| Work force skill | | | | | | | | | | | | | | + | |
| Workforce availability | | + | | | | | | | | | | | | | |
| Workforce experience | | | | | | | | | | | | | | + | |
| Wrong estimates/ master data | | | | | | | | ++C | | | | | | | |

**Table 6.3 Final framework to propose solutions to mitigate delays based on the identified factors.**

| | | |
|---|---|---|
| ++ | Verified fit | Solution has proven effect in ETO. |
| + | Conceptual fit | Solution has proven effect in environments similar to ETO, or has been identified as a potential solution in the ETO environment through a case study and verified through literature. |

**Table 6.4 Explanation to fit indicators in the framework**

The framework presented is the final edition and is based on both literature and case data. The framework was tested for validity in the ETO environment, and solution proposals were evaluated for implementation feasibility in ETO. This makes the framework a robust result and should be valuable for identifying a solution to delays. Before utilizing the framework, it is important to know which factors cause the delay, which can be identified, for instance through the A3 based analysis model used in this research. It is important to have a clear definition of what the goal of making an implementation is and how facilities, product characteristics and strategic choices implicate the decision.

The framework is made as a decision support tool. It guides decision makers at the manufacturing companies towards finding the appropriate solutions to handle delays in their manufacturing processes by investigating the factors systematically and evaluate which solution proposals can be fitting in the ETO environment which makes it easier for the manufacturers to implement the right solutions based on the characteristics of their processes. No factor remains unaddressed, but as there is no one size fits all solution in environments with such high variations (Sriram and Alfnes, 2014), it is possible that for some manufacturers this framework will not propose a fitting solution to all factors.

When using the framework some considerations must be made. The manufacturer must consider what tradeoffs are being made in relation to the current condition (Elstner and Krause, 2014). A common concern in ETO is the tradeoff between leanness and agility or flexibility, which are important characteristics for the customers selecting companies in the ETO environment (Matt and Rauch, 2014). For many of the solution proposals described there are risks involved related to these tradeoffs, where the current system has a lower risk, but implementing a solution could increase efficiency at the cost of increased risk this is indicated through findings in the case research and in the works of Elstner and Krause (2014), (Ansah and Sorooshian, 2017) and (Adaku et al., 2018).

The reason for using the Methodology presented earlier was to construct the framework specific enough to capture the unique characteristics of a single case and at the same time general enough to be applicable for other cases with similar, but not the exact same characteristics and making it applicable to ETO manufacturers independent of geographical location or what their products are. At the same time some of the factors that was considered important in this research was proximity to customers and that the manufacturing processes were characterized by a high degree of variations. Application outside of the ETO manufacturing can be considered but would require adjustments and could include many of the same factors and solution proposals, and the same methodology could be used to construct a framework for other manufacturing environments and other supply chain processes.

Based on the findings by Saad et al. (2013) and steps six and seven in the A3 analysis and it is recommended to have a iterative process to further improve the processes. The case company is an example of how this is important, as when they implemented a takt based assembly line and the assembly processes were improved, other deficiencies in the manufacturing processes were reveled, and further improvements had to be done in order to keep the pace of the assembly line. Therefore, further improvements are proposed to improve their manufacturing processes and there this framework can be used to identify what should be the next step in their process improvements to obtain their goal in significantly reducing manufacturing lead times.

During this research it became clear that the methodology and fundamental concept of this research did not only apply to researching delay but could additionally be used for solving other problems related to improving the performance of industrial processes through identifying what the underlying factors of the problems could be and identifying fitting solutions.

## 6.5 Improvement Proposals to this Research

The framework was constructed to be a decision support tool. Beyond that, it could be further developed to be a solution guide proposing detailed solutions with implementation plans. For instance, information sharing could be solved in many cases by implementing an ERP-system, but there are many ERP systems and the framework could be developed to accurately propose which would be the best fit. This would require a lot of work to investigate *all* possible solutions and could generate a framework that is more complex. It is uncertain whether it is recommended as it require a lot of work to develop, and the effect of picking one solution over the other could be minor.

The framework does not address the tradeoffs by implementing the proposed solutions, but when implementing there is usually a tradeoff related to it (Elstner and Krause, 2014). As the framework stands this would have to be a part of the decision makers evaluations after identifying the solution proposal fitting to mitigate the factors relevant for that company, which the framework should be used for.

The framework will become more robust the more cases it is tested towards for verification. Many factors and solution proposals were found using this methodology and repeating the research for other cases in the same and similar environments would further strengthen the framework.

By using another methodology to develop the framework it is believed to be possible to identify even more factors and solution proposals than in this research, as it can be difficult for one methodology to capture all factors and all solutions, as boundaries has to be drawn to define a manageable workload that fit in the scope for the research.

# 7 Conclusion

This section reflects on the quality of the research, its limitation and potential for improvement. It describes how well the research objectives were reached and the future work that could be done in order to improve the research on the area.

## 7.1 Research Objective

At the beginning of this research the following question was posed:

> ***What are the solution proposals for addressing factors causing delays in ETO manufacturing, and do they sufficiently address these factors?***

The reason for asking this question was to reflect the objectives of the research: Firstly, to investigate and identify the factors that can lead to delays in manufacturing processes, directing the scope towards internal factors in the manufacturing processes in ETO manufacturing.

Through this research, a methodology was designed, theory was presented, and theoretical and empirical research was conducted in order to answer this question and in turn reach the objective of this research and solve the problem by reducing lead times through mitigating factors causing delay through constructing the framework.

Based on analyses which investigated the applicability and relevance to ETO, the results based on literature and case research were used to answer this question. Firstly, before answering the question and addressing the factors, it was necessary to identify the factors in theory and in the case company. The research methodology led to identifying an extensive list of factors and through the contribution of the case research refining the list of factors through adding and eliminating factors to better describe the factors faced in the ETO environment, as some factors could lead to delays, but are not a relevant factors as it describes something that comes with the strategic choice of operating in the ETO environment.

Secondly, it was to identify which solution proposals exist for the factors based on literature from various manufacturing environments in ETO and environments with similar characteristics and based on a case study investigating an ETO manufacturing company. The relevance to factors that exist in ETO and the feasibility of implementing the proposed solutions was the basis for how well they were believed to work in the ETO environment and to what degree they were recommended through constructing a framework pairing up the factors with solution proposals based on how well they were believed to fit, depending on what environment they have a proven effect in.

Constructing the framework was the final step. Based on the findings and evaluating solution proposals towards the characteristics of the case company, it was constructed in order to be used as decision support for identifying and eliminating factors causing delay in the production processes of ETO manufacturers.

This research clearly answers the first part of the research question, through identifying the factors and solution proposals and through constructing a robust and easily understood framework. The second part of the research question is answered through this discussion. It is believed that there might me more solution proposals available, however this research did not encounter these following the defined methodology. And it is difficult to give a final answer to whether it is sufficiently addressed before further refinements have been done.

## 7.2 Contribution of Research

The main contribution of this research is the framework and the extensive list of factors that can cause delays in a manufacturing environment. The framework is built from scratch based on existing literature and empirical data found in this research and is a unique contribution to the body of science in Operations Management. The list is a contribution not from collecting information, but by extracting knowledge from various sources in order to understand underlying factors that lead to delay. This contributes with a useful tool for the industry as well as research.

This research test theory towards empirical data and makes theory more generalizable through investigating if what is found to be true in one environment can be true in another. For this research, most of the literature in the literature study was done for other environments than ETO, but this research was able to confirm it for ETO as well.

The methodology can be a useful contribution as it can be used to do a work with the same focus for a different environment and the methodology can be used to investigate other manufacturing performance related phenomenon in different environments.

## 7.3 Limitations of Research

These are the limitations to the research as identified by the researcher:
During the time set for this research to be conducted it was not possible to follow the development in the case company as implementation is a time-consuming process, and it can take a long time before effect is visible. Especially in the case company where the projects last for a long time. Another limitation related to time is that even though many factors were discovered now, the quality of the historical data was not good enough to identify which factors causes what delays, and for interviews and observations which focused on more recent events, it is not necessarily that all factors become evident during the time of the research.

When studying literature, it is not possible to cover all literature, which is why methodologies are used and with each methodology having its limitations of literature covered by the search processes it can well be that factors and solutions that have been proven for ETO were not covered of this reason.

Due to time constraints and the importance of going into detail in the case research it only allowed to do a single case study. The research could benefit from studying multiple cases as it could further validate or refute findings in order to strengthen the generalizability of the framework.

## 7.4 Future Works

For future research on the area the following is recommended:

Repeat case research for manufacturers similar environmental characteristics. Through doing this it will strengthen the framework and could cover more factors and include more solution proposals, which gives an increased chance of more manufacturers being able to use the framework to mitigate the delays they are experiencing, and it could investigate the tradeoff effects by implementing solutions.

Do literature search with a different methodology could identify more factors and more solution proposals. Especially from research in the ETO manufacturing environment, as this research gives a stronger indication that it will work for other ETO manufacturers, rather than solving based on a conceptual match.

To do a quantitative research could be done to investigate efficiency of implementing solutions and guide manufacturers to make informed decisions based on the effect they can expect to see through implementing solutions. Additionally, this could be done for investigating the delay contribution for different factors in order to prioritize which solutions are more urgent or beneficial to implement.

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# 9 Appendix A – Interview Guide

## Interview guide

### What do I want to know?

- Delaying factors found in or affecting the manufacturing processes

What are the challenges related to delays? What factors cause this? Which factors have the largest impact? What is being done to solve the challenges? And what has been tested and how did it work?

### Round 1, March 26th:

People:
GM, planner, Engineering, Production Manager, parts production/prefab supervisor, purchasing department.

*Factors causing delay*

- How do you experience delays in manufacturing?

- Where do the challenges occur?

- What do you believe cause these delays?

- Which factors have the greatest impact on delays in manufacturing?

- What has been done to reduce delays?

- Why did it (not) work?

- What can be done to reduce delays?