Master's degree thesis

LOG950 Logistics

Lean project planning and control in detail engineering: A case study of Ulstein Shipyard

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Number of pages including this page: 113

Molde, 24.05.2019

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Preface

This master thesis has been conducted during spring 2019 as the final stage of our Master of Science in logistics degree at Molde University College. The thesis has been written as a collaboration between Molde University College, Ulstein Shipyard AS and Møreforskning Molde AS as a part of the ongoing Smart Yard research project supported by the research council of Norway.

We would firstly like to show gratitude to our supervisor Steinar Kristoffersen from Molde University College and co-supervisor and research scientist Kristina Kjersem from Møreforskning Molde for providing us with professional guidance throughout the final semester. We have appreciated the constructive criticism, good advises and good discussions that have led to this final product. Additionally, we would like to thank Kristina for being the key-link to Ulstein Shipyard AS.

Further, we would like to show appreciation to Vidar Gjerdsbakk who served as our contact person and his employees at Ulstein Shipyard AS for providing us with valuable information throughout the process and showed great willingness towards participating in the research. It has been a great experience cooperating with Ulstein Shipyard AS and we appreciate the opportunity of writing our thesis together with you.

And finally, a big thank you to our families, cohabitants, friends and fellow students for encouraging us to stay motivated and work hard to achieve a final product we are proud of.

Molde, 23.05.2019

Martine S. Skagseth and Magnus G. Nordhus

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Abstract

This thesis aims to look at how Lean project planning and control can be used to improve customer value and reduce waste in detail engineering at Ulstein Shipyard AS. The company delivers specialized vessels to the oil and gas industry and has recently moved into other market segments such as cruise ships, RoPax ferries and service operation vessels for offshore wind farms.

The shipbuilding process is characterized as a highly complex engineer-to-order projects where each project is unique with many participants involved, making project planning challenging to carry out. However, the importance of project planning and control is essential to cope with customers' requirements on providing cost efficient, on time delivery and flexible projects. Ulstein shipyard has managed to develop a strong market position, known for providing tailor-made solutions following customer specifications. This building approach results in several design changes during the project, increasing the complexity of coordination.

Ulstein shipyard has been working with implementing Lean since 2006 and has implemented several Lean principles in production over the years. To continuously improve project efficiency, the shipyard is now looking to investigate the possibilities of implementing Lean in detail engineering. Through conducting a qualitative case study, this thesis has located challenges within the detail engineering department.

The case findings gave valuable insights in detail engineering's role in the shipbuilding process and into the internal activities in the department. The findings revealed an extensive degree of interdependence between detail engineering, procurement, design and production, creating the need for good communication and planning for conducting tasks in the right sequential order. The challenges discovered during this case study indicates that there are several sources of waste in the engineering department. Waiting and rework are important because it may affect the hand over time of a project.

To cope with these challenges, several Lean strategies have been researched, and the findings have been compared to similar case studies to locate ways to handle the waste. Last Planner System has been suggested in several research studies as a possible solution but is far from perfect and require several adaptions to handle the complexity of design and engineering activities. The findings of this thesis are that there is no optimal Lean solution to eliminate the variation and waste occurring in detail engineering. However, implementation of an adapted Last Planner System may help reduce waste.

Keywords

Lean construction, Last Planner System, Planning, Shipbuilding, ETO

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List of abbreviations and acronyms

ATO	Assemble-To-Order
CAD	Computer-Aided Design
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
NVA	Non-Value-Adding
NVAR	Non-Value-Adding but Required
OSV	Offshore Specialized Vessels
PPC	Percent Plan Completed
TPS	Toyota Production System
US	Ulstein Shipyard
VA	Value-Adding
VSM	Value Stream Mapping

1.0 Introduction

Until the East Asian competition started in the 1970s there were various types of vessels such as tankers, bulkers, ferries, fishing boats and army vessels manufactured up along the long coast of Norway. However, several of the largest shipyards did not manage to compete against Asian shipyards that benefitted from significantly lower labor costs, resulting in several bankruptcies in Norway. Up through the 1990s, the number of shipyards was considerably reduced to mainly smaller shipyards along the west coast. These specialized in ship repairs and building more advanced ships, designed to work in the oil and gas sector. The booming oil industry resulted in the development of strong clusters up through west coast of Norway, where the Møre region became a well-known shipbuilding cluster specialized in Offshore specialized vessels (OSV) (Hammervoll, Halse, and Engelseth 2014) as depicted in figure 1.

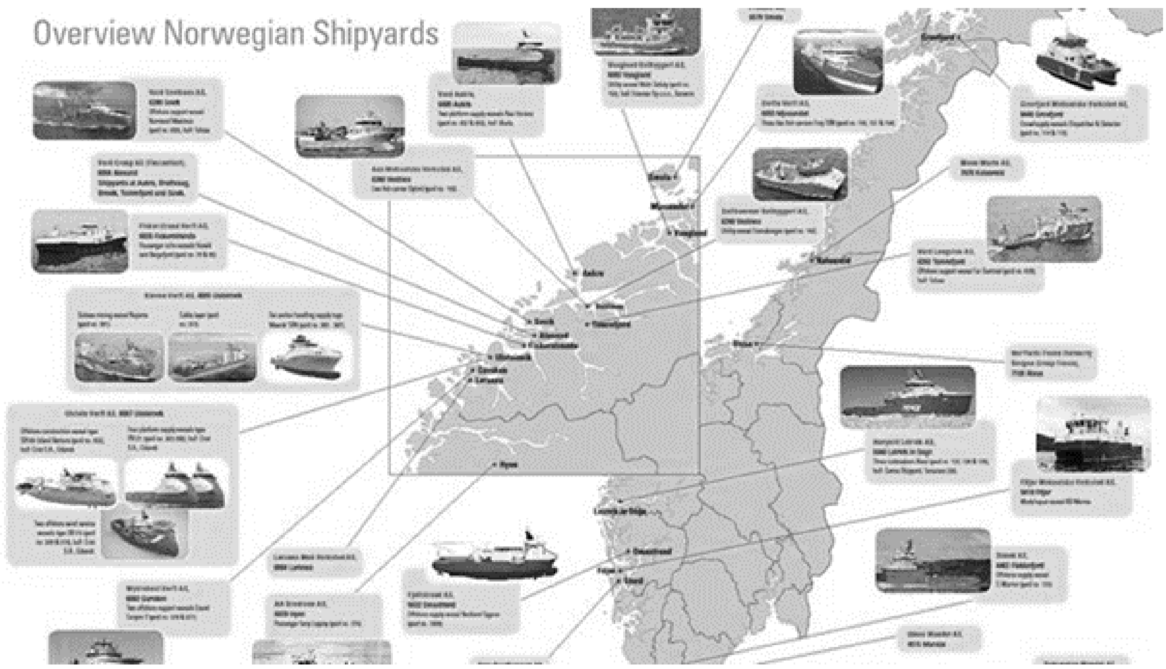


Figure 1. Overview of Norwegian shipyards with focus on Møre og Romsdal (Boer 2015)

The Møre cluster in Møre og Romsdal county is known for its expertise in building highly advanced vessels (Semini et al. 2018) and includes several ship designers, shipyards and maritime component suppliers, who mainly deliver to the oil market (Hammervoll, Halse, and Engelseth 2014). These shipyards have mainly been building OSVs, but also other types of advanced customized vessels such as fishing vessels, live fish carriers, research vessels, cruise ships, mega-yachts, and naval ships (Semini et al. 2018). These are all examples of other market segments that increased after the oil crisis in 2014 (Hammervoll, Halse, and Engelseth 2014).

OSVs are highly customized and complex being tailored to specifications given by the ship operator and often the company it will be charted too. The customer of the ship is involved in an early stage and follows the project through the whole process from developing the design to building the vessel. A significant part of vessels designed by local design companies in the Møre region are also being built at one of the local shipyards, keeping a large part of the value creation whiten the area. Under the ship construction at the shipyard, several local subcontractors get involved. This creates positive repercussions in the local maritime industry when a shipbuilding contract is signed (Hammervoll, Halse, and Engelseth 2014).

A survey conducted in 2015 for the Shipyards in the Møre cluster located the following reasons (figure 2) as to why customers decided to build their vessels there instead of at other shipyards. Price is the most important competitive parameter in the shipbuilding market, but tailor-made deliveries are what make customers choose Norwegian shipyards (Jakobsen, Mellbye, and Zhovtobryukh 2015).

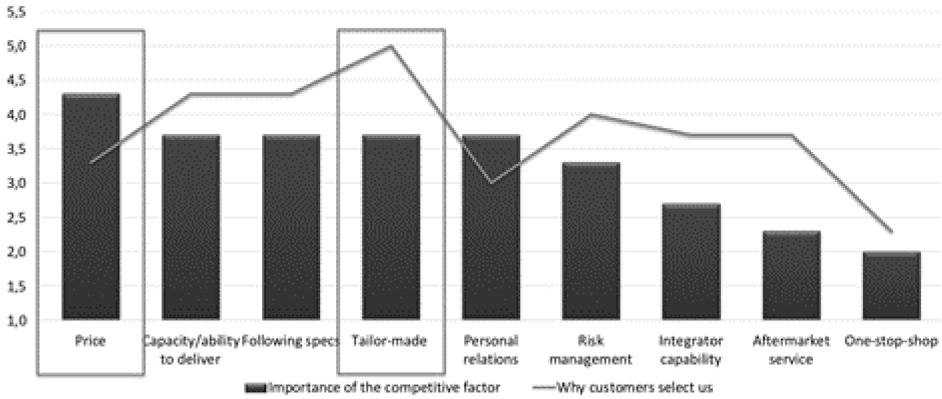


Figure 2. Competitive factors important for customers (Jakobsen, Mellbye, and Zhovtobryukh 2015)

Shipyards in Norway manage to stay competitive by offshoring the steel construction to shipyards in Eastern Europe with a significantly lower labor cost. Steel manufacturing of the hull requires a considerable number of working hours and is not sustainable with Norwegian labor costs. Steel construction of the hull is also characterized as relatively easy to control and does not require advanced competence from the shipyards (Semini et al. 2018).

Offshoring the hull to a larger shipyard also allows economy of scale through stronger purchasing power compared to a smaller shipyard. Norwegian shipyards do instead focus on the outfitting of the hull and being responsible for the whole project, including project planning and control of procurement, outfitting of equipment, manufacturing of pipes and installation of electrics. To be able to conduct such projects, time and cost-efficiency requires highly skilled workforce within system procurement and integration, project management and coordination (Semini et al. 2018).

1.1 Relevance of the study

Based on the competitive factors of why customers choose Norwegian shipyards, one can say that it is essential for shipyards to focus on the level of customer specifications that can be offered, the price and the capability to deliver the product in time. However, one of the significant challenges, as of today, is due to the previous oil crises, which resulted in low demand from the typical customer pool. This has led to a change of marked segment, causing new challenges as the projects have different requirements and expectations, requiring more workforce and suppliers, which causes higher complexity. The transfer from one market segment to another has resulted in the underestimation of tasks, causing delays and complexity issues, thus, making it harder to be flexible to changes in design.

For our thesis, we performed a case study of Ulstein Shipyard (US), focusing on waste in the detail engineering phase. We believe that this topic is highly relevant in today's competitive market where reducing cost, for example through the elimination of waste, is an important aspect for all firms preoccupied to increase their competitiveness. The wide scope of Lean in a rather unfamiliar setting makes it especially engaging, and we have enjoyed becoming familiarized with Lean in detail engineering. Lean is a widely discussed topic, however, Lean in detail engineering is not well studied. The purpose of the thesis is to map out challenges in the detail engineering department and look to see if and how Lean tools and techniques can improve customer value. This leads to the following research problem.

1.2 Research problem and research questions

The primary purpose of this thesis is to investigate how Lean project planning and control can potentially be implemented in detail engineering activities at Ulstein Shipyard. Based on the characteristics in the shipbuilding industry and the relevance of the subject, will this thesis answer the following research problem:

How can Lean project planning and control improve customer value through reduction of waste in detail engineering activities at Ulstein Shipyard?

In order to evaluate the applicability of Lean planning and control in detail engineering activities are two sub questions provided to answer the research problem. Firstly, will the different sources of waste that can be located in detail engineering be described. Secondly, the characteristics of Last Planner System (LPS), a Lean planning and control tool be described, and how it could work detail engineering activities.

- *What waste can be located in detail engineering?*
- *How does LPS work in detail engineering activities?*

1.3 Outline of the thesis

The outline of the thesis is separated into seven main chapters, which again is subdivided into several relevant subheadings. *Chapter 1* introduces and leads to the root of the issue and discusses why the topic is relevant and important to explore. Further, *Chapter 2* presents relevant theory. This chapter is mainly divided into two relevant subsections: Lean and Engineering theory. In *Chapter 3,* the research design and data collection methods are described to show how we have proceeded to respond to the research question. *Chapter 4* is a Case description, introducing Ulstein Group AS and the case company Ulstein Shipyard AS. Further, *chapter 5* concerns the findings of the case study conducted before c*hapter 6,* which is a discussion where the theory and case are compared and analyzed before a conclusion is made in *chapter 7*.

2.0 Theoretical background

In this chapter, we focus on relevant literature related to the research question. The chapter is split into two main chapters, giving the reader an overall understanding of Lean theory and Engineer-To-Order (ETO)/engineering. The first part investigates basic Lean manufacturing theory, principles, practices and tool before diving into Lean construction and Lean shipbuilding theory. The second part focuses on ETO and engineering. This includes the following concepts: Customer order decoupling point, ETO business processes, concurrent engineering, engineering and value in engineering before rounding off with Lean engineering.

2.1 Lean

The theoretical framework of Lean is widely discussed in the literature in a variety of shapes. Lean manufacturing, Lean construction, Lean shipbuilding and Lean engineering are only a few of many variants. The term, Lean, was firstly introduced in the article *Triumph of the Lean Production System.* The article states that Lean production is an efficient production method, while maintaining high quality and a wide product range (Krafcik 1988). However, the term is more known from the book *The Machine that Changed the World*, which in 1990 introduced the term as a western concept based on Toyota's Production System (TPS) (Modig and Åhlström 2014). Based on a lengthy study, the authors proposed four core characteristics of TPS (Womack, Jones, and Roos 1990):

- Cooperation
- Communication
- Effective use of resources and elimination of waste
- Continuous improvement

Liker (2004) highlights the pull system and quality to be the fundament of TPS. Liker and Lamb (2002) describe the goal of TPS to be achieving high quality, low costs, and just-in-time (JIT) delivery by increasing production flow through the elimination of waste. The essence of the concept is improved flow efficiency by reducing all waste that is hindering the flow from running smoothly. They also highlight the importance of teamwork and scientific problem solving as keys to successful implementation of Lean ideas. Just like Liker (2004) states that pull systems and quality are fundamental for TPS, Dennis (2016) argues for the importance of pull, as through JIT, and quality, through Jidoka as fundamental for Lean production. The Dennis model is explained next.

2.1.1 The house of Lean production

Dennis (2016) uses figure 3 below to explain how Lean production functions, and to explain the important aspects of it. The fundamentals of the Lean production model are standardization and stability, the walls are JIT (pull) and Jidoka (built-in-quality), and the roof concerns the overall goal of the company which is customer oriented with a focus on highest quality, lowest cost, and shortest lead-time all by continuously eliminating waste.

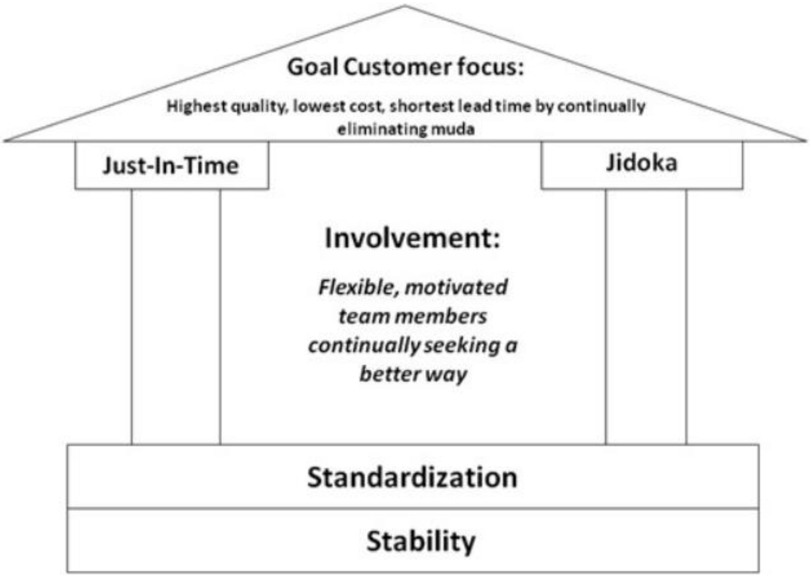


Figure 3. Lean production model (Dennis 2016).

The heart of the model concerns involvement from flexible and motivated employees who seek to always improve.

Muda

The Japanese word *Muda* translates to waste and is an essential component in the house of Lean (Womack and Jones 2003, Dennis 2016). Mossman (2009, p.14) characterizes waste as "*... anything that creates no value for the client/end use*r." Additionally, he notices that in terms of discovering waste, defining value is the number one priority. Liker and Lamb (2002, p.123) define waste as "*anything that adds to the time and cost of making a product but does not add value to the product from the customer point of view.*" Taiichi Ohno, the Toyota executive identified seven sorts of waste (Womack and Jones 2003).

- Defects
- Overproduction
- Waiting
- Transport
- Inventory
- Motion
- Extra processing

Womack and Jones additionally identified an eight sort: non-utilized talent. Even though Ohno identified seven types, he considered the most fundamental waste to be overproduction, because it was a driver causing most of the other waste (Liker 2004).

Mura means unevenness and is another Japanese term. The term deals with activities or information that varies considerably in pace, which leads to someone working fast before having to wait for the next step. Mura leads to all seven types of Muda. Muri is the third Japanese term related to waste in which Womack (2006) translates to overburden. It is related to excessive use of machinery or people which can lead to illness or breakdowns. Three of the main relevant Lean tools are briefly described further.

Just-in-time

Pihl (2018) describes JIT as a way of organizing production to ensure that all parts are at the right place at the right time in each step of production. Dennis (2016, p.89) defines JIT production as "*producing the right item at the right time in the right quality. Anything else entails muda*". He further states that the core concept of JIT is to make value flow, so that customers can pull. Operating JIT is a competitive advantage because it helps companies reduce warehouse costs, ensure high flow of value, and good quality. Additionally, JIT can be said to follow a few simple rules (Dennis 2016):

- Do not produce something unless the customer has ordered it.
- Level demand so that work may proceed smoothly throughout the plant.
- Link all processes to customer demand through simple visual tools (Kanban).
- Maximize the flexibility of people and machinery.

Taiichi Ohno states that JIT is an essential part of TPS. Worldwide, JIT happened to become associated with Japanese production systems known for small batch sizes, short change-over times, high quality and pull system. The point is to eliminate waste through a set of principles, techniques and guidelines which need to be tailor-made to a specific company (Eikeri and Norheim 1989). Essential JIT production principles and tools are: Continuous flow, pull system, Kanban, production leveling and Value stream management (Dennis 2016).

Value stream mapping

Value stream mapping (VSM) is a Lean tool used to explore products or services value chains. Rother and Shook (2003, p.3) define value stream as "*all the actions (both value-added and non-value added) currently required to bring a product through the main flows essential to every product: (1) The production flow from raw materials into the arms of the customer, and (2) the design flow from concept to launch."* VSM includes both the material flow and the information flow where the goal of the process is to implement a Lean value chain that uses the suitable Lean principles and tools that provide improved efficiency through the reduction of waste. The mapping process builds on four steps (Rother and Shook 2003):

1. Selecting a product family is an essential first step to avoid complex value chains with several products. To get the best result, the VSM should cover one product or one product group with similar processes and follow this product from raw material to the customer.
2. The Current state drawing contains how the processes are set up in the current state, where the information is gathered by following the value chain through the different processes. The degree of accuracy is decided by how much information is gathered and is further based on the individual goal of the VSM where more data gathered increases the complexity of the VSM. As shown in figure 4 the arrows are going both ways, this is because the current state drawing is used to make the future state, while the future state often points out information from the current-state that is overlooked.
3. The Future-state drawing visualizes how changes in the current state improve the flow of the processes and reduced waste.
4. Workplan and implementation describe how to implement the changes in the value chain and to achieve the improvements that move the value chain from current-state

to future-state. When the implementation has been conducted, the process starts over as a way to continuously improve the current-state.

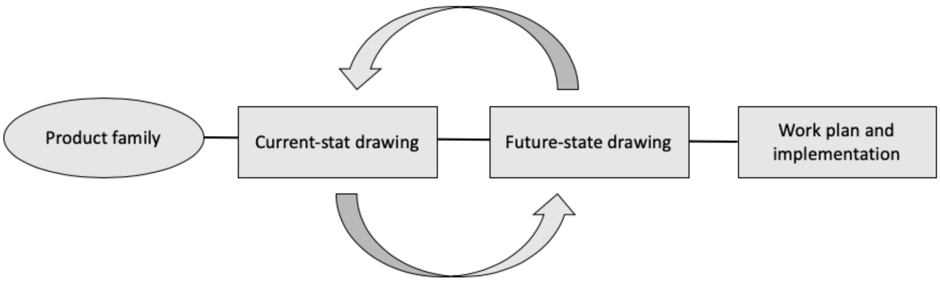


Figure 4. Value stream mapping approach (Rother and Shook 2003).

In theory, VSM is an efficient and simple tool used to locate waste and improve the flow of materials and information through a value chain as described above. However, if VSM is not conducted correctly, it can be challenging to locate waste. Wrong use of the tool can also result in misinterpretations of processes and implementation of unnecessary measures that can increase waste. According to Dal Forno et al. (2014), VSM can provide value to a company through the right use, while it can also lead to bad decisions both technically and financially. As products today become more customized and have complex manufacturing processes, it is difficult to manage to draw a detailed enough VSM that can be used as a tool (Dal Forno et al. 2014).

The most frequent challenge registered in VSM case studies (figure 5) are the difficulties of measuring data in the process, due to product complexity. The technology has also evolved drastically, and the use of technical solutions are presented as a solution to the increasing complexity to be able to use VSM on activities and gather and measure the right data (Dal Forno et al. 2014).

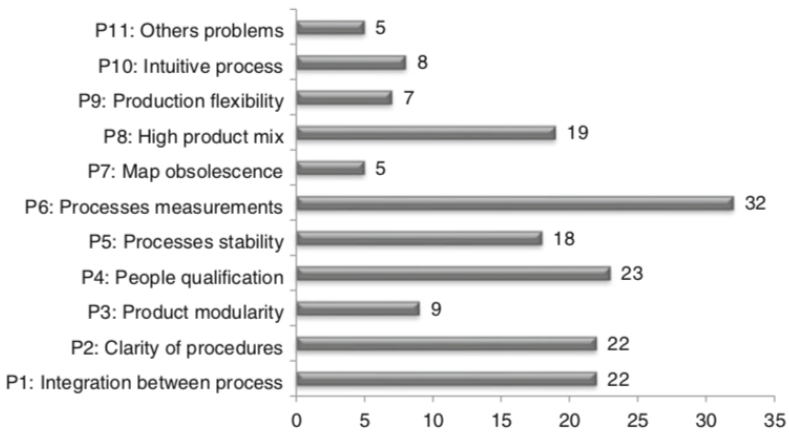


Figure 5. Frequent VSM challenges (Dal Forno et al. 2014).

While manufacturing has gotten much attention the past several decades on how to implement VSM and locate waste, attention toward design and engineering processes is lower. Design and engineering activities differ from manufacturing in several ways that make direct implementation of Lean principles more difficult. It is a gap in the research on Lean in this area. Lean tools need to be modified and adapted to better improve value and reduction of waste in design and engineering activities (Tyagi et al. 2015). From a Lean perspective, McManus (2005) points out the differences between manufacturing and engineering in the following table (table 1).

Table 1. Differences between manufacturing and engineering (McManus 2005).

LEAN PRINCIPLES	MANUFACTURING	ENGINEERING
VALUE	Visible at each step, defined goal	Harder to see, emergent goals
VALUE STREAM	Parts and material	Information and knowledge
FLOW	Iterations are waste	Planned iterations must be efficient
PULL	Driven by takt time	Driven by needs of enterprise
PERFECTION	Process repeatable without errors	Process enables enterprise improvements

Tyagi et al. (2015) support the traditional VSM approach and recommend using a pareto diagram to find the product or activity that stands for the highest cost. Locating and potentially eliminating waste in the value chain for the product that represents the largest share of costs provide the highest improvement for the company. In the next step, the tool Gemba-walk is suggested to map out the current-state drawing. This means getting out of the office and physically following the value chain to manage to map out the information flow. As the flow in design and engineering processes differ from traditional material and are harder to see is the Gemba-walk principle “go-see” described as an efficient way of tracking the information flow. The VSM process is described as challenging and requires more adaption before it can be used on the same level as VSM in manufacturing (Tyagi et al. 2015) but it has proven to give good results according to Dal Forno et al. (2014).

Jidoka (built-in-quality)

Jidoka is a way of doing quality management and is essential to achieve the overall goal of the house of Lean: *best quality, lowest cost and shortest lead-time*. Toyota identifies *Jidoka* as "*automation with a human mind*" (p.123), meaning humans and machinery identifying errors and taking action. Dennis (2016) states that it concerns defect-free processes by continually strengthening process capability, containment so that defects are quickly identified and feedback to quickly take action when an error occur. Typical Jidoka tools are a variety of inspections and control, and *Poka-yoke*. *Poka-yoke* is a robust, inexpensive and simple tool which inspects 100% of items running through each process. It further detects errors and symbolizes a defect by giving a warning or shutting down production (Dennis 2016).

2.1.2 Lean thinking

Lean thinking, often known as just *Lean*, reflects how the Westerners talk about Lean through the application of tools and techniques. On the other hand, the Japanese tend to talk about Lean through Lean philosophy and culture (Dugnas and Oterhals 2008).

2.1.3 Lean principles

Womack and Jones (2003) explain Lean as a way of improving efficiency and customer satisfaction while reducing costs. They state that Lean thinking is conducted through the following five principles; *value*, *value stream*, *flow*, *pull and achieving perfection* (Womack and Jones 2003), which are closely defined below.

Value

According to Womack and Jones (2003) *the critical starting point for Lean thinking is value*. The term value can only be determined by the customer and gives meaning only when used in relation to a particular product and/or service that meets the customer's requirement for the right price and time. Seen from the customer's point of view, a producer is the one creating value. Despite the importance of value, it is hard for a producer to correctly define it. This can cause waste to be generated since a wrong product or service may be provided (Womack and Jones 2003). Koskela (1992) defines value-adding activities as converting material and/or information toward what is required by the customer and non-value-adding activities as activities that takes time, resources or space but does not add value to the result.

Additionally, Mossman (2009) defines value as a provider’s capability to deliver what the customer/end-user requires at the right time and cost. To be able to identify waste, it is essential to define the value of the activities occurring in a process. Womack and Jones (2003) and Rolfsen (2014) use the three categories stated below:

- Value-adding: All activities creating value to the customer.
- Type 1 waste: Non-value-adding activities that currently are unavoidable.
- Type 2 waste: Avoidable activities that are not creating value.

While Diekmann et al. (2004) and Liker (2004) use the following definitions:

- Value-adding (VA) activities
- Non-value-adding but required (NVAR) activities
- Non-value-adding (NVA) activities.

To maximize the value, the goal is to have a process where NVA (type 2) activities are eliminated, and NVAR (type 1) activities are reduced to a minimum (Liker 2004).

Value stream

The point of a value stream is to identify all activities within a process, and mapping them to discover potential waste and eliminate it (Womack and Jones 2003, Tapping 2002). A value stream map visualizes all end-to-end processes, control/decision nodes, and interconnecting flows necessary to generate customer value. The map is a tool to improve the flow by discovering and eliminating all non-value-adding activities, and minimize all necessary but non-value-adding activities (Oppenheim 2011, Weiss 2013). Womack and Jones (2003) state that companies do not give value stream mapping enough attention even though it almost always exposes enormous amounts of waste.

Flow

The next step after identifying the actual value-adding activities is to assure that the remaining activities flow without any stoppages, scrap or backflow (*waste*) (Womack and Jones 2003). Dennis (2016, p.94) state that waste is a symptom of hindrance to flow. Koskela (1992, p.15) defines Lean production system as “*a flow of material and/or information from raw material to end-product. In this flow, the material is processed (converted), it is inspected, it is waiting, or it is moving. These activities are inherently different. Processing represents the conversion aspect of production; inspecting, moving and waiting represent the flow aspect of production.”* Figure 6 below provides an example of a flow.

Further, he defines flow as *"processes can be characterized by time, cost and value. Value refers to the fulfillment of customer requirements. In most cases, only processing activities are value-adding activities. For material flows, processing activities are alterations of shape or substance, assembly and disassembly"* (Koskela 1992, p.15)

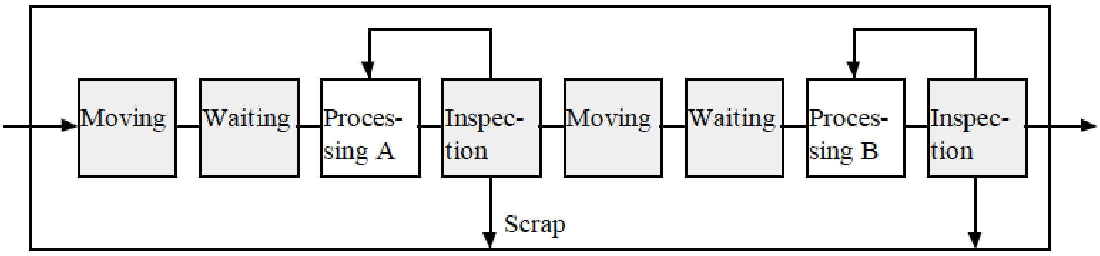


Figure 6. Overview of a production process with VA, NVAR and NVA activities (Koskela 1992).

Flow is essential in Lean production philosophy, where production is demand driven, and production does not start before the customer requirements have been defined. Each activity in figure 6 consumes cost and time, while only *processing A and B* add value to the product that is moved through the production system. Efficiency is achieved by focusing on eliminating or changing activities that are not providing value to the product, and by that improve processes where value is added to the product (Koskela 1992).

To provide an improved process flow, Koskela (1992) came up with 11 principles on how to design, control and improve process flow based on Lean production philosophy:

- Reduce the share of non-value-adding activities.
- Increase output value through systematic consideration of customer requirements.
- Reduce variability.
- Reduce the cycle time.
- Simplify by minimizing the number of steps, parts and linkages.
- Increase output flexibility.
- Increase process transparency.
- Focus control on the complete process.
- Build continuous improvement into the process.
- Balance flow improvement with conversion improvement.
- Benchmark.

These principles are providing a guideline for improving the workflow in production and has been an important contribution to later research on Lean and process flow.

Pull

A pull system means waiting on customers to signal their need before starting production (Womack and Jones 2003) or as Dennis (2016, p.93) defines it: "*Pull means that nobody upstream should produce a good or service until the customer downstream asks for it*". When postponing the production until the customer pull, customer requirements (customization) are easier to fulfill (Womack and Jones 2003). Additionally, according to Dennis (2016), using a pull system help reduce cycle-time, operating expenses, improve quality, ergonomics and safety.

Achieving perfection

After completing all four steps above: specifying value, identifying the value stream, making the value-adding steps flow and letting customers pull, elimination of waste happens. Meaning that all activities in the value stream flow, making every step creating value to the product or service (Womack and Jones 2003).

In addition, Liker (2004) suggests 14 management principles. He describes TPS to be a system designed to provide tools for employees to continuously improve. He states that being Lean the Toyota way, depends on a culture in the company to discover hidden problems, fix them, and reduce inventory levels.

The 14 management principles

Long-term philosophy

1. Base management decisions on a long-term philosophy, even at the expense of short-term financial goals. Right process will produce right results
2. Create continuous process flow and bring problems to the surface.
3. Use "Pull" systems to avoid overproduction
4. Level out the workload
5. Create a stop culture to fix an issue when it occurs, so the quality gets right the first time
6. Standardization of tasks are essential to have continuous improvement and employee empowerment.

7. Using visual control, no problems are hidden.
8. Use reliable and thoroughly tested technology that serves your people and processes. Add value through the development of people and partners
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams who follow the company's philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve. Continuously solving root problems
12. Get close up with situations to thoroughly understand
13. Make decisions slowly by consensus, thoroughly considering all options. Implement decisions rapidly.
14. Become a learning organization through relentless reflection (Hansei) and continuous improvements (Kaizen).

(Liker 2004).

Liker and Lamb (2001) claim that the basic principle of Lean is to give customers what they want with a shortened lead-time. This is highly important in any industry. However, not all principles of Lean manufacturing based on TPS fit all industries. Liker (2004) also states that any kind of organization can benefit from the implementation of Lean principles, not by coping TPS, but by developing their own principles, practicing them, achieving high performance and by continuously adding value to the customer.

2.2 Lean Construction

Lean has proven to provide extraordinary results in manufacturing and has been adapted by manufacturing companies all over the world since the concept became known through the book *The machine that changed the world*. Lean was introduced to the construction industry in the 90's where researchers saw the potential of implementing Lean on construction sites to improve efficiency and reduce waste. Implementing Lean was proven difficult, due to the differences where manufacturing plants produced finished goods while construction sites dealt with large units and produced in low volumes. The differences required some adjustments from the Lean manufacturing and the adaption to the construction industry resulted in a new Lean approach called Lean construction (Salem et al. 2006).

Compared to project management, Lean construction aims to come up with a better project planning and control method able to cope with the uncertainty and the variation in the workflow. By using Lean principles and focusing on the reduction of constraints, Koskela and Howell (2001) argue for reduced project lead time and costs, as a result of reduced uncertainty. Reduced project lead time and cost are achived by more predictable workflow and just in time delivery of equipement and services. They further describe how project management are less favorable and the need for reforming project management when projects are getting more uncertain, complex and the client demand lower lead times.

According to Ballard and Howell (1994), Lean construction differs from traditional project management in two ways. First, it focuses on locating waste and the reduction of waste, as this means that the use of material and information in construction projects are not optimal and is further affiliated with loss of time and money. The other difference is the focus on flow management, describing the flow of material and information through the project. Construction projects differ from manufacturing by the degree of complexity. The high complexity is due to many participants in the project, complex supply chains and potential design changes. Lean construction was developed to cope with this complexity by adopting the Lean philosophy to suit the characteristics of construction projects (Ballard and Howell 1994).

One of the primary improvements in applying Lean in manufacturing or construction projects is reduced cycle time, as a result of eliminating waste (Koskela 1999). Cycle time can be calculated by Koskela (1999):

Cycle time = Processing time + inspection time + wait time + move time

By managing to eliminate waste and improve flow management successfully, the cycle time of construction projects is reduced and, that further result in lower project costs. Achieving this effect in real life, on the other hand, is extremely difficult because of the high variability in the information and material flow at construction sites. Some of the most common requirements required to execute a construction task is visualized below in figure 7 (Koskela 1999).

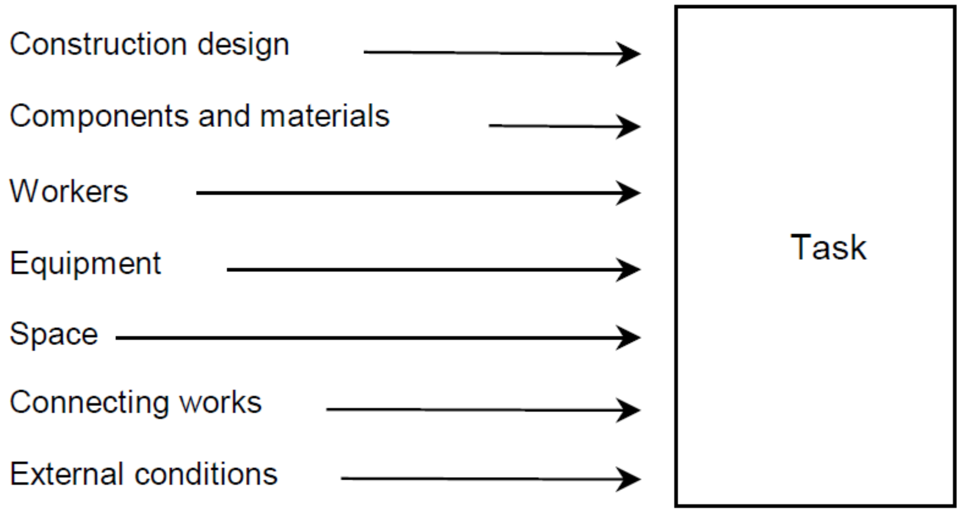


Figure 7. The preconditions for a construction task (Koskela 1999)

To manage to control and improve the planning in construction projects, Ballard (2000) developed an own planning and control tool called Last Planner System (LPS), designed for handling complex projects better than standard project management.

2.2.1 Last Planner System

Last Planner System (LPS® hereby referred to as LPS) is a tool invented to suit the construction industry. It was developed by G. Ballard in the 1990s as a project management control system to eliminate potential barriers and by that improve the realization of project plans and provide better flow in a project. The construction industry is well known for its project overruns of time and/or budget, due to uncertainty in the different phases of a project. Construction projects usually have several different actors such as an owner, designers, engineers, contractors and suppliers that are involved through the project life cycles. The interdependency of all participants makes planning and coordination highly challenging and complex. This high level of complexity makes it challenging to use the same planning and scheduling approach as in manufacturing (Kalsaas 2012, 2017).

LPS contains five integrated elements as depicted in figure 8 are proven a positive effect on the planning and coordination of projects and can bring significant advantages to projects if it is implemented successfully. These elements are: master plan, phase planning, lookahead planning, weekly work plan and finally weekly report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017), which are all further described.

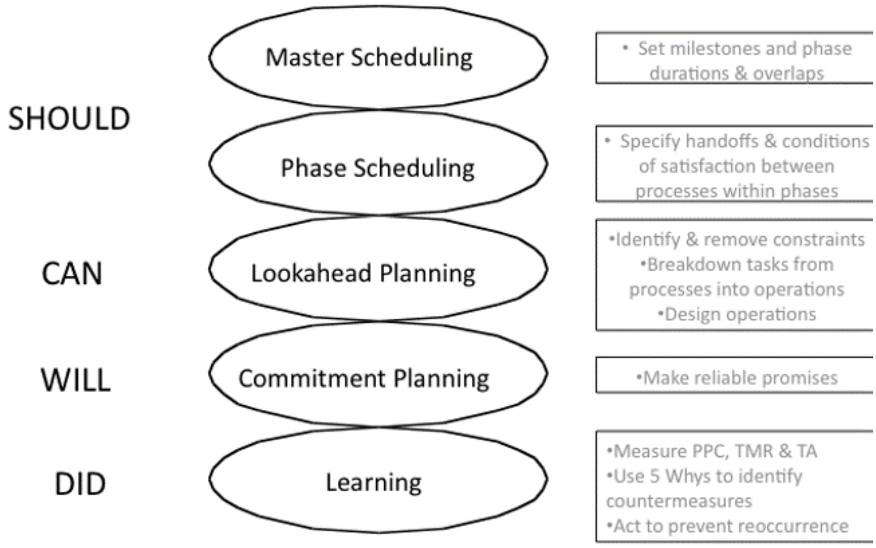


Figure 8. The LPS of production control (Ballard and Tommelein 2016).

Master Plan

A master plan contains the general plan for the project and identifies all the milestones and work packages, including their duration and sequence report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017).

Phase planning

The master plan is further divided into phases containing more detailed work plans and goals. The phase plan is a schedule made in collaboration between involved parties to find the most effective and suitable approach for the project. Phase planning also provides a bridge between the master plan and the lookahead plan report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017).

Lookahead Planning

A lookahead plan aims to prepare the management on what is coming and facilitate processes that are planned. The lookahead plan aims to schedule activities and resources for 3-12 weeks ahead of time and match the workflow with capacity report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017).

Weekly Work Plan

A weekly work plan is a weekly meeting with all the managers that are involved in the project and are characterized as the last planners. The last planners represent those who work with the current activities in a project and has firsthand experience on the requirements for the task. With complex projects and many interdependent activities, it is the last planners who are responsible for coming up with a plan over activities for next week that are considered possible to achieve and is selected in the right sequence. Weekly meetings are planned based on the work that has been finished, work that is currently being done and work that is made ready to be done. Weekly work plans are often changed due to delays from the previous week. The weekly work plan builds upon what *will* be done that is the result of the planning process that matches *will* with *should* within the constraints of *can*. The weekly work plan meeting also covers the weekly plans, safety issues, quality issues, resources, construction methods, and any problems that occur in the field report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017).

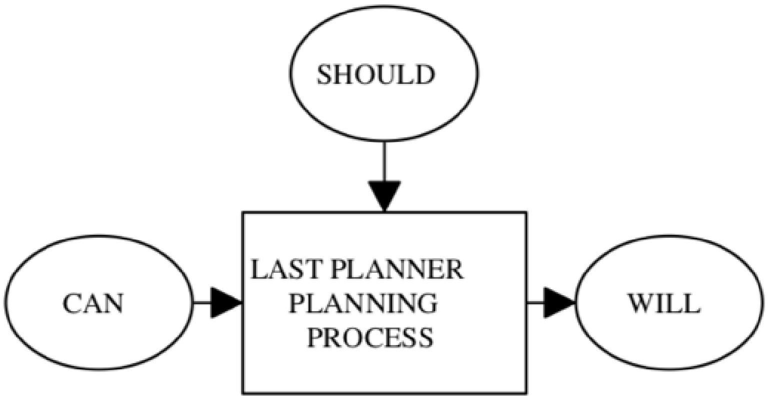


Figure 9. Last Planner Planning Process (Ballard 2000).

Figure 9 shows how the terms *can, should* and *will* are connected to different levels in the planning process. *Should* are the overall master plan of the project that describes what *should* be done through the project and are also divided into different phases or milestones that are more detailed overall plans of what *should* be done within each phase. What *can* be done is determined based on whether all the necessary resources are available at the right time. Lookahead planning facilitates the flow of activities by removing any constraints that prevent activities that *should* be done to be accomplished. The weekly work plan decides what *will* be done based on which activities *should* be done according to the master plan and are within the constraints of what *can* be done. The connection between *can, should* and *will* give the foundation of LPS report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017), as described in figure 10.

Weekly report

Weekly report concerns reporting the amount of planned work completed in per cent to control the progression and improving project planning by continual assessment and learning from failure. Continuous improvements depend on knowing the root of the problem to why the planned work is not completed in compliance with the weekly work plan. Percent Plan Completed (PPC) makes it possible to follow the development of the project and how many of the activities are delivered on time *(*Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017). PPC can be calculated as following:

$$PPC = \frac{Number\ of\ completed\ as\ planned\ activities}{Total\ number\ of\ planned\ activities}$$

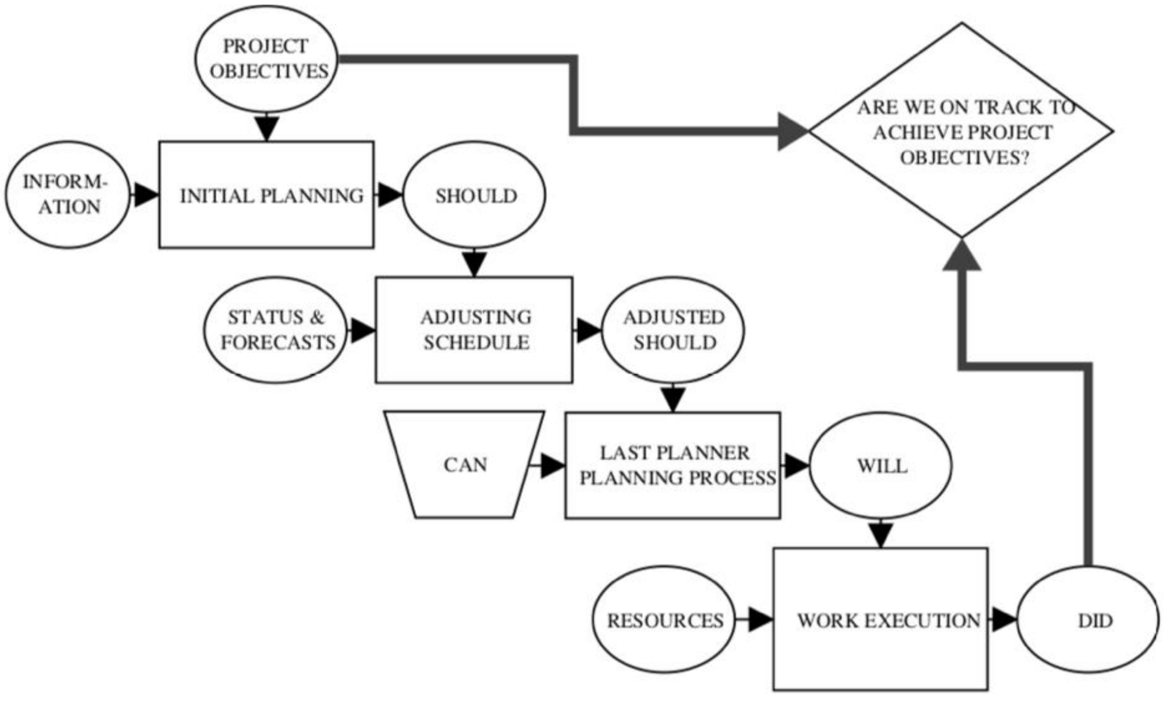


Figure 10. Last Planner System (Ballard and Howell 1994).

LPS require more extensive adjustments to handle uncertainty and complexity compared to the simple model in figure 9. A more advanced model is depicted in figure 10, describing how the planning system is adjusting itself based on input from each level. The master plan is at the top level of the model and stands for initial planning, describing the overall plan of activities, while the next level in the model is the lookahead plan to see if what *should* be done are on line with what *can* be done. Status for the project and forecasts decide if it is necessary to adjust the schedule of what *should* be done early in the planning process or handle any problems or constraints that *can* be solved before causing problems later in the project. The weekly work plan on the lower level builds upon what *will* be done that is the result of the planning process that matches *will* with *should* within the constraints of *can* as earlier described (figure 9). The last level is the work execution, were *will* and *did* are supposed to match, and if not is an important part of the LPS to locate the root cause to why the weekly plan over what *will* be done, not match with *did,* describing the results of the work week. By learning of planning mistakes, LPS provide continuously learning and improve future planning. The status of the project is updated for each week and sent up in the planning system to provide improved planning at each level report (Koskela, Stratton, and Koskenvesa 2010, Kalsaas 2017).

LPS plans the activities in projects using standard project management, however, the differences between the two methods lay in the lookahead planning. Compared to standard project planning that is expecting that *should* always are the same as *did* are lookahead planning adapting through the process (Kalsaas, Skaar, and Thorstensen 2009, Ballard 2000), as described in figure 11.

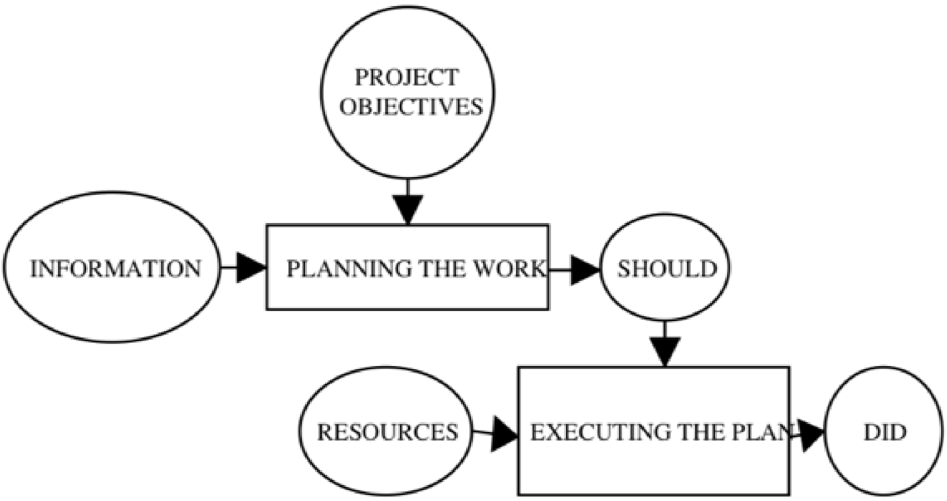


Figure 11. Standard project planning approach (Ballard and Howell 1994).

This standard approach (figure 11) works until someone do not manage to deliver in time, often resulting in delays, while in LPS the lookahead planning is continuously doing constraint analysis on each activity. The constraint analysis identifies what must be done in order to make each activity ready for execution, resulting in a stable flow of activities that are sent to the weekly assignment plan that *can* be done. The last planners decide what is realistic to be achieved during the week and evaluate the project plan by measuring the PPC. When delays occur, each case is followed up to find the root cause and provide continuous learning of mistakes (Kalsaas, Skaar, and Thorstensen 2009).

Porwal et al. (2010) found through literature research the most common challenges when implementing and using LPS.

Implementation challenges

1. Lack of training
2. Lack of leadership/failure of management commitment/organizational climate
3. Organizational inertia & resistance to change—This is how I have always done it attitude
4. Stakeholder support
5. Contracting and legal issues/contractual structure
6. Partial implementation of LPS & late implementation of LPS

User challenges

1. Human capital and lack of understanding of the new system; difficulty making quality assignments/human capital–skills and experience
2. Lack of commitment to use LPS & attitude toward the new system
3. Bad team chemistry and lack of collaboration
4. Empowerment of field management/lengthy approval procedure from the client and top management
5. Extra resources/more paperwork/extra staff/more meetings/more participants/ time
6. Physical integration

Porwal et al. (2010) state the importance of enough training of management and their understanding of the tool before it is implemented in a project. Lack of training, resistance to change, lack of leadership, and lack of human capital in implementing and using LPS are some of the significant challenges that were found. This can be enough to ruin the implementation of LPS and the impression from the workers.

2.2.2 Last Planner System in Design and Engineering

LPS has proven to give a positive effect on project planning and control in construction projects, but the adaption to design and engineering activities have been known to be more difficult. When Ballard (2000) developed the LPS, it was designed to cover the whole value stream from design and engineering activities to the different phases of construction. Since Ballard came up with LPS, this project planning and control tool has been implemented in construction sites all over the world, while applying LPS to design and engineering has proven to be more challenging. Completion of engineering activities requires input from proceeding work, technical specifications and the right resources to carry out the activity (figure 12). In addition, external condition given in some activities as for example from a class company or public regulations that need to be taken into account. With the use of LPS planning processes are conducted continuously, focusing on delivering necessary input to the planned activities and stabilize the flow (Bertelsen et al. 2007).

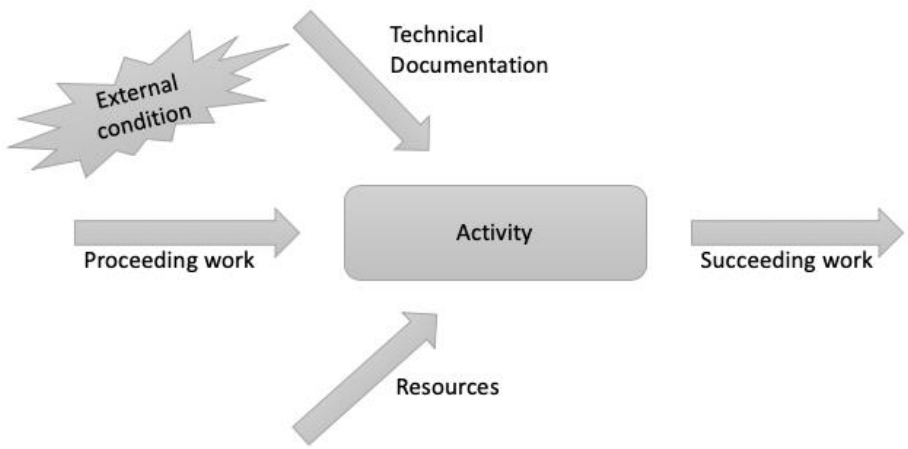


Figure 12. An executable engineering activity (Bertelsen et al. 2007)

Kalsaas, Bonnier, and Ose (2016) describe the difficulties of implementing LPS in design and engineering activities arguing that they are too different compared to construction activities. A solution to the problem is to adapt the LPS developed by Ballard (2000) to suit the design activities by doing some minor changes. Wesz, Formoso, and Tzotzopoulos (2013) support the need for adaption of LPS. They found out through a case study how weekly meetings and short-term planning improved the performance of a design team. It further provided improved process transparency and workflow, stronger commitment and collaboration among design team members. Under the weekly meetings, LPS gave better predictability and flexibility in decision-making, as well as compliance with the project schedule. Improved coordination with production planning and manufacturing was also a result of the use of LPS. Feedback from design teams regarding the use of LPS has been positive. However, it requires some changes as it suits construction management better than design management. Earlier research on LPS in design and engineering activities has mostly covered the implementation phase, and the findings register some resistance to implementing a new practice. With little research on companies that have successfully implemented the LPS in design and engineering activities, it is difficult to confirm the positive effect and its challenges (Kerosuo et al. 2012).

2.3 Lean in Shipbuilding

Emblemsvåg (2014) discusses the importance of Lean project planning in the shipbuilding industry and states that the norm in the shipbuilding industry is to be project-based. He further denotes that the peculiarities of the shipbuilding industry are much like in construction as both industries are characterized by one-of-a-kind projects, on site production, temporary multi organizations, and regulatory intervention. Additionally, he describes a fifth peculiarity, which may be unique for the shipbuilding industry to be that production of ships often starts before all engineering issues are solved due to the technical complexity and the importance of short lead-times.

The shipbuilding industry differs from ordinary production such as in the automobile industry because ships are produced through an ETO approach, with production requiring more time due to its need to deliver highly customized products (Liker and Lamb 2002). The Norwegian shipbuilding industry is further mainly specialized in complex vessels designed to operate in harsh environments and for offshore purposes. For the production of these vessels, shipyards operate with an ETO approach, meaning that the customer takes part in the whole process from design to production (Halse, Kjersem, and Emblemsvåg 2014). Emmitt, Sander, and Christoffersen (2004) argue for the opportunities of moving Lean thinking upstream in the project phase. Earlier construction projects have used the Lean philosophy to reduce waste in the construction, but he argues that this can be improved even further through implementing Lean in the conceptual design stages. This would provide greater synergy between design, manufacturing and construction, and further reduce waste and increase coordination in the whole process.

2.3.1 The Lean shipbuilding model

Liker and Lamb (2000) conducted a study of one Norwegian and three Japanese shipyards before using TPS and Lean production and translated it into a shipbuilding model shown in figure 13. The model embraces familiar Lean principles such as JIT, continuous flow, built in quality, 5S, standardization, and continuous improvement through being a learning organization with motivated, flexible and appropriate employees. The overall goal of the industry is 100% customer satisfaction at the lowest cost, shortest lead-time and with the highest quality.

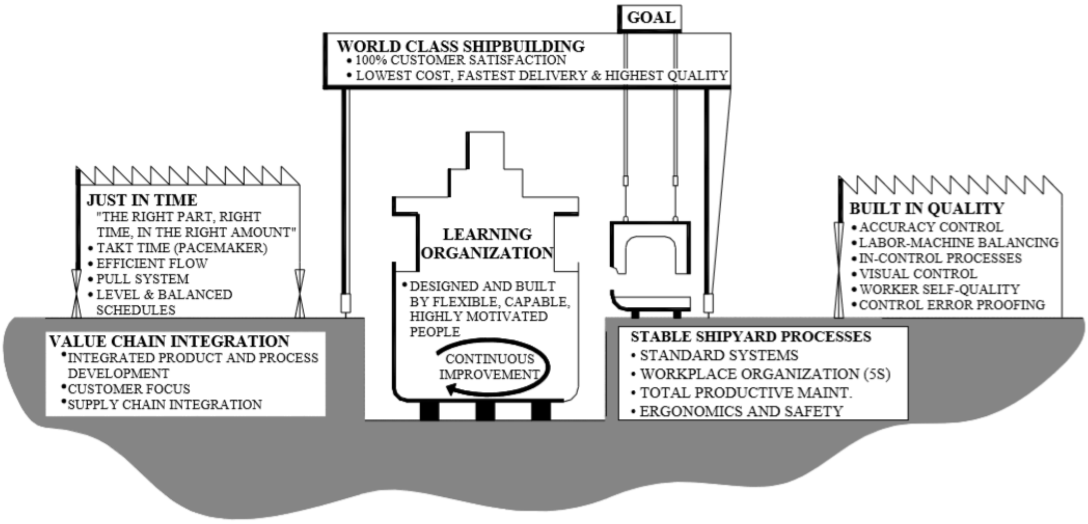


Figure 13. Lean Shipbuilding model (Liker and Lamb 2000).

Just-in-time in shipbuilding

The ideal approach of JIT is one-piece flow. With this approach, all parts needing the same processes are gathered, and one piece at the time flow through a common process line. This approach has typically been used in high volume production but also by Japanese shipyards. If a one-piece flow is not possible, the smaller batches, the better due to the waste that occurs as material are waiting on their batch to be further moved (Liker and Lamb 2000).

Stable shipyard processes

The model accentuates stable and reliable shipyard processes as essential because there are no large inventory buffers. Keys to assure stability are standardization of manual work processes, standardized procedures showing the sequence of tasks, quality checks, safety issues and gives other information, efficient workplace design and layout, 5S (sort, stabilize, shine, standardize and sustain) and ergonomics (Liker and Lamb 2000).

Built in quality

The importance of assuring high quality at first is because it is less costly and more efficient than inspections and repairing afterward. Accuracy control is problem solving tools, adapted to help do the job right the first time (Liker and Lamb 2000).

Learning organization

Lean is dependent on people. It is essential for an organization to have flexible, capable, motivated, skilled and empowered people who are willing to continuously improve and solve everyday issues. To continuously develop and sustain the improvements is it essential to have focus on proper training, have committed managers with focus on 5S, following standardized procedures becomes a habit and participation from all employees (Liker and Lamb 2000).

The shipbuilding model gives an overall insight to how Lean production and TPS principles can be introduced in the shipbuilding industry. However, the model is inspired by the Japanese shipyards which after the second world war faced challenges regarding low productivity, low quality and a low degree of innovation. Liker and Lamb (2000) state that the implementation of Lean principles such as standardization, JIT, moving production lines and continuous learning employee can take credit for their improved productivity occurring afterward. Efficiency improved by 100% over a period of five years from 1960-1965, and further a 150% the next 25 years. Unlike Japanese shipyard factories, the Norwegian shipbuilding industry focuses on complex and highly specialized vessels and mainly use the ETO approach (Liker and Lamb 2000).

2.4 Engineer-to-order

Engineer-to-order (ETO) is described as a production approach where products are engineered to the specific requirements of the customer (Haug, Ladeby, and Edwards 2009). A typical ETO industry is characterized by low production volume, where each order is produced as a project, and with high customization requirements, making each project unique (Haartveit, Semini, and Alfnes 2011). Companies performing ETO are often responsible for all parts of a project from the design phase, including product development, engineering, procurement and logistics, to manufacturing, assembling and commissioning of the product (Strandhagen et al. 2018, McGovern, Hicks, and Earl 1999, Hicks, McGovern, and Earl 2000). Managing highly customized products often involves complex engineering processes, resulting in long lead-times of a project (Rauch, Dallasega, and Matt 2015). In addition, the producer must often wait until delivering the product to the customer before receiving payment for the product. In large capital-intensive projects, ETO is vital to accelerating the whole operation and avoid long project times (Rauch, Dallasega, and Matt 2015). Todays' situation is a constantly increasing demand for customized products, especially in high capital-intensive industries requiring heavy machinery as for example the shipbuilding, maritime and oil and gas industries (Strandhagen et al. 2018). Typical industries operating with ETO are shipbuilding, construction, and steel fabrications (Rauch, Dallasega, and Matt 2015). ETO can further be explained through the customer order decoupling point as shown next.

2.4.1 Customer order decoupling point

The customer order decoupling point (CODP) defines where in the manufacturing value chain a product is connected to a specific customer order. The location of a CODP is related to the market, product and production characteristics, and are divided into four different strategies: *make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and ETO* (Olhager 2003). These strategies are depicted in figure 14.

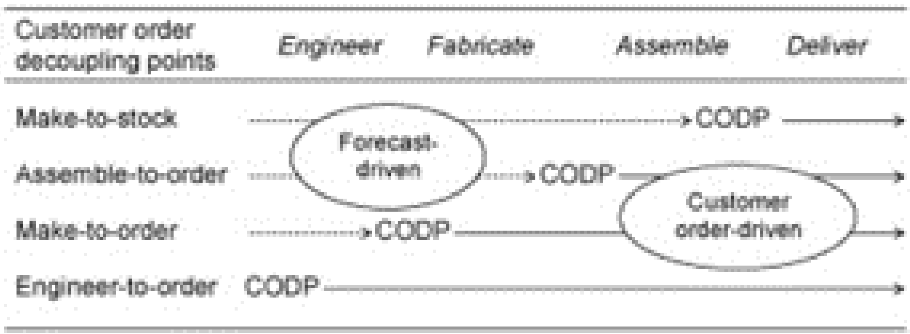


Figure 14. Customer Order Decoupling Points (Olhager 2003).

The suitable market interaction strategy in manufacturing are decided by demanding volume and volatility, and the relationship between production lead-time and delivery time to the customer. MTS is characterized by a high and stable demand volume and demanding customers requiring short lead-times, while on the other side of the scale is ETO characterized by low demanding volume and volatility in the market (Olhager 2003). Powell et al. (2014) states that the conflicts of interest between operating within the four categories are from a supply and a demand perspective. Companies operating MTS and ATO may desire to move the CODP from right to left to reduce variability and large inventories, while companies operating with MTO and ETO strategies may want to reduce lead-time by moving CODP from left to right. Due to the market, product and production characteristics that decide the demanding volume is it difficult to change from one approach to another. However, it is possible for companies to improve their efficiency in production and reduce variation from a supply perspective without reducing the customer lead-time with the implementation of different improvement strategies. This has made it possible for some companies that are producing high volumes of standardized products to move from MTS to ATO, resulting in reduced lead-time, as well as at the same time reducing the variation and need for forecasts. ETO on the other side has the CODP at the start of the value chain, making it challenging due to its characteristics (but also highly interesting) to locate strategies and tools that can reduce the customer lead-time (Powell et al. 2014).

2.4.2 Engineer-To-Order Business processes

Hicks, McGovern, and Earl (2000) list three main business processes in ETO companies.

It all starts with marketing, where an ETO company market their product designs and competence. Additionally, they will also look at tenders in the market and assess if there is any worth responding to, based on the customer requirements, commercial factors, the company’s ability to compete and the likelihood of success. Responding to a tender is the beginning of interaction with a customer where the producer is required to come up with an offer including the development of the conceptual design and interact with suppliers to come up with the expected cost and lead-time for the project. At this stage, price, delivery time, quality and technical requirements for the project are settled. Until this point, the producer work for free to potentially win the contract. The third stage starts after a contract is signed and awarded a producer. At this point, the planning of the project starts, and the design and engineering phase. After the project plan is developed, the assembly and construction begin before commissioning of the product Hicks, McGovern, and Earl (2000) (figure 15).

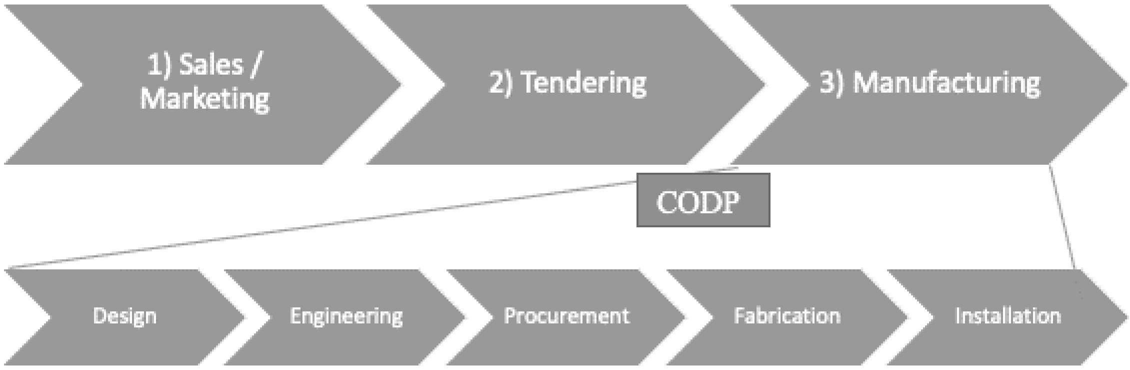


Figure 15. ETO business processes (Hicks, McGovern, and Earl 2000)

ETO companies are usually involved in the whole value chain, and it is therefore essential to improve the business processes as they contribute for a considerable part of the total lead-time. To deal with such challenges in highly complex environments as ETO manufacturing, several strategies and concepts have been introduced as an attempt to reduce the lead-time for a project. Several of these strategies have been gathered from Lean thinking and Lean manufacturing strategies with the point of reducing waste and increase the value. However, the implementation of Lean has mainly been used in manufacturing instead of the whole value chain (Strandhagen et al. 2018). Several researchers point out the potential of implementing Lean through the whole process from design to manufacturing to reduce waste and project lead-time (Rauch, Dallasega, and Matt 2015). According to Marodin et al. (2018), implementing Lean in product development and design, in addition to Lean manufacturing, has proven to have a moderate positive effect on quality performance.

Some strategies highlighted in earlier research to improve performance in ETO projects are (Marodin et al. 2018, Gosling and Naim 2009, León and Farris 2011, Strandhagen et al. 2018):

- Concurrent engineering
- Standardization
- Modularization
- Value stream mapping
- Last planner system

The implementation of Lean in other industries has received a lot of attention over the years, especially after Koskela (1992) introduced the opportunities of implementing Lean in the construction industry. However, there is no definitive answer to what is the optimal strategy of implementing Lean tools and achieve increased efficiency. Babalola, Ibem, and Ezema (2019) have conducted a systematic review of published literature about Lean construction and Lean practices that has been implemented successfully with a positive return. Between 1996 and 2018, 102 documents were published about the subject with thirty-two different Lean tools and practices. Seventeen of the documents points out the benefits of using LPS in project planning, while other practices as JIT, concurrent engineering and VSM are all approaches that can refer to improved efficiency. The 10 most used Lean construction practices are presented in figure 16.

Lean Construction Practices	Number of articles with evidence of implamantation	Ranking
Last Planner System (LPS)	17	1
Just-in- time (JIT),	10	2
Pull Scheduling/Planning	8	3
Visualization tools/management	7	4
Daily clustering/huddle meeting	7	4
Concurrent Engineering (CE)	7	4
Teamwork and partnering	6	5
Value Based Management/Value Streaming Mapping (VBM/VSM)	6	5
Total Quality Management (TQM)	6	5
Virtual Design Construction (VDC)	6	5

Figure 16. Lean construction practices and tools (Babalola, Ibem, and Ezema 2019).

Powell et al. (2014) came up with ten new principles based on principles from Lean manufacturing, Lean construction and Lean product development, that should enable ETO-companies operational excellence.

1. Defining Stakeholder Value
2. Leadership, People and Learning
3. Flexibility
4. Modularization
5. Continuous Process Flow
6. Demand Pull
7. Stakeholder- and Systems Integration
8. Transparency

9. Technology
10. Continuous Improvement

The new set of principles are defined based on the differences between manufacturing and ETO manufacturing and are supposed to provide better guidance of the most important Lean aspects in ETO. The principles are built upon original Lean principles from Womack and Jones (2003) but have required several adjustments as ETO differs from manufacturing. It is especially the level of uncertainty and variation in ETO compared to manufacturing that require another approach through flexibility and modulization. Compared to manufacturing, ETO projects have several participants and require more attention to transparency and integration, and further focus on delivering value to all stakeholders, instead of just the customer. The use of concurrent engineering as a strategy to achieve continuous process flow has also become a known strategy in ETO projects and are used to improve lead-time and pull the product through an integrated value chain more efficiently.

2.4.3 Concurrent engineering

Concurrent engineering is a production strategy used to reduce product development time and production lead time (figure 17). The strategy has gotten attention from the construction industry that wants to explore the advantages of the strategy by implementing it in ETO-projects (Ahmad et al. 2016). Concurrent engineering has several definitions, but the most used is the definition given by the Institute for Defense Analysis in the USA: "*Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements*" (Pennell and Winner 1989, p.11).

According to Anumba and Kamara (2012) concurrent engineering embodies two key principles:

1. Integration here is in relation to the process and content of information and knowledge, between and within project stages, and of all technologies and tools used in the product development process. Integrated concurrent design also involves

upfront requirements analysis by multidisciplinary teams and early consideration of all lifecycle issues affecting a product.

2. Concurrency is determined by the way tasks are scheduled and the interactions between different actors (people and tools) in the product development process

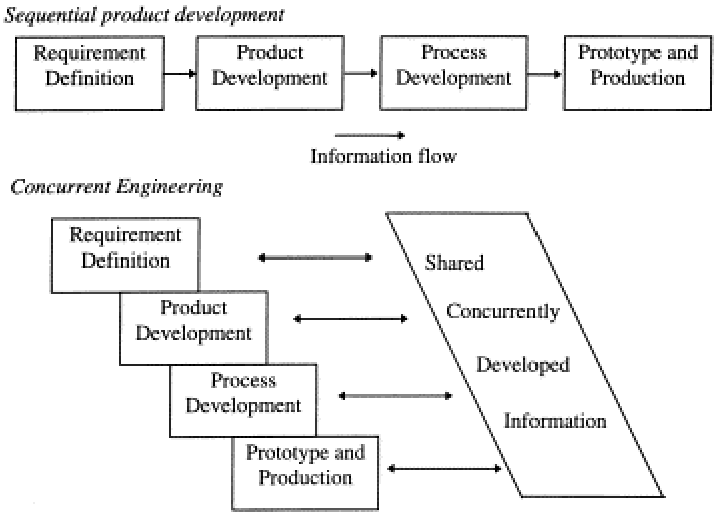


Figure 17. Concurrent engineering practices and prospects (Pennell and Winner 1989)

Concurrent engineering has still not managed to become a successful strategy in the construction industry, much because of the missing involvement from the contractors, subcontractors, suppliers and operators in early phases of the project. While the role of the owner further requires to be extended to the operational level to be able to integrate the planning and coordination with the contractors, subcontractors and supplier (Zidane et al. 2015). As integration is one of the two key principles in concurrent engineering (Anumba and Kamara 2012), the integration between the owner, contractor and suppliers need to happen within the early stage of the project and be a part of it throughout the project life cycle stages. First then will the concurrent engineering strategy work optimally. By improving integration, information, planning and knowledge transferred through the phases can concurrent work run efficiently. The second key principle in concurrency concerns how the different participants communicate, and planning and scheduling of tasks (Zidane et al. 2015).

A challenge with using concurrent engineering is the difficulty of synchronizing design and engineering processes with production and installation processes, resulting in inefficient processes between the different parts of the project. Coordination is a significant difficulty in construction ETO-projects involving several actors and interdependent processes. A research conducted by Zidane et al. (2015) looks at the most common reasons to why delays occur and extends a projects life cycle or makes the project slower than planned. Findings from a survey conducted in the Norwegian construction industry gave the following 10 reasons to why projects are going slower than planned (figure 18).

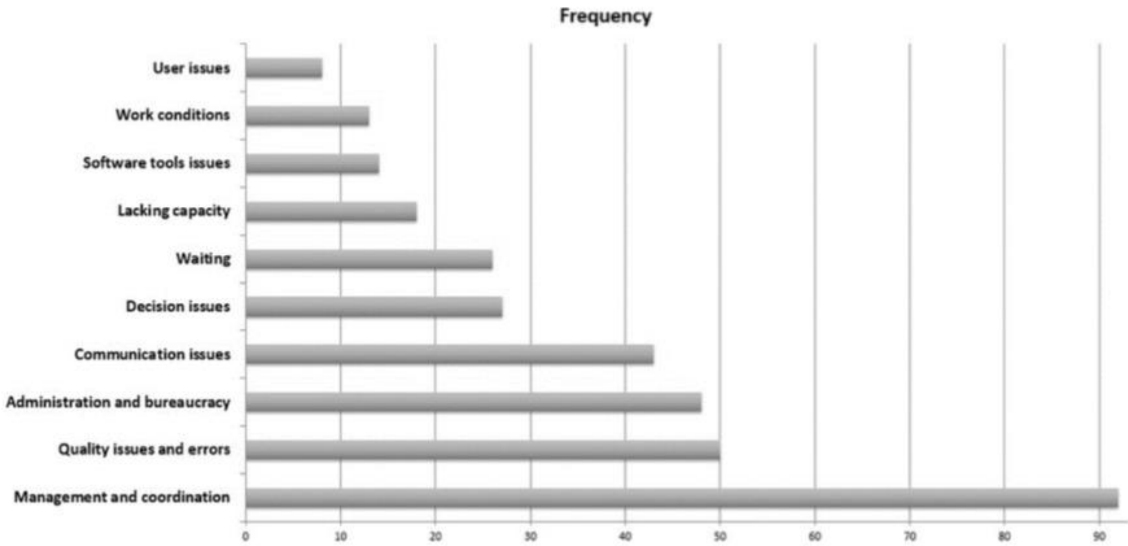


Figure 18. 10 largest time thieves in Norwegian construction projects (Zidane et al. 2015).

Management and coordination are the most common reason for the extension of project life cycles and are therefore also an important area to focus on to be able to reduce project lead-time. The result also supports the difficulties of optimal use of concurrent engineering as a time reducing strategy in construction. Management and coordination, was in the survey a sum of five different subgroups: rush work, unstructured colleagues, unstructured meetings, unclear demands from the management team and poor interdisciplinary coordination (Zidane et al. 2015). Examples on inefficiencies due to difficulties in coordinating different departments (engineering, production and installation) in ETO projects can be:

- Manufacturing is producing parts that are not required on-site, while installation do not get the right parts and must stop the whole installation process while waiting on production
- Manufacturing can not start their work since they are waiting for technical information (drawings) from engineering.

Both examples are different forms of waste that must be eliminated to improve customer value and can be achieved by improving planning and control between the different areas in ETO projects (Rauch, Dallasega, and Matt 2015).

2.5 Engineering

Engineering processes differ from manufacturing processes in several ways. Firstly, engineering activities are performed at the end of the product development phase where the finished product is still not known. The uncertainty in this phase is at a higher level, compared to manufacturing where the processes are characterized as more standardized and repetitive processes. Engineering activities on the other hand, is unique with a higher degree of customization and variation. Another significant difference is the physical material flow in manufacturing processes, while it is a flow of information in engineering (figure 19) (McManus 2005).

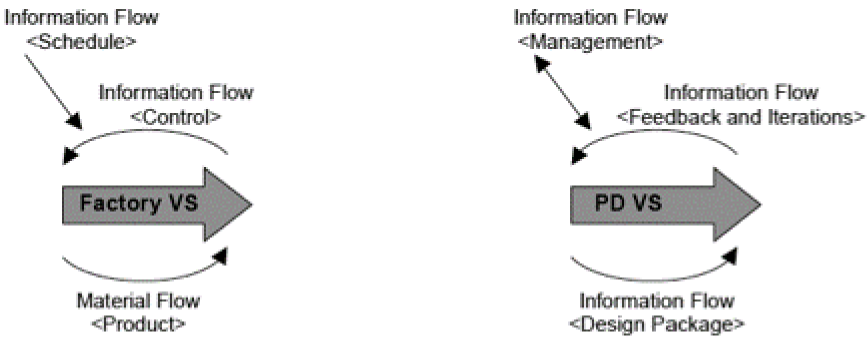


Figure 19. Difference between factory flow and design flow (McManus 2005).

2.5.1 Value in engineering activities

Defining value in engineering activities has proven to be challenging due to its characteristics of processing information rather than physical changes to a product as in manufacturing. According to McManus (2005), the value must be understood within two different contexts. Firstly, is it essential to look at the whole process and see if the process provides value to the stakeholders. Secondly, if it provides value can the value during the execution of the process be further defined at a more detailed level within the process to differ between value-adding activities and non-value-adding activities. Examples of engineering outputs are: (Rauch, Dallasega, and Matt 2015):

- Bill of material (BOM)
- Shop floor drawings for manufacturing
- Working plans for manufacturing

- Installation instructions for installation on-site
- Technical drawings and specifications for purchasing
- Due dates for manufacturing or purchasing
- Selection of processing technology.

The definition of value can be decided by if an activity contributes with the function, form or fit of the material form that is consistent with the stakeholder requirements. Activities that not contribute value, are defined as necessary or unnecessary waste. Compared to manufacturing, this function-form-fit metaphor is not suitable to use when mapping engineering and product development activities. There are two reasons for that (McManus 2005):

- The flow in and out of detailed engineering and product development activities is difficult to see as it does not consist of physical material that is processed.
- A key aspect of information in these activities is uncertainty, including the risk that the product not will meet the customer requirements.

These characteristics make it challenging to measure value adding activities in engineering and product development, compared to manufacturing which additionally has not been getting the same attention. A survey conducted on engineer members of Lean Aerospace Initiative (a consortium of aerospace companies and the US Airforce) were asked to assess how much of their work time was spent on value adding activities. The work was divided into three different categories: value adding, non-value adding but required, and pure waste. The result of the survey (figure 20) shows that only 31% of the time was used to value-adding activities, while 40% was characterized as pure waste. These results show an alarming picture of the potential waste in engineering departments and the potential opportunities in eliminating the waste to a lower share (McManus 2005).

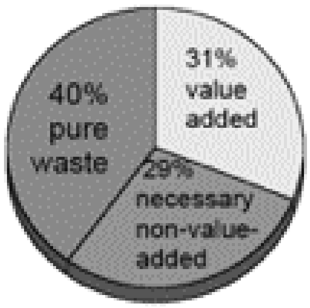


Figure 20. Value assessment of Aerospace engineering activities (as % of charged hours)(McManus 2005).

Engineering plays an essential part in ETO projects with a concurrent engineering approach where engineering, fabrication and installation processes must be coordinated to achieve short lead-time. If processes are not well coordinated, installation can for example experience delays due to missing parts on-site from fabrication, which fabrications again can not produce them due to missing technical specifications and drawings from the engineering department. Lack of coordination can occur from unsynchronized work schedules for fabrication and installation (Rauch, Dallasega, and Matt 2015).

Engineering changes are a considerable challenge in ETO projects because it can result in significant costs and potential delays of a project. Changes happens due to the design and engineering uncertainty that follows a project from the planning phase until production. Uncertainty in design and engineering activities generates uncertainty in drawings and technical details, which further leads to continuously adjustments in the project plan. With continuously adjustments to a project plan, the complexity of planning procurement and production also increasing drastically (Vaagen, Kaut, and Wallace 2017). Iakymenko et al. (2018) illustrates the differences by comparing the automotive industry operating with an MTS strategy with the shipbuilding industry operating with an ETO manufacturing strategy. Changes in car interior under the production of a car can be changed in batch sizes. Meaning that the production batch has the opportunity to use procured material before implementing new changes in the next batch, as shown in figure 21, while engineering changes in the shipbuilding industry must be implemented on the existing customer order. This results in a various degree of complication of the project and can thereby result in an increased amount of rework and a considerable increase in project cost and time (Iakymenko et al. 2018).

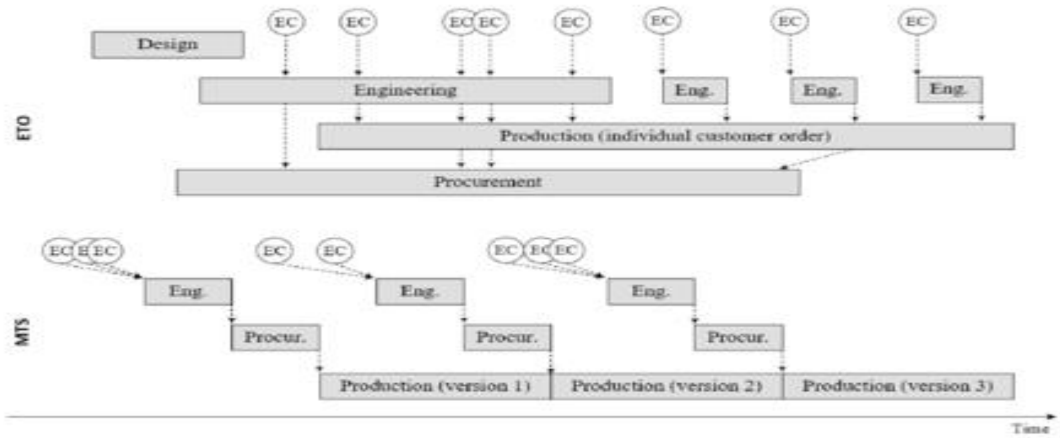


Figure 21. Engineering changes in ETO compared to MTS production (Iakymenko et al. 2018).

Hamraz, Caldwell, and Clarkson (2013) describe engineering changes as changes and/or modifications to completed and released drawings/documentation regarding structural, behavioral or functional artefacts, or the relationship between behavior and functions, or behavior and structure. Such changes can be initiated based on new requirements from customers, the company's management or internal departments, suppliers, partners, governmental restrictions and changes in market drivers such as technology (Iakymenko et al. 2018). Additionally, Strandhagen et al. (2018) points out that changes can be requested from designers, manufacturing department or the procurement department.

A case study conducted by Strandhagen et al. (2018) on a Norwegian ETO company looks at ways to reduce lead-time by implementing Lean. It uncovered several challenges in the engineering processes linked to changes. To gain successful engineering of a product is it essential to achieve an efficient flow of information when a change occurs. Changes in engineering is common and can potentially improve customer value by adding new and better solutions to the product. The case study uncovered a lack of internal quality checks and routines for handling, tracking and investigating engineering changes. To improve such challenges, Strandhagen et al. (2018) suggest to implement quality checks at different stages throughout the process to detect errors at an earlier stage and avoid rework. The further down in the value stream an error is detected, the bigger is usually the problem. Additionally, is it necessary to look at the reason to why the errors occur. One measure to achieve an overview is to implement engineering change management to gain continuous improvements. The occurrence of delays due to engineering changes is a significant problem in ETO projects, resulting in increased lead-time and costs. The amount of changes is affected by the uncertainty of the project, and the high uncertainty is a considerable reason to why engineering changes and delays occur in large ETO projects (Haji-Kazemi et al. 2015). In a study of shipbuilding projects, Mello (2015) locate the following uncertainties (table 2).

Table 2. Uncertainty elements of ETO-projects (Mello 2015).

Uncertainty elements	Relevant stage
Product changes after the production process starts	**Manufacturing and assembly**
Delay in delivering the detailed engineering drawings	**Engineering**
Occurrence of unpredictable events	**Whole life cycle**
High number of quality problems	**Engineering, manufacturing**
Self-over-evaluation of partners on their skills	**Concept design, engineering**
Delay to deliver equipment	**Procurement**
Poor quality of design alternatives	**Concept design**
Poor risk management	**Project planning and detailed design**
Inadequacy of supplier competence	**Procurement**

Even though several of the uncertainty elements are not directly linked to engineering activities, the degree of interdependence between internal departments usually affects each other. According to Haji-Kazemi et al. (2015) can critical changes in ETO-project most probably be discovered under the design and engineering phase as described in figure 22, and be solved in this phase before manufacturing begins. To manage the reaction of early warnings of potential critical changes is it vital to have good communication with suppliers, manufacturing and designers, and be able to find suitable solutions and handle changes as efficiently as possible. Further, Haji-Kazemi et al. (2015) explain the challenges with locating early warnings and react on them when the project is using concurrent engineering because the time to respond to the warnings are significantly reduced. Even when project phases are moving concurrently is it possible to act on potential changes and warnings. The potential is even higher under these circumstances as several processes are conducted simultaneously (Haji-Kazemi et al. 2015).

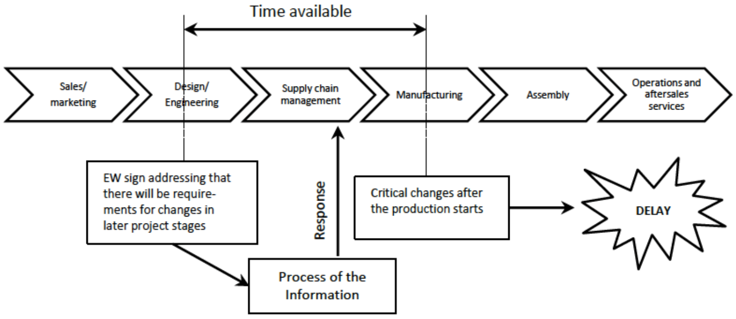


Figure 22. Identification of early warning signs within a shipbuilding project (Haji-Kazemi et al. 2015)

To cope with the coordination challenges, Rauch, Dallasega, and Matt (2015) propose implementing LPS as a tool to enhance efficient planning and control of a project. Cannas et al. (2018) on the other hand, suggest using project requirement planning with Lean management tools to improve coordination between engineering, fabrication and installation. Rauch, Dallasega, and Matt (2015) further state that the value of implementing Lean practices allow different departments in the company (engineering, fabrication and installation) to be more involved throughout the process, improved coordination by informing each department about activity status, identifying possible problems at an early stage and come up with solutions faster. Babalola, Ibem, and Ezema (2019) have conducted a systematic review of published literature about Lean construction and Lean practices that have been implemented successfully and had a positive return. In the systematic review the most common tool was LPS, while in engineering activities (figure 23), concurrent engineering and virtual design construction were the most used tools that could refer to positive effect after implementation.

Lean Construction Practices	Number of articles with evidence of implemantation	Ranking
Concurrent Engineering (CE)	7	1
Virtual Design Construction (VDC)	6	2
Standardization	2	3
Target Value Design (TVD)	2	4
Design Workshop or Big Room	2	5
Prefabrication and Modularization	2	6
Design Structure Matrix (DSM)	2	7
Detailed Briefing	1	8
Integrated Project Delivery	1	9

Figure 23. Lean construction practices (Babalola, Ibem, and Ezema 2019).

2.5.2 Lean engineering

McManus (2005) describe three goals in Lean engineering within three different areas of process improvement where each goal is essential to reduce waste in engineering processes. The goals are:

- *Creating the right products.* Creating product architectures, families, and designs that increase value for all enterprise stakeholders.
- Effective lifecycle and enterprise integration using Lean engineering to create value throughout the product lifecycle and the enterprise.
- *Efficient engineering processes.* Applying Lean thinking to eliminate wastes and improve cycle time and quality in engineering.

The last goal, *efficient engineering processes*, can be achieved using value stream mapping, a sufficient tool to map out the engineering processes and eliminate waste by improving the flow throughout the processes (McManus 2005).

2.5.3 Waste in engineering

McManus (2005) states that the value stream in engineering differs from manufacturing because the flow consists of information flow and knowledge rather than physical material flow. He uses the same seven types of waste as defined by Womack and Jones, but re-defines the meaning seen from an information flow perspective. The types of wastes within information flow are defined in the table below (table 3) (McManus 2005).

Table 3. Types of Information Waste (McManus, 2005)

Types of Information Waste	Examples	Causes
Waiting *Idle time due to unavailable information*	People waiting for information	• Lack of access • Untimely updating of data bases • Multiple approvals • Poorly designed or executed process to provide information
	Information waiting for people	• Information created too soon may be obsolete by the time it is used
Inventory *Information that is unused or is "work in progress"*	Too much information	• Poor understanding of user needs
	Multiple/redundant sources	• Tendency for everybody to maintain their own files
	Outdated/obsolete information	• Lack of "version control" • Lack of disciplined system for updating new and purging old information • Inadequate archiving standards or practices
	"Just-in-case" information	• Collection, processing and storage of every element of data that process participants can think of, whether or not a specific end use has been identified
Excessive Processing *Information processing beyond requirements*	Excessive/custom formatting	• Lack of standardization
	Numerous, fragmented reports	• Poor output design • Lack of understanding of the needs of the users of process outputs
	Unnecessary serial processing	• Poor system design • Lack of understanding of concurrent processing capabilities
	Excessive approvals for information release	• Stove pipe, command and control mentality • Turf protection
Over Production *Producing, distributing more information than needed*	Unnecessary detail and accuracy	• Tendency to "over-design" • More detail than necessary in early design
	Pushing, not pulling data, information	• Uncontrolled process
	Over-dissemination	• Poor understanding of each participant's needs • "Send all information to everyone," rather than to meet specific needs

Types of Information Waste	Examples	Causes
Transportation *Unnecessary movement of information between people, organizations, or systems*	Information handled by multiple people before arriving at user	• Lack of direct access due to IT system limits, organizational inefficiencies, knowledge hoarding, security issues
	Information hunting	• Lack of clear information flow paths, failure of process to produce information needed
	Data re-formatting or reentry	• Incompatible information types (drawings *vs.* digital descriptions) • Incompatible software systems or tools • Lack of availability, knowledge, or training in conversion and linking systems
	Switching computers (e.g., CAD to PC) to access information	• Software/hardware incompatibilities • IS support
Unnecessary Motion *Unnecessary human movement (physical or user movement between tools or system)*	Walking to information, retrieving printed materials	• Lack of distributed, direct access • Lack of on-line access • Lack of digital versions of heritage information
	Excessive keyboard, mouse operations	• Lack of training • Poorly designed user interfaces • Incompatible software suites • Too much information to sort through
	Poor physical arrangement or organization	• Team members not co-located • Organization structure inhibits formation of right teams
Defects *Erroneous data, information, reports*	Errors in data reporting/entries	• Human error • Poorly designed input templates
	Errors in information provided to customers	• Lack of disciplined reviews, tests, verification
	Information does not make sense to user	• Raw data delivered when user needs derived information, recommendations, or decisions

2.6 Summary of theory

The theoretical framework describes the fundamentals of Lean theory and how the theory has been implemented in manufacturing with the overall goal to achieve the highest quality, lowest cost, and shortest lead-time by continuously eliminating waste.

Further, Lean has been implemented in other industries, such as the construction industry, where Lean theory has been developed into Lean construction. The construction industry differs from manufacturing in several ways but can also benefit from the elimination of waste with the help of Lean principles. The most used tool in Lean construction is LPS, a planning and coordination tool developed to improve project planning of complex construction projects. Lean has also been presented to the shipbuilding industry that has several similarities to the construction industry. Both industries differ from manufacturing in several ways and are further described in the ETO part of the theoretical framework. ETO projects have a more substantial degree of complexity and variation, making project planning and control increasingly more difficult.

3.0 Research design

The research is conducted to answer a specific research question, where the research design works as an overall plan for the research. The research design can further be described as a framework for how the data will be collected, what type of data and how it will be processed (Ghauri and Grønhaug 2005). The purpose of the research is defined by the research question and can be exploratory, explanatory or descriptive. Exploratory research aims to explore topics and problems where the goal is to get a better understanding. Explanatory research focuses on explaining the relationship between two or several variables, while descriptive research describes an accurate profile of a person, event or situation (Saunders, Lewis, and Thornhill 2012). This research study has a descriptive approach focusing on exploring Lean project planning and control principles and how it may improve customer value by reducing waste.

3.1 Case Study

The research is conducted based on a case study, that is the preferred approach when the research aims to get a better understanding of the context and the processes in the study. Yin (2009) highlights the opportunities of generating answers to questions as “why?”, “what?” and “how?”, and are therefore often used in explanatory, exploratory and descriptive research. Primary data in case studies are usually collected through verbal reports, personal interviews and observations, while secondary data is collected through financial reports, budgets, archives of production and project reports and so on. Primary data is original data collected to specifically answer the research question, while secondary data is data collected for other purposes by others (Ghauri and Grønhaug 2005). The research in this case is conducted as a single case due to the limitation of time and resources in the study, and it is therefore vital to be critical to the data. Saunders, Lewis, and Thornhill (2012) underlines the importance of using multiple sources of data called triangulation. This technique is using several data sources to improve the quality of the research.

3.2 Data Collection

Before starting the data collection, is it important to decide if the case study will be based on either quantitative or qualitative data (Saunders, Lewis, and Thornhill 2012).

Quantitative is numerical data that often is given as raw data that is required to be processed and analyzed before it is possible to understand the data. The data needs to be categorized and linked to different variables before the data can be readable and the researcher can look at the relationship between the variables. After the data is analyzed, the results are often represented through graphs, charts and tables, and then linked to theories and used to answer the research question. Research strategies for quantitative data are associated with experimental and survey research methods where the goal is to collect standardized data from a larger group (Saunders, Lewis, and Thornhill 2012).

Qualitative data is non-numerical or standardized data and requires a higher degree of interoperation of the data to make sense of the subjective and social meanings that are expressed. The data is gathered through different techniques such as interviews, observations and focus groups where the researcher must interpret the meaning of the gathered data. It is essential to sustain the content of the data since the meaning of words can be interpreted in different ways (Saunders, Lewis, and Thornhill 2012).

According to Yin (2009) there are primarily six different sources used to collect data in case studies. He further applies the importance of multiple sources to improve the validity of the case study, a case study database with all the data and a chain of evidence, containing a red line connecting the research question to the data collected and the conclusion of the research. These three steps are crucial to delivering a high-quality case study and are also relevant for each of the six sources of data. The six data sources are (Yin 2009):

1. Documentation can be a vital source of data and is likely to be relevant in a case study to retrieve information. The documentation can be gathered in different types and forms as letters, agendas, announcements, minutes of meetings, administrative documents or newspapers. The different type of documentation is produced for another purpose than what the case study is researching and is therefore characterized as secondary data. Documents must be carefully handled since the validity and reliability of the documents can be poor and should instead be used to corroborate and argue evidence from other sources.
2. Archival records can in many case studies be relevant and are often presented as data files and records, for example: Service records, organizational records, list of names and products, survey data and personal records. These type records are often used in

quantitative analysis and can be used in conjunction with other sources of data to answer the research question in a case study.

3. Interviews are presented as one of the most essential sources in a case study where the researcher can retrieve information from several people with different positions at the case site. The interview is a guided conversation with the ability to get a broader understanding of the research field. Another reason to why interviews are so important in case studies is that they often concern people and human affairs and should therefore be interpreted through observation to gain a greater insight into the situation.
4. Direct observations are often an effective opportunity to get a better understanding of the case study site and the processes that are researched. The formality of the research varies from formal observations where observations are done constantly, and workers can be measured in different processes. While less formal observation can be done throughout a day just to get a better understanding of the subject that is researched.
5. Participant-observation is a type of observation where the researcher is taking a more active part and participates in the processes or the activities that are researched. This data collection method is often used in anthropological case studies to get a better insight into different cultural and social groups.
6. Physical artifacts can be used to gather specific information from the use of a technological device or a tool to gain a better understanding of the use of the physical artifact.

In this thesis, most of the data is qualitative, gathered mainly from interviews, while the rest is quantitative data from archival records to supplement the qualitative data. The interviews can further be characterized as primary data, meaning that the data are collected for the purpose to answer the research questions in this specific thesis. The rest of the collected data is characterized as secondary data, meaning that it has been gathered for another purpose, but is still relevant for this research. The purpose of this paper is to investigate the opportunities of Lean project planning and control, and how these tools can increase customer value and reduce waste. As part of describing the possibilities of implementing Lean tools, has this thesis also been focusing on describing the characteristics and sources of waste in the detail engineering department.

The first part of the data collection was a broad literature search done to get a better understanding of the research theme. According to Yin (2009), a literature review has two primary purposes. First, it shows that the author has researched the topics of the study and the literature review also highlights the importance of the research and support the findings of new research. The literature search was divided into two parts, where the first part was about Lean, while the second concerned ETO theory. The information found in this literature search was used in describing the research that already has been conducted on the area.

After conducting the literature search on how to locate waste in engineering activities, VSM was chosen as the most suitable approach to locate waste in the detail engineering department. The value stream in engineering activities differs from production by being an information flow instead of a material flow, requiring a different approach to be able to make a VSM. A method developed by McManus (2005) to VSM engineering activities was adapted to suit the research area of the thesis. The first step in the VSM approach was to get an overview of the processes in the department and each of the six data sources that Yin (2009) presents above was assessed based on which method that was the most suitable for the purpose. Since interviews are presented as one of the most essential sources in a case study, it seemed natural to start with an interview to get a better overview of the detail engineering department and all the process that are conducted within the department. Through interviews could the information be adapted in a way, so the authors would understand the technical processes in the department and ask clarification of technical terms.

Unfortunately, in the early stage of the first meeting with the case company, after getting a better overview of the processes, it became clear that it would be challenging to conduct VSM over the whole engineering department. The number of processes that were done simultaneously in the same area would make the mapping extremely complex and difficult. In order to be able to do VSM within the time and resource limits for the research, it had to be done a limitation from the entire department to just a minor part of the detail engineering department. On the other hand, the case company would like to locate waste in the entire department and was not interested in downsizing the research area. A new approach was then adapted by focusing on several similarities to the VSM, but at a higher organizational level. The new strategy was to understand how the case company operate and how waste occur in detail engineering, and then use Lean theory to investigate if Lean project planning and control could help increase customer value.

3.2.1 Interviews

In case studies, interviews are one of the most important data sources and are especially helpful when trying to get an overview of the situation. When conducting interviews under case studies, the interview is often open-ended as an in-depth interview where the interviewer hopes to get a guided conversation with the interviewee (Yin 2009).

Our interviews were organized in two rounds where the first round (appendix 9.1) was conducted as a guided conversation where questions gave the opportunity to be more flexible. The purpose of this interview was to get answers on how the department operated and how project planning and control activities were used today. "How" questions were used to make the conversation run easy and the interviewee could talk openly about how they worked. When more information was preferred, follow-up questions were added. Yin (2009) underlines the advantage of using the same interview questions to several persons as the answers could verify specific findings, but also locate differences in the answers from the respondents. The second interview (appendix 9.2) was a semi-structured interview where questions were developed based on the information gathered from the first interview. The interview was in this case much stronger guided but was still a conversation there the correspondent could answer the questions easily. All questions were designed in such a way that they were not leading or too direct so that the interviewee did not feel uncomfortable, but at the same time clear enough that it could provide a reasonable basis for comparison.

3.2.2 Survey

To control the data collected through interviews, a survey was conducted (appendix 9.2.1) on the case company department to look at the correspondence between the employees. Data collection with a survey gives the opportunity to have many participants and generate structural answers that can provide quantitative data for analysis. Initially in the survey, respondents were categorized based on their position and working division. The respondents further answered a set of ten questions regarding challenges by rating each statement from 1-5 based on personal perception. Half of the permanent employees (23 of 50) working at the department answered the survey, which was enough to generate tables and compare the divisions up against each other. Yin (2009) recommends using several data sources to strengthen data collection when conducting a case study.

3.3 Validity and reliability

The quality of the data collection is an important aspect that requires it to be considered to ensure the quality of the research. The quality of the research is measured in terms of validity and reliability and can be especially challenging in qualitative research studies. Validity describes to which extent the data collection method accurately measures what it is intended to measure, and in which degree the research findings are consistent with the research method. Reliability describes to which extent the data collection technique can provide consistent findings and the same conclusion would be made if the same research under the same conditions was conducted several times (Saunders, Lewis, and Thornhill 2012).

The validity in qualitative research studies can be challenging, due to several variables that affect the data collection. The use of triangulation of the findings by conducting several data collections methods can be used to crosscheck the findings and strengthen the validity (Yin 2009). In this thesis where the primary data source has been interviews, was it essential to be critical to the data gathered during these interviews. To improve the validity of the data was standardized interviews conducted with the same main questions to be able to compare the answers. Each interview round contained three interviews with representatives from different divisions, as well as persons with different roles within each division. Additionally, a survey was used as a secondary data source to validate the findings from the interviews.

Reliability describes to which degree the study can be replicated and come up with the same results. In qualitative studies, is it more challenging to replicate the study, as the research approach is not standardized, and it is almost impossible to conduct a replication of the data collection. This is because the author plays an essential role in the data collection that can affect the research (Bryman 2015).

4.0 Case description

In this chapter, we give a brief introduction and description of Ulstein Group ASA, as well as Ulstein Shipyard (US) which is the case company. The department of interest for this paper is detail engineering, and today's planning situation to which the reader will have an overall understanding of the case. Information in this chapter is mainly based on interviews, but also taken from Ulstein Group ASA online website.

4.1 Ulstein Group ASA

Ulstein Group ASA is a family-owned company, originally founded as Ulstein Mekaniske Verksted ASA in 1917. The company is a parent company for a group of maritime companies shown in figure 24. They are all specialized in ship design, shipbuilding, maritime solutions, shipping, and power and control. However, Ulstein Groups primary business operation is shipbuilding. Ulstein Group ASA focus primarily on business development across the business structure and operate from offices in six countries in addition to the headquarter located in Ulsteinvik (Ulstein.com 2018). This case focuses on the shipbuilding segment and specifically on US.

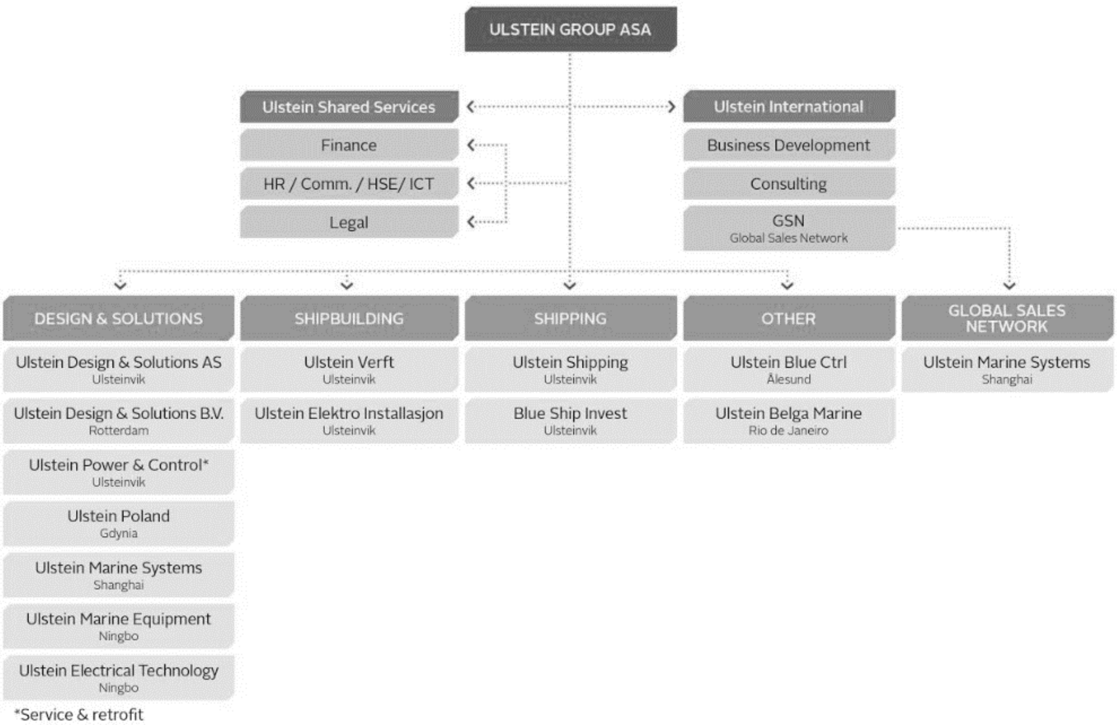


Figure 24. Overview over Ulstein Group ASA (Internal document provided by Ulstein Shipyard)

4.2 Ulstein Shipyard (US)

US is a part of the maritime cluster in Møre og Romsdal, known for their highly advanced production of ships and maritime equipment. US deliver special purpose vessels designed with high quality and specialized for harsh environments. Their unique ship design, known as the X-Bow, is a patent solution making the ships more approachable for harsh weather conditions. For a long time, the company delivered mainly different types of service vessels including offshore support, offshore construction, seismic, cable-lay, anchor handling, tug supply, and research vessels. Previously, the oil sector has been their most important customer base, but after the oil crisis in 2014, the company decided to look for new segments (Ulstein.com 2018). Over the last few years, they have therefore moved into new market segments and today they deliver service vessels to the offshore wind market, along with cruise ships, expedition ships, RoPax vessels and yachts.

4.2.1 Lean at Ulstein Shipyard

US has taken an active part in the Lean shipbuilding program, a collaboration with Møreforskning and Molde University College to exploit the possibilities of implementing Lean in shipbuilding. The program started in 2006 and resulted in a guideline system called Quality in Ulstein – Shipbuilding. The research developed into several projects, intending to increase the efficiency by customizing Lean manufacturing principles and tools to suit the shipbuilding industry (Oterhals and Guvåg 2016). Back in 2007, US started the implementation of LPS in production. However, US has never explored the use of Lean principles in the detail engineering department.

4.2.2 Initiating a new project

The beginning of a new project starts with a presale, before checking the capacity. Followed by the design process, estimations and calculations, before negotiations and finally signing of a contract. A milestone plan is conducted by the planning department. Further, the project is handed over from sales department to an established project organization to review the project and hold a kick-off meeting to ensure an overall understanding of the general arrangement and vessel specifications among all project participants. A typical organization chart is visually illustrated below (figure 25).

Figure 25. Organization Chart from Ulstein Shipyard (internal document provided by Ulstein Shipyard)

4.2.3 Ulstein Shipyards value chain

The integration between the different departments at US is highly integrated and dependent on each other, when constructing a new vessel. Already at the presale is sales department interacting with both the customer, design and procurement to retrieve the necessary information to come up with an offer to the customer. When the contract is signed, detail engineering is involved in the process, while the customer stays involved throughout the project interacting with the design company and the shipyard (figure 26).

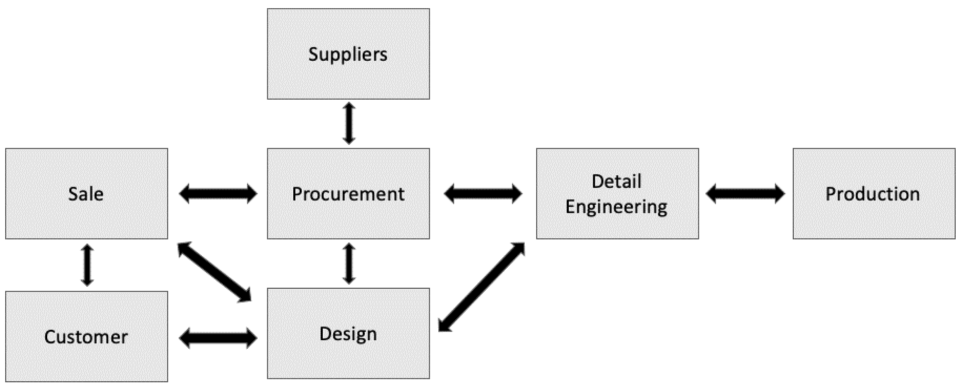


Figure 26. Value chain of Ulstein shipyard

4.2.4 Detail engineering department

The detail engineering department has the responsibility of coordinating and preparing 3D models and drawings on all equipment going on or in the vessel. It is vital to have plans due to the high complexity. A list of drawing deadlines is made as an overall plan for the engineers. In US's case, the engineering department is divided into four specialized divisions (1) *Steel and hull,* (2) *machinery, piping and Heat, Warming and Air Condition (HVAC),* (3) *interior, and* (4) *electronic*.

Each of the specialized divisions is dependent on input from the design and procurement department to start working. They are also involved in the procurement and design process by providing information and recommendation throughout the process. The input processed in detail engineering is information that is transformed into a 3D model that are further sent to production and used as detailed building plans (figure 27).

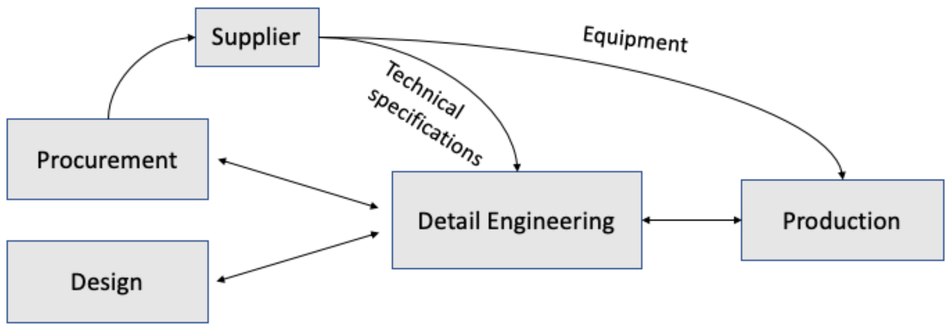


Figure 27. Value chain of detail engineering

To be able to deliver drawings to production, detail engineering is dependent on several steps. First coordinators from each department provide detailed information over expected work hours for each task to engineers. The coordinators also deliver equipment requirements to procurement and initiate the procurement process. When a tendering process is completed in the procurement department. The potential suppliers are presented to both detail engineering and production to come up with the most suitable supplier. At this point, the plan is provided, technical specifications are delivered, and the modeling starts. Information from the designer combined with technical specifications on equipment from suppliers are the primary sources of information to detail engineering. Since design drawings are often delivered in 2D is it a continuous interaction between design and detail engineering as errors occur in the 3D model. While the 3D model is being developed, the production of the hull often starts 2-3 months after project initiation. From this point, engineering and production run concurrently and production is starting to require drawings that are used as building specs for the vessel. By conducting the two processes concurrently, the project lead time is reduced, while the complexity of the project increase.

Figure 28. Structure of detail engineering department

These divisions are highly interdependent and work parallel to decrease the lead-time of each project as depicted in figure 28.

Steel and hull division

Steel and hull are the first detail engineering division that starts working on a new vessel. The division starts with finding a suitable shipyard to produce the hull and a steel supplier with capacity. Today, the production of the hull is outsourced, usually to shipyards in Eastern Europe. Drawing a hull takes longer time than they can refrain. Therefore, they make a batch-plan to which they model one part of the hull at the time in the 3D model. Then, they can transmit documentation to the shipyard for hull production to start. Further, it is essential to work closely with internal divisions because the weight and placement of heavy machinery must be taken into consideration to finish the support structure of the vessel. *Steel and hull* are also responsible for modeling the exterior of the vessel, the wheelhouse and poles.

Machinery, pipes and HVAC division

Machinery, piping and HVAC division mainly start by initiating a need to the procurement department so that they can send out requests to potential suppliers. Then, two technical coordinators are chosen – one for machinery and one for piping and HVAC. These coordinate a chosen team of engineers. Technical coordinator and engineers cooperate with the procurement department to decide on suppliers because of their technical understanding. After completing the requesting process and choosing and signing a contract with a supplier, they can use the information about the equipment to model it into the commonly used 3D model. Additionally, it also necessary to communicate information to both *hull and steel* regarding placement of heavy machinery that must be taken into consideration regarding structure, and *electrical* regarding the need for power to machinery and pipes. This is important for the other divisions to complete their job right as soon as possible.

Interior division

The *interior* division is responsible for onboard interior and cooperates with external companies such as R&M to achieve interior perfectionism. This is because of the high level of customization regarding interior required on vessels like cruise, RoPax and yachts.

Electrical division

The *electrical* division is responsible for power distribution from generators on the vessel. They are responsible for steering systems such as communication systems and navigation systems. Additionally, they are accountable for alarm systems, light and sound systems or other specific systems addressed in the general arrangement. They are responsible for surveillance of all existing electrical systems aboard the vessel. Typically, they start by purchasing essential equipment before starting the 3D modeling process of cables and cable trays all through. After completing the modeling of cables, they transmit documentation to production to finalize the job. At this point they use time on supporting and supervising production workers, correcting eventual errors and finally testing. The last work that must be conducted is a final handover documentation from the *electrical* division. As the *electrical* division is the last one to complete a project, they often experience short deadlines due to challenges and delays from earlier phases in the project.

4.2.5 Computer-aided design

All drawings used in production are retrieved from a 3D model of the vessel that is built by the detail engineering department. Detail engineering is using CAD software to build a virtual 3D model of the vessel that are generating detailed drawings to production that become their building sketches. The 3D model does not just illustrate the details of the vessel, all parts and equipment are also assigned technical specifications. With all technical specifications gathered in one place in the same format, is it easier to find the information required in the modeling process and later in production. The use of CAD in shipbuilding improves design quality, provides higher precision and reduces the risk of errors.

Additionally, it makes it easier to deliver classification drawings and approval reports on: Weight and the center of gravity, bill of material and other details used in calculations (Revista de ingenieria Naval 2016). By modeling in the 3D model before construction of the same area starts in production, changes can be faster taken care of and it is possible to try several approaches to come up with the best solution. At US, vessels are modeled from start to end - the hulls, machinery, equipment, pipes, cable trays, ventilation and so on. The program lets all engineers work on the same platform and connect the different divisions at US together. All modeling is done online, making it possible to work on the 3D model worldwide.

4.2.6 Challenges

US experience a wide range of challenges, many of which gives repercussions. In this thesis, the focus is on existing challenges which are stated below. These challenges are further described in detail in the next chapter.

- Planning
- Resources
- Communication
- Quality control

5.0 Case study findings

In this chapter, findings from the case study data collection described in chapter 3 are presented. The case study intends to look at how Lean project planning and control can be used to improve customer value and reduce waste. The data collection has been carried out in the detail engineering department at US as an extension to a Lean project on how to improve efficiency and reduce waste with the use of Lean principles. Firstly, a short overview of the department is presented to visualize the coordination challenge US stands upon when conducting a project. The findings are presented in two parts: planning and coordination, and communication, quality assurance and control. These are the primary sources of waste and have the highest potential of improving customer value through the elimination of waste.

5.1 Interdependency

The detail engineering process of highly complex vessels is a difficult assignment with several challenges and potential sources of waste. The engineering process is conducted concurrently with procurement and production, where each activity is required to be delivered within a given time limit. Figure 29 show the different participants involved with detail engineering throughout the shipbuilding process, highlighting the need for excellent communication and coordination routines. However, when project planning and coordination is not efficiently carried out, several sources of waste occur.

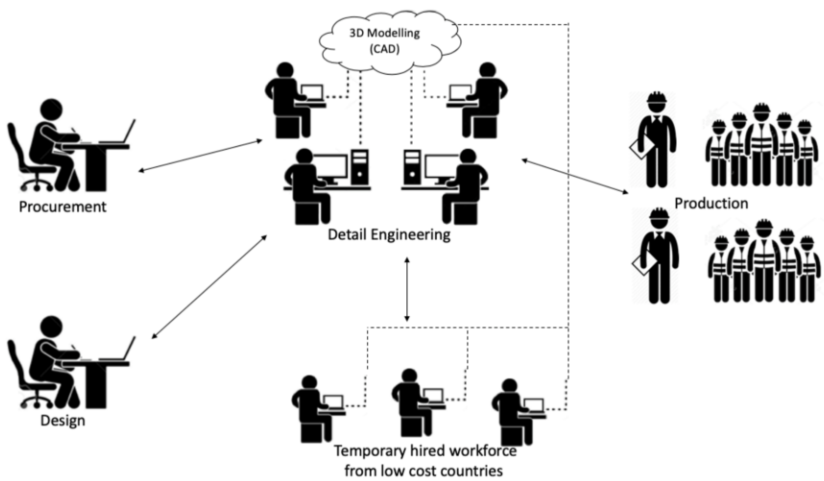


Figure 29. Illustration of detail engineering dependency

5.2 Planning and coordination

US has a planning department who makes a rough plan of a project. The plan is further divided into several phases and contains milestones which are important goals with specific dates, such as "*start burning steel to the hull*" or a fixed date the hull is supposed to be completed. Based on the project plan, coordinators from technical department suggest hourly consumption per task to the planning department. The plan is presented to the coordinators when completed and is further adjusted based on what coordinators believe is feasible to conduct. However, the estimated consumption of hours per task has not been enough to complete tasks. One of the reasons is that US has been introduced to new marked segments with different expectations than previous market (oil and gas industry). Figure 30 illustrates the planned working hours and the extra working hours required to actually complete the engineering of a project. As visualized, each department has exceeded their planned hour consumption to varying degrees. This confirms the planning challenges US is facing and how it affects the lead-time of the project, as the planned hour consumption is one of the variables used to estimate the total project lead time.

Figure 30. Illustration of planned versus the actual time spent.

Customer specifications are agreed upon in the contract between a customer and US. Specifications are listed and are usually between 200-250 pages of detailed information. Such specifications are converted into a drawing list, describing which drawings that are required and what they should contain. The drawing list includes deadlines for drawings/modeling and is the plan for the detail engineering department. The drawing list is uploaded to the planning software and is used by coordinators to distribute tasks to engineers. The planning software is accessible for everyone. An engineer gets the responsibility of several tasks and is assigned the required information from a coordinator to get started with modeling. Each assigned task has a deadline date, making each engineer responsible for making a plan for completing all assigned drawings in time. The planning software used today works well if the engineers have received the required information for completing the task. This includes technical descriptions from suppliers. However, receiving the required information at the right time is presented as a repeating problem throughout the project.

Meetings are held every two weeks where representatives from all departments are present, including all four detail engineering divisions (*hull and steel, machinery, piping and HVAC, interior, and electrical).* The goal of these meetings is to strengthen the coordination between departments and agree upon which upcoming tasks that must be prioritized. They always plan two weeks ahead, and an assessment is made as to whether it is possible to deliver or if there is a need to change the current plan. It is further based on whether all required information is available to be able to carry out the planned tasks. In cases with missing information or constraints that prevent conducting the activities, the activity is postponed by one to two weeks. Since there are constant changes and adjustments to the plan, plans are mainly based on a two-weeks ahead perspective in terms of drawings.

Monthly reporting is also provided to the customer. The project's progress is continuously monitored through the planning software, which shows the drawing list with information about completed tasks and how many tasks that are delayed. This information is used to make decisions on how to resolve delays. Additionally, it can be used to create more detailed reports showing the progress in each of the divisions at detail engineering.

A significant challenge is late commencement of projects. The challenge arises because coordinators and engineers are needed for the completion process on another project, which affects the planning of the new project. This results in late and inaccurate planning, and delays in the drawing process. One of our interviewees emphasize the situations as followed: "*we are not great at starting projects fast, things take too long time in the beginning of a project before we start to experience pressure from construction regarding the need of drawings*".

The start of a project depends on sending out a request to suppliers and getting offers from potential suppliers before coordinators in cooperation with the procurement department decide on a supplier (procurement process). This process can be time-consuming. Technical equipment specifications are a necessity for engineers to start modeling, and because of the importance for engineers to start their job is it important to start the purchasing process as soon as a project is initiated. Further, during an interview, an engineer describes how todays' situation could be improved by, "*better planning of resources, early start and increase workforce early in the project and rather be in front in the beginning than having to catch up at the end. Ensure enough coordinators and 3D modeling engineers, and that we have more pressure in the beginning instead of at the end*".

Late commencement gives repercussions such as short deadlines for engineers to model and/or the need for extra resources. For example, modeling a pump into the 3D model requires the engineer to have the weight, dimensions, and information regarding how much heat it emits and the required power supply. All details are needed before the process of drawing in the 3D software can begin. If the information is not available, the engineer must skip the task and wait. This can cause rework because of missing information. A survey answered by 50 per cent of all permanent engineers in detail engineering indicates that 70 per cent of the information must be requested or is missing necessary information (figure 31, appendix 9.2.2, Q1).

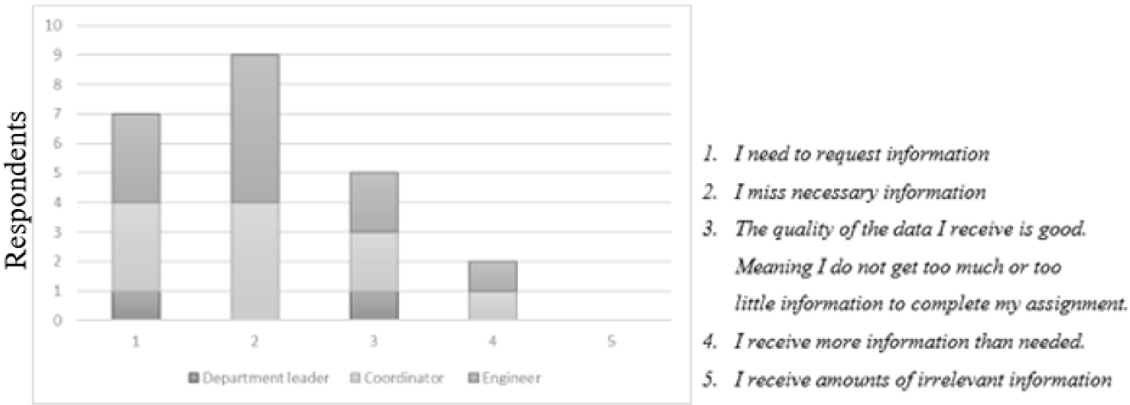


Figure 31. Quality of incoming data (appendix 9.2.2, Q1)

Even though representatives from detail engineering need to request information or request more information because it is inadequate, the received information is still highly relevant. Twenty-one of twenty-three representatives describe the incoming data as advantageous, important or necessary to conduct the activity they are working on (appendix 9.2.2, Q3). How the information is provided also differs. For example, suppliers that US has a strong relationship to and have worked with for several years know exactly what information they need. On the other side, new suppliers tend to send too much information, requiring extra work to retrieve the right information. Extracting the necessary information causes disruption in the workflow and delays the process.

There is a great deal of time-pressure occurring throughout a project. Time-pressure often arise because of the lack of technical specifications or changes to design. Activities are conducted concurrently, meaning that engineers from all divisions (*hull and steel, machinery, piping and HVAC, interior and electrical*) model in the 3D model concurrently while production is ongoing. An employee stated this by saying that "*we 3D model the vessel simultaneously with production. It is not like we draw first and build after*". To be able to use concurrent engineering, the project plan is programed so that drawing go straight to construction when completed. Theoretically, it reduces the lead-time of a project. However, it requires each department to work seamlessly together. This makes US able to significantly reduce the lead-time of a project, which is one of their competitive advantages. In situations when drawings are delivered after the deadline it affects the whole project and increases the time-pressure on the detail engineering department. In cases of time-pressure, repercussions arise. Drawings are completed without necessary information, which often causes errors which again causes rework. Because of the interdependence within the detail engineering department, correcting an error will potentially cause errors or collisions to other engineers completed work which then also must be redone. By collisions, the interviews speak of items in the 3D model that collide and are not feasible to conduct in production.

Work that is planned to be conducted under construction at a foreign shipyard which is not completed due to late delivery of drawings, the discovery of errors or changes can be costly for US. It may be up to ten times as expensive completing the work at a Norwegian shipyard. This is only one part of the process but shows the importance of being on time.

As stated above, delays in the detail engineering process are often caused by lack of required information or it can be caused by high workload compared with the hourly consumption proposed by coordinators planning the project. In periods with too much work compared to permanent employees, detail engineering uses temporary hired workforce from low-cost countries to support the detail engineering department. As the demand in the shipbuilding industry is fluctuating, this is also a way to avoid reducing the workforce in times with less work and holding on to the competence at the shipyard.

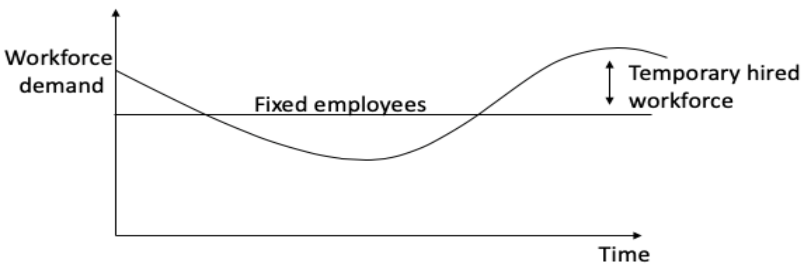
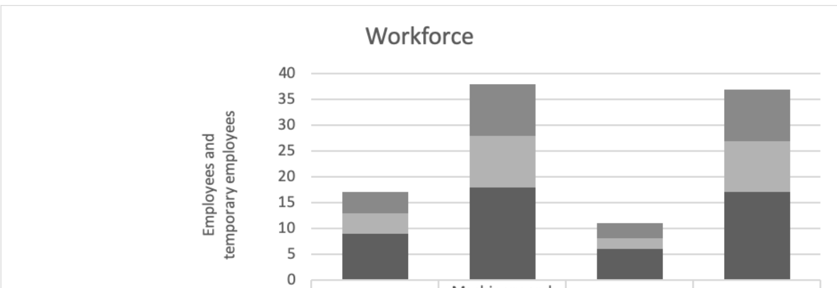


Figure 32. Market demand for resources.

Today, US works on several projects simultaneously which require more workforce then what they have employed (figure 32). This results in a high percentage of temporary resources. Figure 33 illustrates the approximate numbers of employees on a project. In average, approximately 50% of the engineers working on an US project are temporary employed, including engineers working for the company from worldwide offices. The temporarily hired engineers are well educated and have the right competence to do the tasks and support engineers at US. Some of them also have more experience with 3D modeling within the cruise segment than engineers at US.



	Steel and Hull	Machinery and pipes	Inventory	Electro
Maximum temporary workforce over minimum	4	10	3	10
Minimum temporary workforce	4	10	2	10
Hired workforce	9	18	6	17

Figure 33. Overview of the amount of internal versus external resources

However, it varies between departments how big of a challenge they see temporary employees. *Hull and steel division* has over the last ten years been using external resources regularly and has a pool of engineers in Poland that they get in contact with in need of extra resources. *Machinery, piping and HVAC*, and *electrical* on the other side have just over the previous year's needed extra external resources, and therefore they also experience external resources as a more significant challenge. The survey conducted indicates however that all divisions experience working with external workforces as challenging. Figure 34 shows that 82,5% of permanent employees experience working with the external workforce as ineffective or just "okay" (appendix 9.2.2, Q8). On the other hand, 60% answers that working with the permanent workforce are efficient or optimal (appendix 9.2.2, Q9). Even though the survey indicates that external resources are not optimal to work with, do the engineers further state that "*...at the same time, we are on the top part of our limit when it comes to capacity and we have these big projects, there is no other choice*".

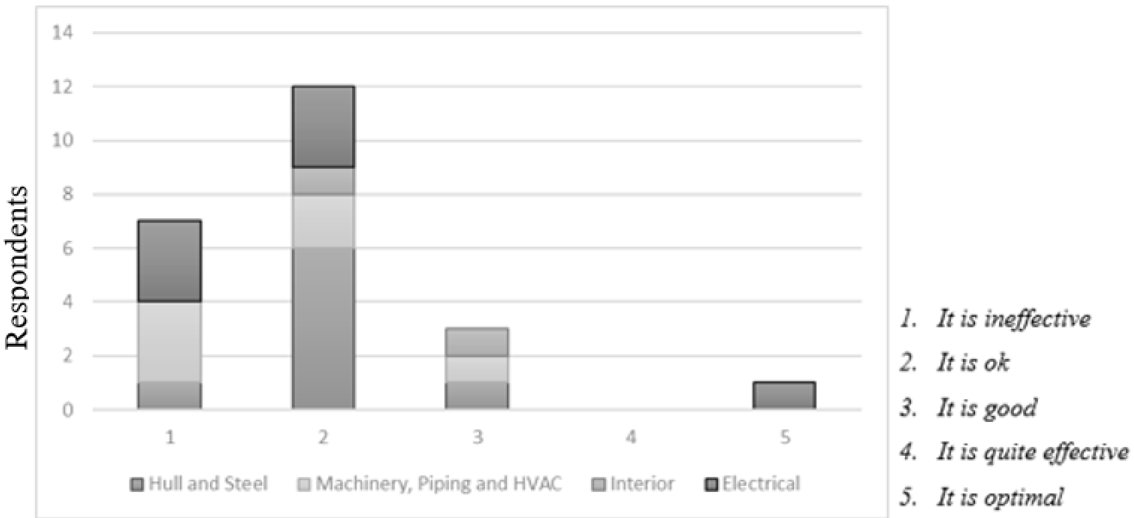


Figure 34.Experience of working with external resources (appendix 9.2.2, Q8)

Steel and Hull experience communication as one of the biggest challenges with external resources because it is easier and takes less time to communicate about an existing problem or ask a simple question directly to a person instead of over e-mail and phone calls. It is also easier to control their work instead of discovering a problem at deadline day when they hand in the final drawing. Finally, they point out that external resources do not have the same relationship to US as permanent employees when it comes to efficiency and cost. By this they mean that a temporary external resource that is given an assignment estimated to take 100 hours will use 100 hours to ensure a hundred hours of work even though they could have completed in half time. While permanent employees have ownership of the whole project and are motivated to deliver drawings efficiently and take care of potential collisions while working.

Unlike *steel and hull*, *machinery*, *piping and HVAC,* and *electrical* experience the quality of the work to be a part of the challenge. This means that they discover collisions and disagreements between temporary and permanent employees. An example is that temporary resources potentially could draw 50 meters of piping, which completes the assigned task. However, the optimal solution may have been 30 meters. Building the unnecessary 20 meters may also lead to a higher cost than necessary in production. Such issues occur because temporary employees follow their given instructions regardless of existing problems or potential collisions. Therefore, external resources in these divisions require more supervising and better control. The need of supervising requires a lot of time from permanent employees that rather could be used on modeling. This causes inefficient use of their own permanent resources.

Another challenge is to adapt the information level to be punctual enough for the engineers to understand the task. Permanent employees have more experience working with US and require less information to be able to understand the requirements of a task, while external engineers usually need more information to be able to understand what is expected of the drawing. During an interview, an engineer describes the situations the following way: "*it becomes a bit cumbersome for us when we have to spend a lot of time explaining, time we could have spent on doing the job myself. All work has to go to a quality control, but we need to give very clear information and it takes quite a long time to teach them, which affects our resources. It also varies, some are good, some are not*". Even after spending time on explanation, there is no guarantee they have understood the task. It is also challenging for coordinators to be able to formulate the information in a way it is understood, especially in the beginning when the engineer is inexperienced with working for US. The possibility of misunderstandings due to an inaccurate description of the task can result in worthless drawings that need to be redone. In cases with more substantial tasks and longer deadlines, misunderstandings and mistakes that are not discovered before drawings are delivered can cause serious consequences as of delays.

5.3 Communication, quality assurance and control

Communication, quality assurance and control routines are affected when a project falls behind schedule at detail engineering, making it more challenging to deliver high quality drawings to production in time. Detail engineering employees have specific routines on how to handle different situations and whom to turn to when challenges occur. Division leader, coordinators and engineers have assigned their own responsibilities including communication, quality assurance and control over given areas.

Initially, communication was mentioned as an overall challenge in the company which affect all parts of a project. Put in context with the information given above regarding parallel planning, production, and resources is it also essential to see communication as a challenge causing delays and higher costs. Communication is conducted in several ways at US and is an important tool to coordinate all divisions in detail engineering because they operate concurrently in the same 3D model. As explained above is it a coordinators' job to provide information to the modeling task distributed to the engineers, and for communicating with procurement, design and production. Engineers modeling in the 3D model are also required to communicate with each other to come up with the best solution. The planning software provides information regarding when a task is ready to be started, while additional information can be provided by email. An error or collision in the 3D software that are not detected can cause minor to major issues depending on the timing and scope of the issue. When collisions occur, the employees have clear guidelines on how to handle the situation. The engineer causing a collision is responsible for informing the engineer responsible for the part where the collision is discovered. Together they are responsible to find a solution that favors both parties. In cases where errors are not corrected at the right time, they can experience the price to be up to ten times as high as expected. However, our findings indicate that information sharing is not optimally and correctly conducted. Our interview objects state that when an error or change occur, affected engineers are not always informed, resulting in a collision not to be detected early enough and corrected. An engineer describes a such situation as:

"*Collisions occurs quite often, especially as today, when everyone is a bit behind schedule. Suddenly someone put in some extra steel, or interior is placed wrong, or even walls placed a little bit off. Almost daily do collisions occur and it has been especially bad lately because all departments are behind schedule*". Although several examples of communication difficulties were presented under the interviews, the survey conducted describes the overall communication as “pretty good”. The survey (figure 35) further confirm the difficulties of how information is communicated and are consistent with the findings in question 1 (figure 30).

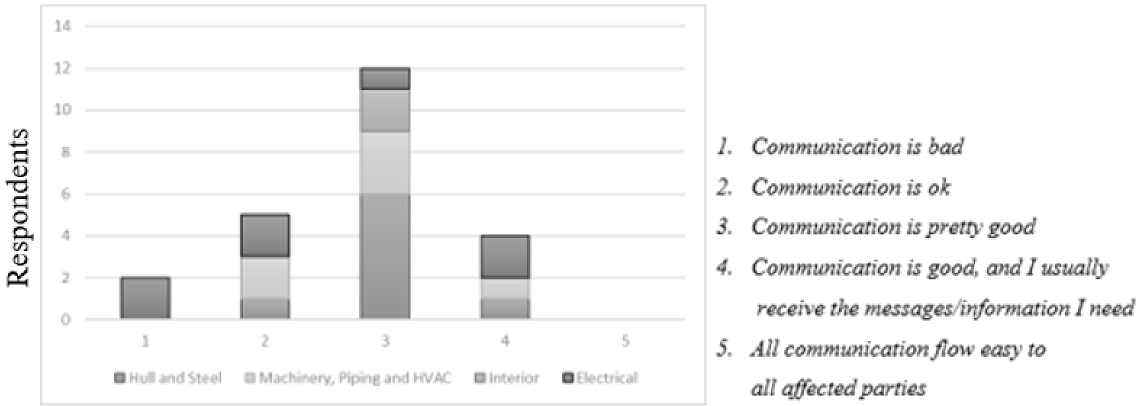


Figure 35. Experience of the communication level

Communication with temporary hired engineers have been a challenging process as the need for more elaborate communication has been necessary to make them understand what and how to carry out tasks. Differences in cultural background and working location limits the cooperation and make it considerably more difficult to ensure that efficient communication is conducted between the parties. Unlike permanent employees who work in the same building and can easily find each other to solve problems and answer questions, temporary hired engineers are dependent on email or phone. In cases where they call because of a question and do not get in touch with the coordinator in the morning, they often try calling again after lunch. Seated in the offices in Ulsteinvik, it would be easier to find the coordinator and avoid the time-loss that occurs when waiting before trying to call again.

Communication between departments and divisions, and between internal and external resources can today be described as difficult. However, they are all interdependent to complete a project. It is pointed out that collisions/errors occur more often when a project falls behind schedule.

Quality controls are carried out continuously throughout the drawing process as assurance and is an important task that provides improved drawing quality and potential cost reduction. US have clear controlling routines and have defined who is responsible for conducting the routines. All engineers are responsible for controls of own drawings and signing for completed control before handover to the coordinator. Then the coordinator is responsible for going over the same drawing once more as an assurance control before being handed over to production. The extent to which drawings are controlled is further determined by the severity of the equipment modelled in the 3D software. Larger and more important equipment are also controlled by an external class company like DNV GL. The last control is conducted in production were errors are reported into the engineering department. At this point, most errors should have already been located. However, all occurring errors and collisions cause changes and require extra resources, and potentially extra costs and delays.

Even with control routines collisions and errors occurs throughout a project and are caused by engineers modeling at the same location, modeling with wrong information, or even that someone has put in equipment at the wrong place and forget to inform about relocation. In this case for example, electro who already modelled a connection to an equipment may need to change it. However, due to the high time pressure, quality control is not always prioritized. This is because conducting controls can be very time consuming, even for high competence employees with several years of experience.

It is also pointed out that quality controls are higher prioritized on external resources because they experience challenges with the use of temporary hired workforce. Work delivered by temporary hired engineers require extra follow up under the drawing process and extra control when delivered. As the number of external resources sometimes are higher than the number of permanent employees at US, follow-up and controls become much more resource demanding. Coordinators do not have the needed capacity to provide assistance to high number of external resources, and the capacity is then taken from other engineers. Instead of spending time drawing in the 3D software, several local resources are used to control and support the temporary hired engineers. Even with extra resources assigned to the controlling process of external resources is it incredibly difficult to follow up because permanent employees still have their own tasks that must be completed in time. As a result, the temporary workforce is not continuously controlled throughout the drawing process, which causes late discovery of collisions, errors or deficiencies.

5.4 Summary

US has well established routines regarding planning and coordination for new construction projects and for modeling the vessel in 3D at detail engineering. Project planning is conducted through an overall master plan and a more detailed weekly plan with a two-week horizon to be able to more easily handle changes and variation. US is also using temporary hired engineers in periods when the workload exceeds the working capacity to provide better flexibility in a fluctuating construction market. Several challenges have been identified within the planning and execution of activities in detail engineering, with a particular focus on coordination, communication and control. These areas will further be discussed in the next chapter up against relevant theory.

6.0 Discussion and analyzes

This case study has provided a description of several challenges and problems occurring through a shipbuilding process, which can be traced back to the detail engineering department. In the shipbuilding process, production and engineering represent the two main activities, where production is primarily dependent on information and drawings from detail engineering to move forward in the production process. The number of participants and the degree of interdependence makes the project complex and increasingly more challenging to manage. On top of this, the shipbuilding process is further characterized by several changes in design that occur through the project, making it difficult to follow a fixed plan. For this thesis, we set out to analyze how Lean project planning and control can be used to improve customer value and reduce waste in detail engineering at US. Furthermore, we identified sources of waste in detail engineering and how Lean- and LPS theory could be applied to eliminate waste and improve customer value.

6.1 Understanding the role of obstacles in planning and coordination

There are quite a few challenges in the Norwegian shipbuilding industry that makes it an interesting research field within efficiency improvements. Even with many problematic areas through the shipbuilding process, the Norwegian shipbuilding industry is still one of few that manage to deliver complex vessels with a short lead-time. Even though the cost of the project is higher in Norway compared to low cost shipbuilding nations, customers still choose Norway. The reason why customers select Norway over other countries is because of the tailor-made solutions the shipyards manage to provide and the ability to take on projects and follow the specifications (Jakobsen, Mellbye, and Zhovtobryukh 2015).

The shipyard has the capacity to take on several projects at the same time, providing a potential larger revenue for the company. The capacity is decided based on physical capacity and available resources at the yard. Interviews indicate that resources assigned to a new project often are needed to finalize ongoing projects due to the increased needs of resources to deliver on time. This occurs because several projects overlap, where closing projects are under a constant time pressure to deliver on time and avoid potential loss of revenue. However, when a closing project is behind schedule, extra resources are applied to be able to deliver in time. From the shipyard's, perspective is it more important to deliver the closing project within the delivery date. Therefore, resources to start planning new projects are not prioritized as there is no visible costs to it, and the loss of time potentially can be recovered throughout the project. However, from a project management perspective does late commencement causes repercussions creating a variety of challenges further into the project life cycle, which will be further discussed in this chapter. From an optimal perspective it would be possible to handle several projects as US is doing today, as long as the project is delivered in time without the need for extra resources.

Struggling with commencing as planned is unfortunate for a project, because it is operated concurrently, and delays can affect the entirety of the project. A late start-up increases the planning and coordination challenges, as it is increasing the degree of concurrency and the need for improved coordination. Advantages of the concurrent engineering approach is reduced lead-time and increased flexibility to handle design changes as project specifications are completed during the project. However, successful use of concurrent engineering requires proper planning and coordination because of the complexity of the project increases (Mello, Strandhagen, and Alfnes 2015). To conduct a project concurrently, Anumba and Kamara (2012) two key principles defined in the theory chapter should be fulfilled. The first concern integration and transparency across all departments with a focus on the use of multidisciplinary teams early on in the design phase to consider and discuss potential issues. The second, refers to how concurrency can be determined through how well tasks are planned and the level of interaction between actors.

Based on concurrent engineering theory, the optimal solution for US would be involvement already in the design phase of the project (Zidane et al. 2015). In that way, multidisciplinary teams from design, engineering, production and procurement could at an early phase of the project be able to cooperate to find optimal solutions and eliminate potential challenges in upcoming projects. Today, US is not involved before the conceptual design is developed, meaning that integration potentially could be improved if US gets involved earlier. The findings at US is consistent with several of the characteristics in the construction industry, applying the possibility to compare the two industries. According to Mello, Strandhagen, and Alfnes (2015) is the optimal use of concurrent engineering requiring proper planning and coordination. However, our findings describe several challenges US is experiencing, which affect the planning and coordination of a project. These challenges are on the other side consistent with the findings Zidane et al. (2015) present, referring to the largest time thieves in construction. From a Lean perspective, time thieves would be associated with waste, and the findings from the construction industry offer compelling evidence for focusing on improving coordination and management of projects to improve efficiency. Late commencement causes US to often reduce the time gap between production and engineering startup because the beginning of production starts regardless of how far engineering has come (figure 36). This increases time pressure on engineering activities, giving less flexibility and by that less room for unforeseen changes in design or other unexpected reasons for delays.

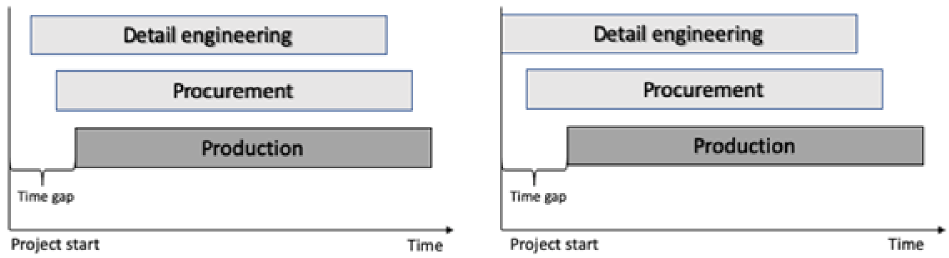


Figure 36. Late versus on-time commencement

Conducting concurrent engineering requires proper project planning, to the extent that the necessary input is available when the planned task is to be completed. Concurrent engineering is therefore dependent on following the processes after the JIT strategy, where requests are sent out in time for the procurement department to take decisions and receive equipment specifications in time for engineers to start modeling according to plan. When applying JIT as a strategy in concurrent engineering projects, procurement must assure the on-time delivery of materials and equipment, as well as ensuring the engineers deliver drawings to production in an adequate amount of time. As a result, this effort will enable production to start as planned. Unlike the optimal JIT approach, US experiences a delayed project start. This delay leads to the late delivery of information in the start phase of the project. As a result, the engineers focus their time on other tasks while they request and wait for the necessary input. Mello, Strandhagen, and Alfnes (2015) illustrates how delays in engineering can lead to repercussions causing the late delivery of a project (figure 37). This also illustrates the issues US experiences because of late commencement. Since it is crucial to complete a project on time, late commencement increases the time pressure and by that reduces the flexibility of a project.

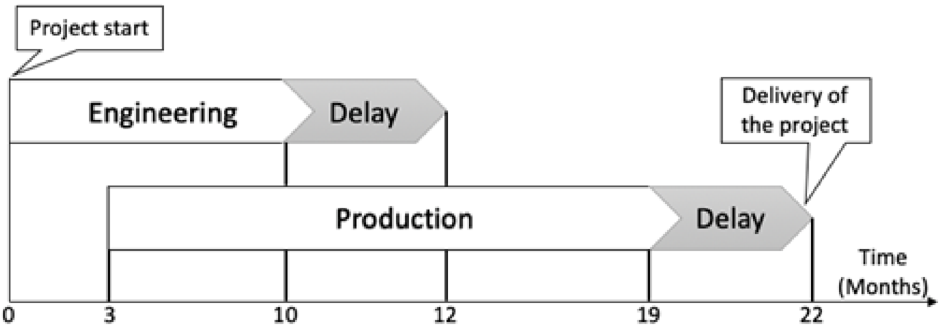


Figure 37. Delay model (Mello, Strandhagen, and Alfnes 2015)

In contrast to the findings provided by Mello, Strandhagen, and Alfnes (2015) in a case study, *On the Role of Coordination in Avoiding Project Delays in an ETO Supply Chain,* the findings of this thesis are not aligned with their recommendation. Their case study suggests increasing the level of concurrency. A prerequisite for increasing the level of concurrency would be improved interactive coordination mechanisms. However, the findings from US is contradictory to their solution. Furthermore, since US already experiences difficulties with coordination at a lower concurrency level, increasing the level of concurrency would not be optimal today.

A consequence of the high time pressure that occur due to late commencement is increased number of errors. The problem of the increased number of errors are observed and confirmed by interview objects from each detail engineering divisions and are a substantial issue as a result of coming behind schedule. As the degree of concurrency is correlating with the need for coordination (Mello, Strandhagen, and Alfnes 2015), US should theoretically reduce the concurrency level to avoid high time pressure. Despite the potential improvement US could benefit from, it also increases the project lead-time and reduce their competitive advantage. Instead, implementing Lean project planning and control routines may be a potential solution to improve coordination and planning of projects, by not changing the degree of concurrency but rather by focusing on eliminating waste in the detail engineering department to increase flow.

6.2 Waste in detail engineering

When US is behind schedule, they tend to increase the resources applied to the project to manage to complete the project within the delivery time. Delivering behind schedule can potentially result in high costs due to fines agreed upon in the contract if US not manage to deliver in time. The use of external resources has through our case findings been highlighted as a significant source of waste, and further proven to be difficult to integrate into the engineering process. Additionally, extra resources are used to reduce the overburden (*muri*) on engineers as the time pressure increases. Despite the fact that extra resources should help reduce the amount of time pressure, our findings show that use of external resources generate waste such as inefficient use of internal resources, which Womack and Jones (2003) identified as the eighth sort of waste. Scaling up an engineering department can not be compared to manufacturing, according to Brooks (1986), as the elements in engineering interact in a nonlinear way, and the interdependence between the process increases the complexity more than linearly. With more work resources involved in the project increases the complexity of communication and coordination, that may lead to product flaws, cost overruns and schedule delays. Findings at US confirm the difficulties when external resources are applied to the project, affecting the internal workforce with increased coordination and complexity. The workload also exceeds the capacity of the coordinators, results in inefficient utilization of internal engineers as they must take on extra coordination and control tasks. This is consistent with Brooks (1986), who further argues how the complexity causes not only technical challenges, but also management difficulties as it is more difficult to get an overview and manage to control loose ends.

The occurrence of waste in detail engineering differs from manufacturing as the flow consists of an information flow instead of a material flow as the seven wastes Womack and Jones (2003) refer to. Waste in engineering has further been characterized by McManus (2005) based on the seven original sources of waste, while Bonnier, Kalsaas, and Ose (2015) describe the drivers to waste in detail engineering. Findings from the case study at detail engineering department at US share a number of similarities with the waste drivers presented by Bonnier, Kalsaas, and Ose (2015) linked to coordination, information handling and changes. Waste can further be divided into different sorts of waste. Waste occurring within processes that are conducted in the department as for example waiting on information or rework. However, waste can also come as a result of engineering activities which generate waste further down-stream in the project, as for example waiting on drawings in production or errors in completed drawings which causes rework.

In the detail engineering phase of the project the product is still not completely defined and contains a high degree of uncertainty that is reduced through the processes. Engineering changes in ETO projects are practically unavoidable (Strandhagen et al. 2018), which increases the complexity of planning and coordinating the project. Detail engineering at US experience collisions in the 3D model daily in different severity. Compared to ETO theory, the engineers are experiencing collisions in the 3D model as more challenging than design changes. Collisions occur when items are colliding within the 3D model, while design changes occur when the customer request changes during the production process. As a result of changes, the workflow is disturbed and further characterized as an extensive source of rework as collisions require to come up with a new solution. However, Womack and Jones (2003) defines waste as a*nything that creates no value to the end user*. Defects causes rework, and in this case, changes are not always bad. A change can occur due to missing information or failure or as a result of changes requested by the end customer which in the shipbuilding industry can be seen as value adding. Despite the fact that rework as a result of mistakes can be categorized as waste, rework caused by customer changes are value adding for the end user and may also create economic benefits for US. Case findings from US is consistent with Strandhagen et al. (2018) statement on unavoidable changes in ETO projects. Despite the fact that changes are unavoidable, is efficient handling before sending drawings to production essential to reduce the amount of rework being affected and creating waste.

The impact of changes in the design or collisions is decided on how far in the value chain it goes undetected, and to which degree it affects other parts of the value chain. For each phase an issue goes undetected increases the cost of fixing the error and the risk of affecting other drawings. To cope with changes that occur at US, control routines are carried out on several levels based on how important the task is. This support previous findings regarding control of the uncertainty by Mello (2015) and Haji-Kazemi et al. (2015) who reviews on how uncertainty causes delays in large ETO projects, and how to avoid it. The way US is handling changes in detail engineering shares a number of similarities with the solution (Haji-Kazemi et al. 2015) presented in their research. However, technical coordinators and engineers are experiencing increased challenges with controlling the drawings under high time pressure, and even more when the use of external resources is applied. If collisions in the 3D model are not detected in the engineering phase, the drawings are sent to production where it causes significantly more waste as it increases the need for rework, use of unnecessary resources and causes delays. The case study further provides additional support to Haji-Kazemi et al. (2015) on how concurrent engineering makes controlling increasingly more challenging. It also demonstrates how critical controlling routines are in the shipbuilding process because of the potential cost savings that can be achieved in the detail engineering phase.

6.3 Last Planner System in detail engineering

This study has not confirmed previous research on LPS. However, the thesis describes the characteristics of detail engineering in the Norwegian shipbuilding industry and emphasize planning and control difficulties. Findings from the case study further provides additional support to the compelling similarities between the shipbuilding industry and the construction industry. LPS has been successfully implemented in construction projects all over the world and are developed to handle complex projects with several participants and a high degree of variation. (Ballard 2000). Ballard refers to several successful implementations in construction projects, but not in design and engineering. Over the last decade several studies have been conducted on the implementation of LPS in design and engineering activities in ETO projects (Hamzeh, Ballard, and Tommelein 2009, Ballard, Hammond, and Nickerson 2009, Kalsaas 2013). With the evolvements of the market conditions and projects becoming more complex, Lia, Ringerike, and Kalsaas (2014) argue for the importance of design and engineering to increase predictability in ETO-projects. This may reduce the risk and improve the stability of the projects, as design and engineering activities often have repercussions to other parts of the project.

Further research carried out by Kalsaas (2013) corroborates with the findings from US for the need for improved coordination mechanisms to cope with the complexity in design and engineering activities. The four types of prerequisites for sound activities in engineering as presented by Bertelsen et al, (2007) are crucial for coordinating a stable flow in detail engineering. Especially the use of lookahead planning as a part of LPS can benefit the shipbuilding process, and handle constraints before it provides difficulties and potential delays. Earlier research has yet to come up with a solution optimal for planning and control in detail engineering, although LPS manage to cope with several more of the difficulties compared to project management methods. The results from the case study at US offer compelling evidence for the potential effect of eliminating waste by improving the planning and control mechanism.

7.0 Conclusion

Short lead-time and customization are seen as two competitive advantages of the Norwegian shipbuilding industry and is why customers choose Norwegian production. By commencing a project as scheduled and reducing waste that occurs throughout the processes, US can potentially deliver the project within a shorter lead-time or using the same amount of time allowing better handling of last-minute changes required by the customer. This will potentially increase customer satisfaction as both factors are essential to the customer group. Today, the company is behind schedule causing repercussions further into the project and a constant need for *putting out fires* to be able to deliver drawing in time for production.

Due to high variability, many participants that are involved in the project and design changes occurring throughout the project making it significantly challenging to plan and coordinate the shipbuilding process. Several approaches have been suggested as potential solutions to handle the high interdependency without any that have come up with a strategy or tool that solves the problem. Using Lean tools and technique has been suggested to eliminate waste and LPS has been presented in several research studies as a planning and control tool developed to handle the characteristics of ETO-projects. LPS has been a successful tool in construction, but in design and engineering processes on the other hand, has it been proven difficult to implement. Even with adjustments to handle the characteristics of design and engineering better has it not been provided an optimal solution.

Therefore, the finding of this thesis is that there is no silver bullet for the planning and execution of shipbuilding projects today, which mean that there is no optimal solution to eliminate the variation and waste that occur in detail engineering. However, several measures can be provided to reduce the variety and waste to a lower level. LPS is suggested as a potential solution all though it requires several adjustments before it can work optimally. Findings from earlier research also underline how learning and experience is essential to develop LPS over time and adapt it to make it suitable to the detail engineering department at US.

7.1 Limitations

To reinforce the findings proposed in this thesis could it be advantageous to have conducted several case studies at several shipyards as to compare with the characteristics found at Ulstein Shipyard. By conducting several case studies, this thesis could potentially also strengthen the findings of waste in the industry. Additionally, it could be an advantage to conduct several data collections from other sources than interviews to emphasize our findings. Time and resource limitations also affected this thesis as we unfortunately could not follow a whole project which could have given us better insight and understanding. Such insight could have been advantageous to conduct direct observations, examples and data to the thesis. Finally, our findings thus need to be interpreted with caution because the main data is collected from interviews.

7.2 Practical application of findings

Our main findings indicate that the detail engineering department at US has several sources of waste, that are causing waiting, rework and repercussions to other parts of a project. These sources can further be traced back to planning, coordination and communication both internally and externally with other departments. The findings point out difficulties in the late commencement of projects that are caused by inadequate planning of resources in ongoing projects. We believe several of the different sources of waste can be reduced to a lower level, with the use of LPS as a planning and coordination tool. From our perspective, engineering activities would benefit from the implementation of LPS and especially the lookahead planning, as a way of continuously handle constraints before it causes any difficulties. The importance of an efficient project start is also found to be fundamental to be able to handle the concurrency in the project and maintain the flexibility to handle potential changes better throughout the project.

7.3 Theoretical implications

In this thesis, the subjects of Lean and ETO theory have been applied to describe how Lean project planning and coordination can be used to eliminate waste and improve customer value in engineering activities in the shipbuilding process. Our study provides additional support for the complexity in engineering departments and how concurrent engineering affect the shipbuilding process from an engineering perspective. The correlation between the degree of concurrency and the need for coordination is also confirmed through several of our findings. Our findings show that at a given point, increased concurrency is leading to longer lead time due to the difficulties caused by the complexity it leads to. The results from the case study findings also offer compelling evidence for the exponential complexity in an engineering department when extra resources are applied.

7.4 Suggestions for further research

For further research, there are several suggestions on topics. An interesting research would be to follow a project from the beginning to completion, identify all activities and using value stream mapping as a tool to discover and eliminate potential waste. However, this is both a time consuming and comprehensive task.

Based on the findings in this study is it important to assure on time initiation of projects. An interesting research could be to look at the beginning of a project and examine the possibilities of a more efficient project initiation process and whether extra resources in the beginning could help benefit projects.

Finally, it could be interesting to try out the findings of this paper by implementing and adapting a suitable LPS system for detail engineering at US to explore the impact on planning and coordination further.

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9.0 Appendices

9.1 Interview guide 1

Can you explain how the detail engineering department operate?
How are projects controlled?
How does planning across various departments work? (meaning design, detail engineering, procurement and production).
What would you say are the biggest challenges within the detail engineering department?

9.2 Interview guide 2

Coordination

- *Do you have fixed plans?*
    - *How long time in advance do you know what you will be working with? Daily plan, weekly plan, monthly plan?*
    - *How do you think this is working?*
    - *Do you think it could be useful with several plans, fewer than today, or is it okay the way it is?*

If you do not have any plans, what determines what you will work with from day to day?

Communication

- *How is it communicated that the process prior to yours is completed?*
- *How do you communicate that you are done with your task?*
- *How often do you experience changes to work you had already completed?*
- *How often do you experience not to get information regarding collisions?*
- *How often do you experience that someone has done work that comes in way for your task?*
- *Do you remember to inform involved parties about collisions you make?*
- *Do you feel that you get the information you need to complete your task?*
- *How often do you have to request missing information that is essential to complete your work?*

Resources

- *How does it work to cooperate with the hired/temporary workforce?*
    - *Does external workforce require more follow-up than permanent employees?*
    - *Does bad communication with external workforce affect permanent employees?*
    - *Is external workforce at the same competence level?*

Do you have a perception that temporary resources have the same routines and understanding as permanent?

Quality Control

- *Are modeling approved by a second part?*
    - *How?*
- *Do you experience that quality control are prioritized because of its importance?*
    - *If yes, do you experience that this reduce number of changes later in the project?*
    - *Other?*
    - *If no, is it because there is no need for it?*
    - *Other?*
- *To what degree are completed models/drawings controlled?*
- *To what degree are a projects progress controlled according to a scheduled project plan?*

9.2.1 Questionnaire

As a part of our Master thesis at Molde University College we want to receive feedback on the following 10 questions from permanent employees in the detail engineering department. The goal is to get an overview of challenges and the scope of the challenges and finally use the result to see how challenges are observed across the different divisions and positions. The questionnaire is anonymous.

<u>Section 1:</u>

I am aware that the results of the questionnaire are used for a Master thesis at Molde University College and hereby agrees.

1. *Yes, I agree*
2. *No, I do not agree*

What division within detail engineering are you hired?

- ☐ *Steel and hull*
- ☐ *Machinery, piping and HVAC*
- ☐ *Interior*
- ☐ *Electrical*

What position do you have?

- ☐ *Coordinator*
- ☐ *Engineer*
- ☐ *Other…*

Section 2.

In the following section we ask you to kindly range your question from 1-5 based on your perception.

Q1. How are the quality of incoming data?

1. *I need to request information*
2. *I miss necessary information*
3. *The quality of the data I receive is good. Meaning I do not get too much or too little information to complete my assignment.*
4. *I receive more information than needed.*
5. *I receive amounts of irrelevant information*

1	2	3	4	5
○	○	○	○	○

Q2. If you answered 1 in the previous question, how are the quality of the incoming data when you receive it?

1. *The information I need is not available*
2. *I miss some essential information*
3. *The quality of the data is good. Meaning I do not get too much or too little information to complete my assignment.*
4. *I receive more information than needed.*
5. *I receive amounts of irrelevant information*

1	2	3	4	5
○	○	○	○	○

Q3. How relevant is the incoming data?

1. *It is not relevant for my activity*
2. *It is indirectly relevant for my activity*
3. *It is advantageous for my activity*
4. *It is important for my activity*
5. *It is necessary for my activity*

1	2	3	4	5
○	○	○	○	○

Q4. How good are the format of the incoming data?

1. *I must reformat all data to be able to use it*
2. *I must reformat some data to be able to use it*
3. *Acceptable formatting*
4. *Good formatting*
5. *Ideal formatting*

1	2	3	4	5
○	○	○	○	○

Q5. How well do you experience processes to be planned?

1. *Processes are not planned*
2. *The processes are well thought out, however, there is no specific plan*
3. *There is a simple specific plan*
4. *There is a well formatted plan describing what are to be done and in what order*
5. *There is an excessive and complicated plan which are hard to use*

1	2	3	4	5
○	○	○	○	○

Q6. How do you experience that the plan is followed?

1. *There is no plan*
2. *The plan is not followed at all*
3. *The plan is partly followed*
4. *The plan is mostly followed*
5. *We always work after the plan*

1	2	3	4	5
○	○	○	○	○

Q7. How good do you experience communication?

1. *Communication is bad*
2. *Communication is ok*
3. *Communication is pretty good*
4. *Communication is good, and I usually receive the messages/information I need*
5. *All communication flow easy to all affected parties*

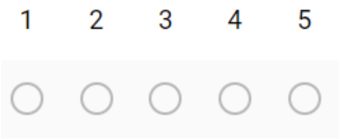
1	2	3	4	5
○	○	○	○	○

Q8. How do you experience working with temporary hired resources?

1. *It is ineffective*
2. *It is ok*
3. *It is good*
4. *It is quite effective*
5. *It is optimal*

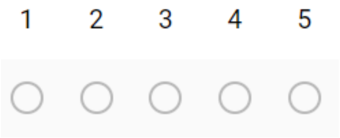
1	2	3	4	5
○	○	○	○	○

Q9. How do you experience working with permanent resources?



1. *It is ineffective*
2. *It is ok*
3. *It is good*
4. *It is quite effective*
5. *It is optimal*

Q10. How do you experience the amount of resources?

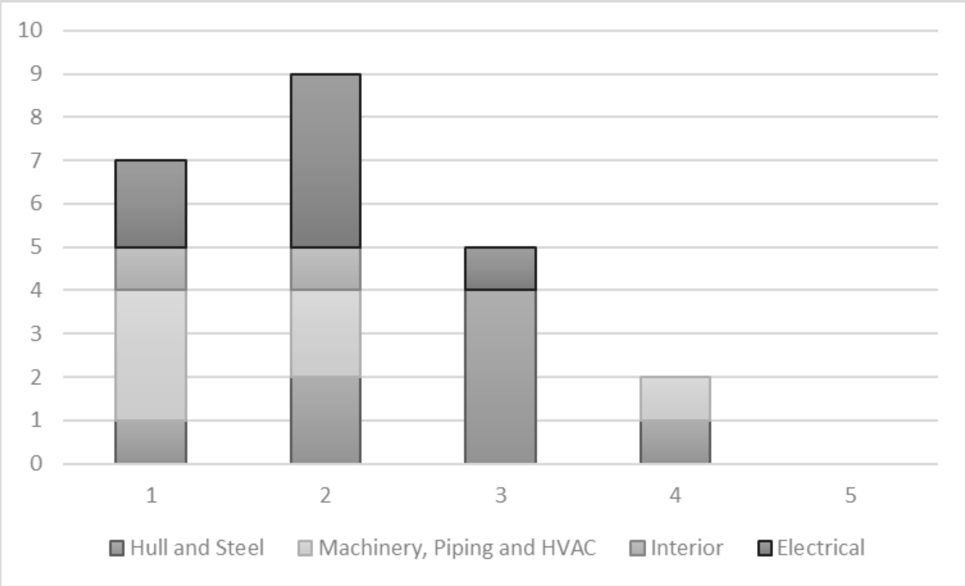


1. *We are way too few compared to the amount of work*
2. *We are almost good, but I wish we were a few more based on the amount of work*
3. *We have ideal amount of resources compared to the amount of work*
4. *We are a few too much compared to the amount of work*
5. *We are way too many compared to the amount of work*

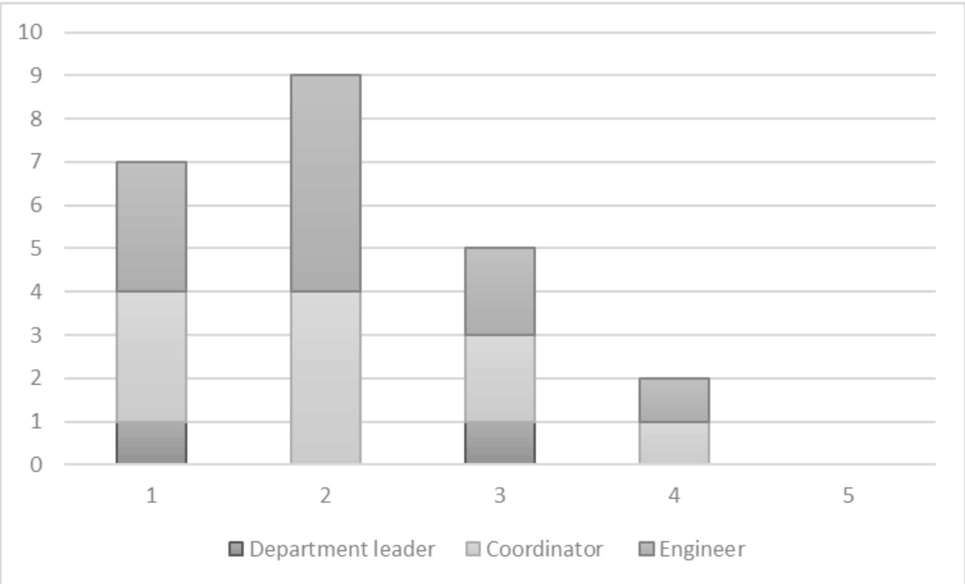
9.2.2 Results of the questionnaire

Q1. How are the quality of incoming data?

	1	2	3	4	5
Hull and Steel	1	2	4	1	0
Machinery, Piping and HVAC	3	2	0	1	0
Interior	1	1	0	0	0
Electrical	2	4	1	0	0
Sum:	7	9	5	2	0

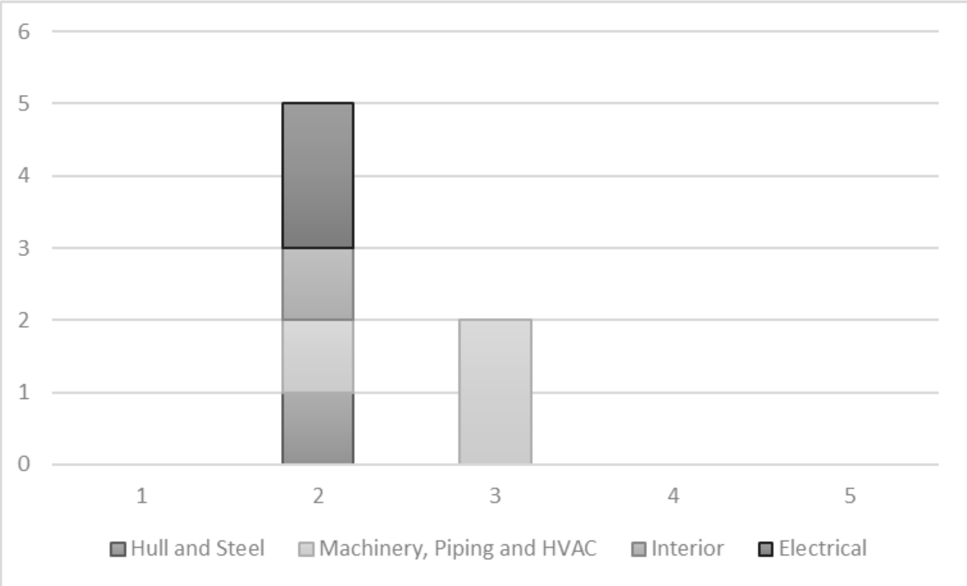


	1	2	3	4	5
Department leader	1	0	1	0	0
Coordinator	3	4	2	1	0
Engineer	3	5	2	1	0
Sum:	7	9	5	2	0

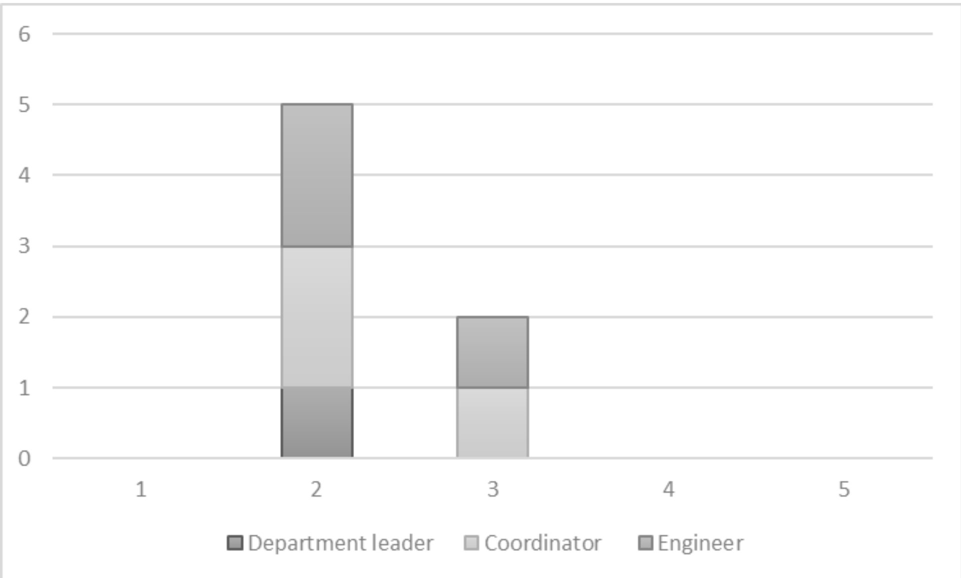


Q2. If you answered 1 in the previous question, how are the quality of the incoming data when you receive it?

	1	2	3	4	5
Hull and Steel	0	1	0	0	0
Machinery, Piping and HVAC	0	1	2	0	0
Interior	0	1	0	0	0
Electrical	0	2	0	0	0
Sum:	0	5	2	0	0

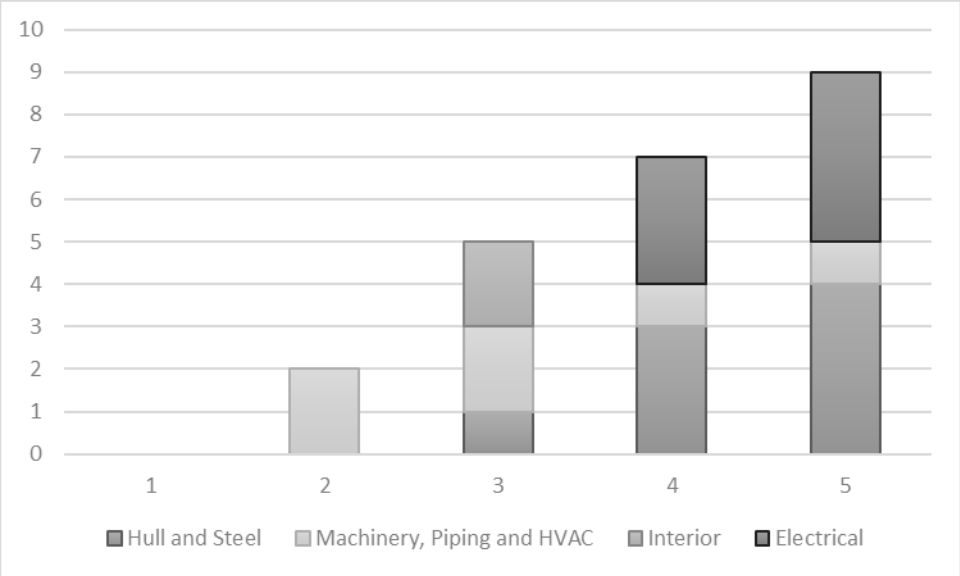


	1	2	3	4	5
Department leader	0	1	0	0	0
Coordinator	0	2	1	0	0
Engineer	0	2	1	0	0
Sum:	0	5	2	0	0



Q3. How relevant is the incoming data?

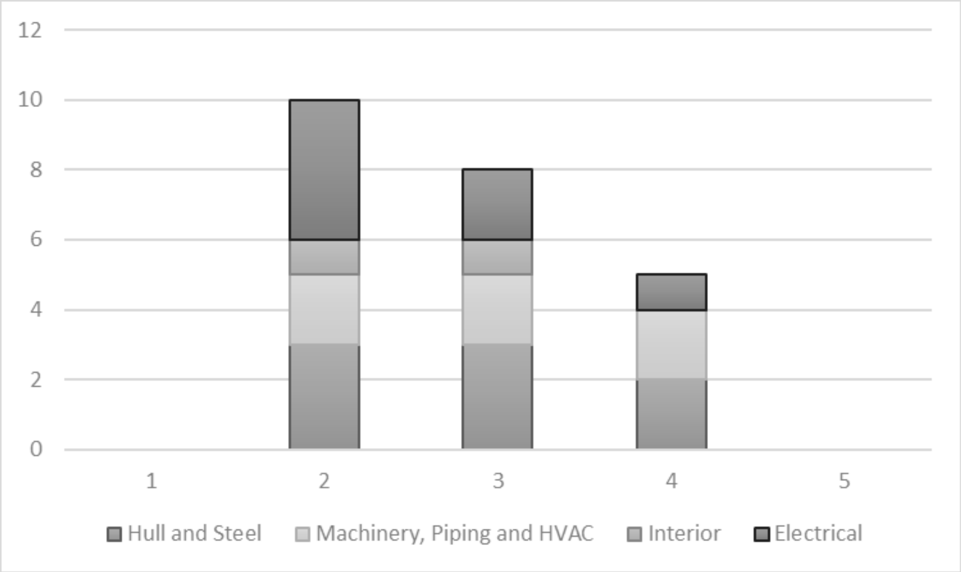
	1	2	3	4	5
Hull and Steel	0	0	1	3	4
Machinery, Piping and HVAC	0	2	2	1	1
Interior	0	0	2	0	0
Electrical	0	0	0	3	4
Sum:	0	2	5	7	9



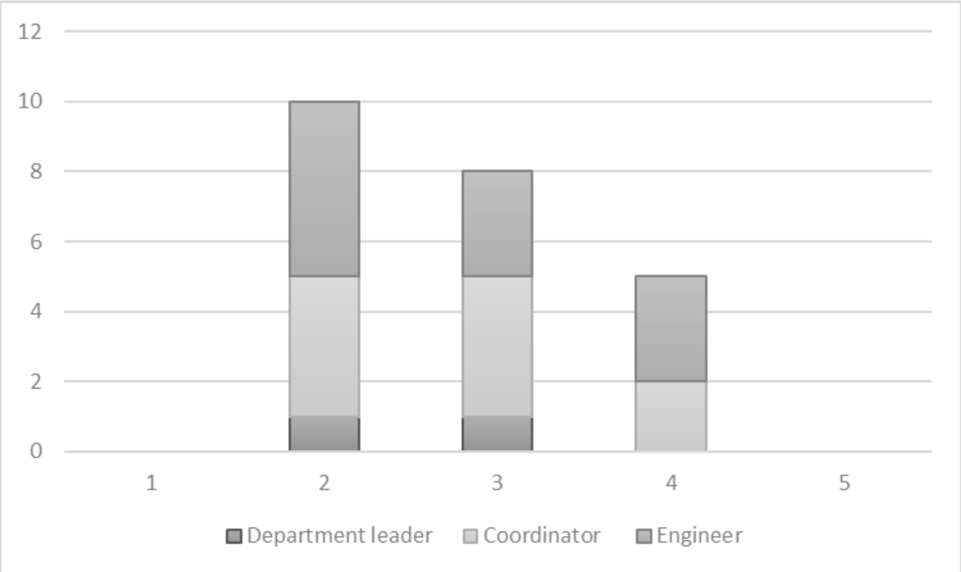
	1	2	3	4	5
Department leader	0	1	0	0	1
Coordinator	0	0	4	3	3
Engineer	0	1	1	4	5
Sum:	0	2	5	7	9

Q4. How good are the format of the incoming data?

	1	2	3	4	5
Hull and Steel	0	3	3	2	0
Machinery, Piping and HVAC	0	2	2	2	0
Interior	0	1	1	0	0
Electrical	0	4	2	1	0
Sum:	0	10	8	5	0

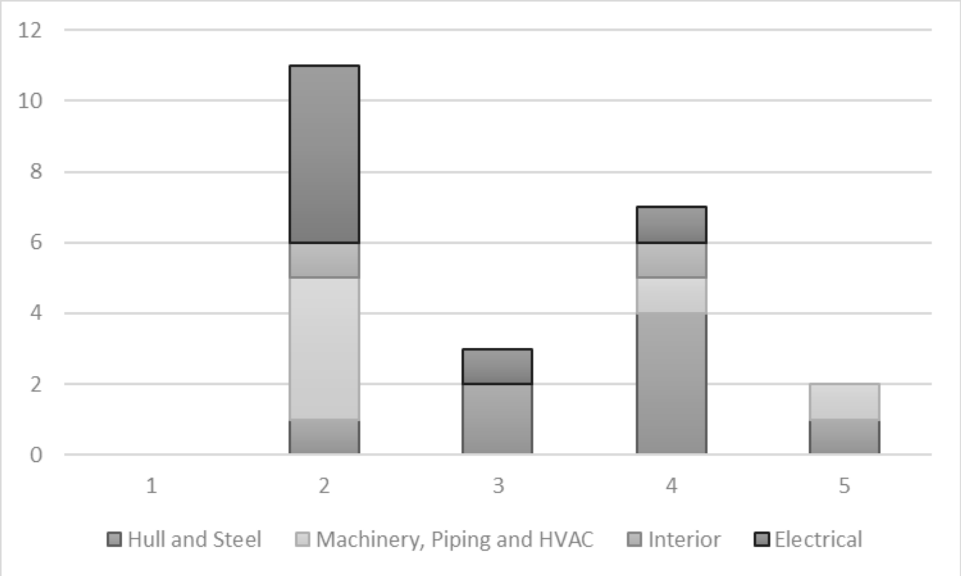


	1	2	3	4	5
Department leader	0	1	1	0	0
Coordinator	0	4	4	2	0
Engineer	0	5	3	3	0
Sum:	0	10	8	5	0

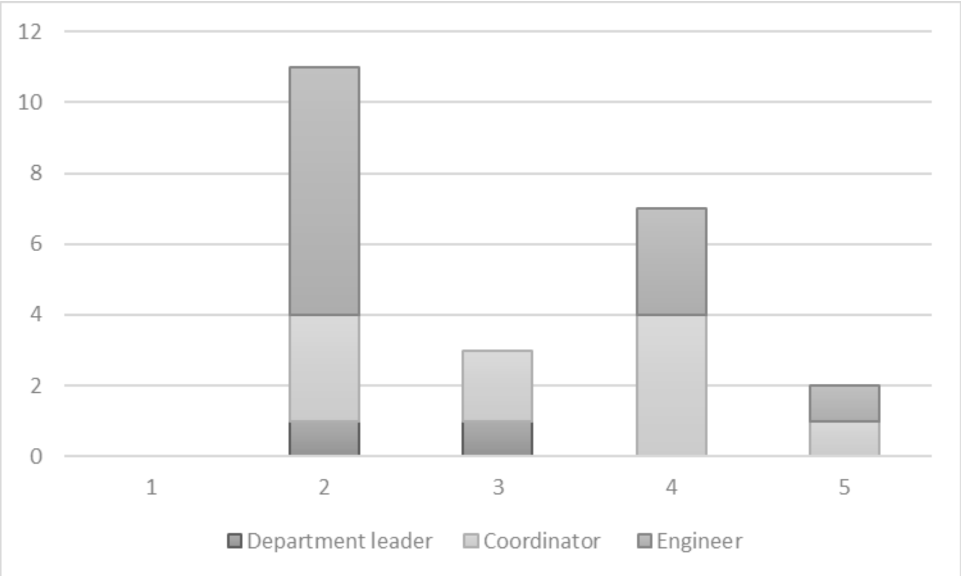


Q5. How well do you experience processes to be planned?

	1	2	3	4	5
Hull and Steel	0	1	2	4	1
Machinery, Piping and HVAC	0	4	0	1	1
Interior	0	1	0	1	0
Electrical	0	5	1	1	0
Sum:	0	11	3	7	2

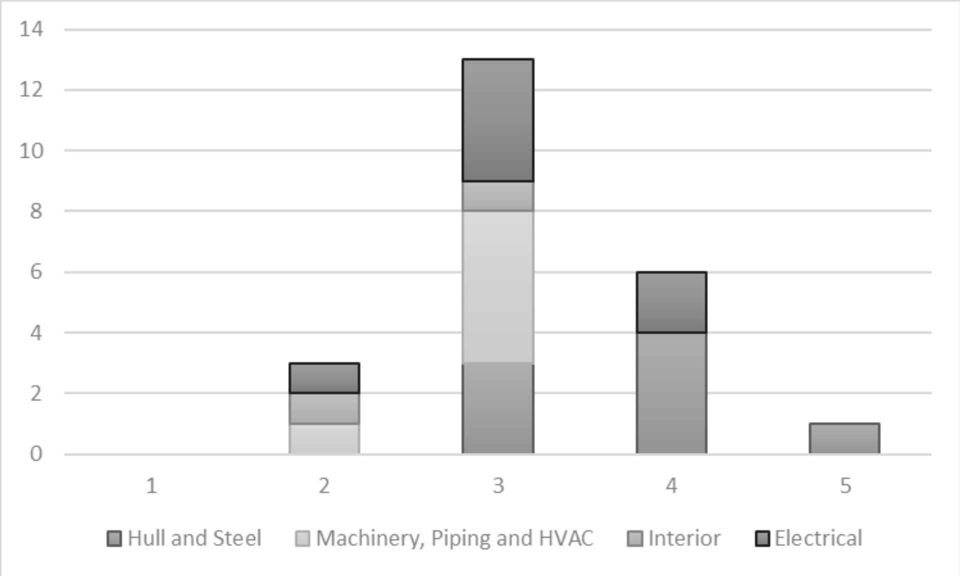


	1	2	3	4	5
Department leader	0	1	1	0	0
Coordinator	0	3	2	4	1
Engineer	0	7	0	3	1
Sum:	0	11	3	7	2

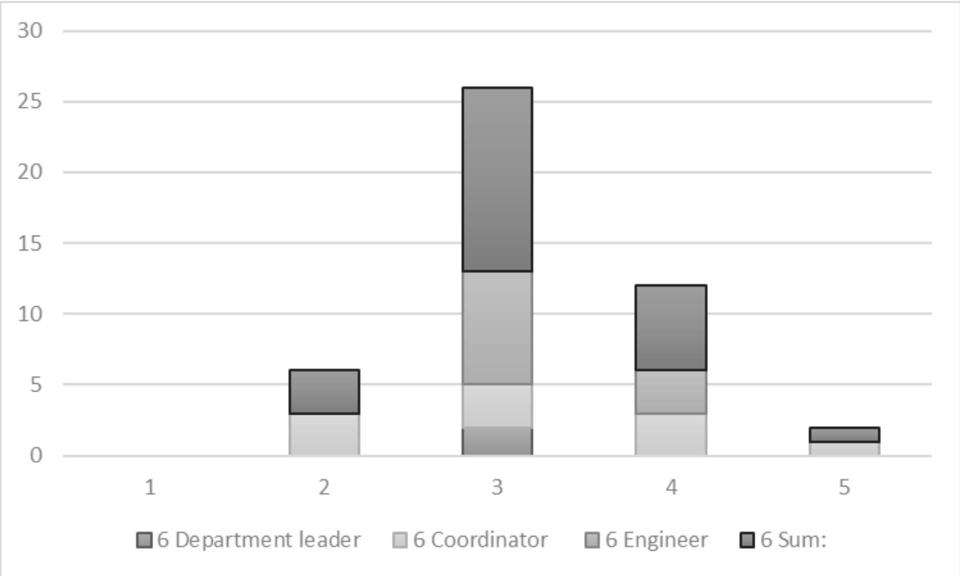


Q6. How do you experience that the plan is followed?

	1	2	3	4	5
Hull and Steel	0	0	3	4	1
Machinery, Piping and HVAC	0	1	5	0	0
Interior	0	1	1	0	0
Electrical	0	1	4	2	0
Sum:	0	3	13	6	1

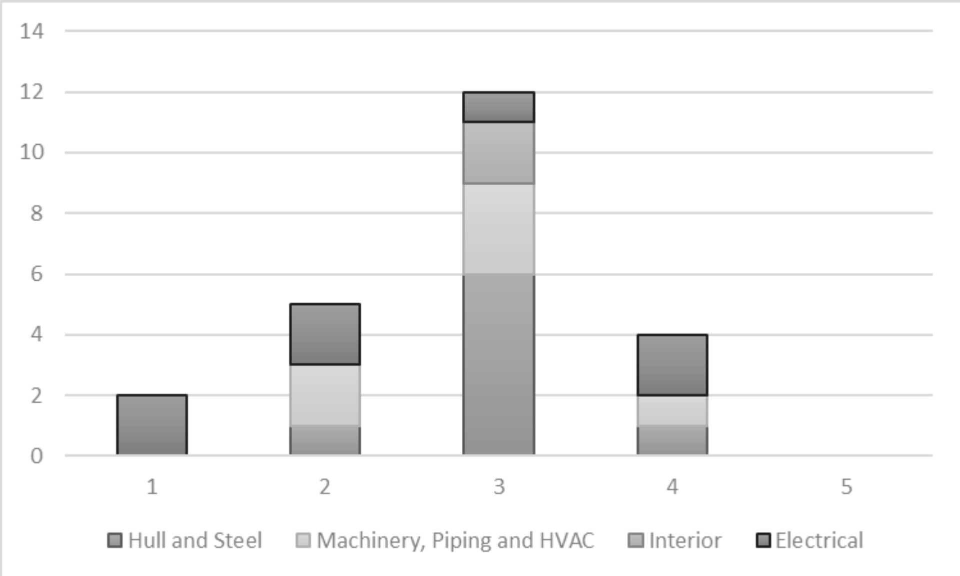


	1	2	3	4	5
Department leader	0	0	2	0	0
Coordinator	0	3	3	3	1
Engineer	0	0	8	3	0
Sum:	0	3	13	6	1

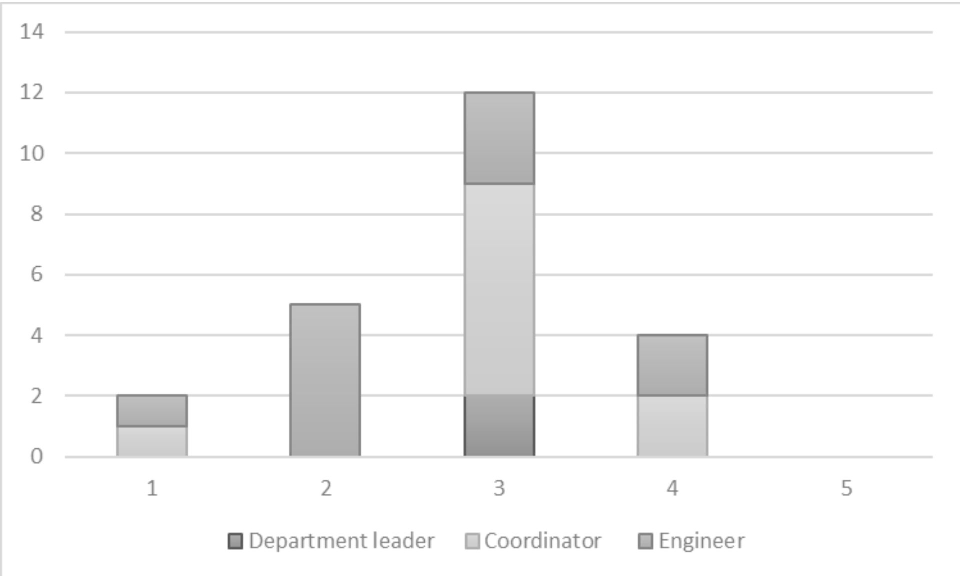


Q7. How good do you experience communication?

	1	2	3	4	5
Hull and Steel	0	1	6	1	0
Machinery, Piping and HVAC	0	2	3	1	0
Interior	0	0	2	0	0
Electrical	2	2	1	2	0
Sum:	2	5	12	4	0

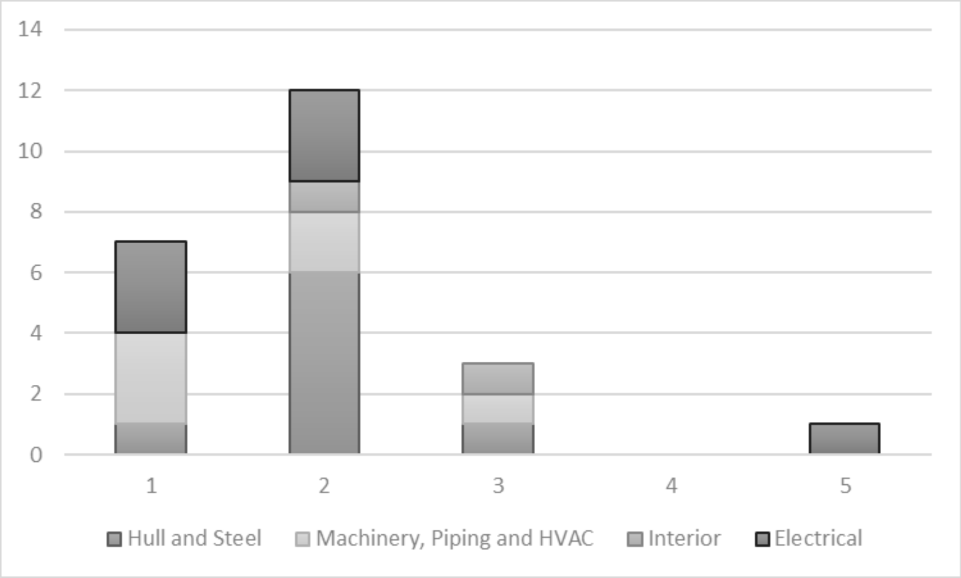


	1	2	3	4	5
Department leader	0	0	2	0	0
Coordinator	1	0	7	2	0
Engineer	1	5	3	2	0
Sum:	2	5	12	4	0

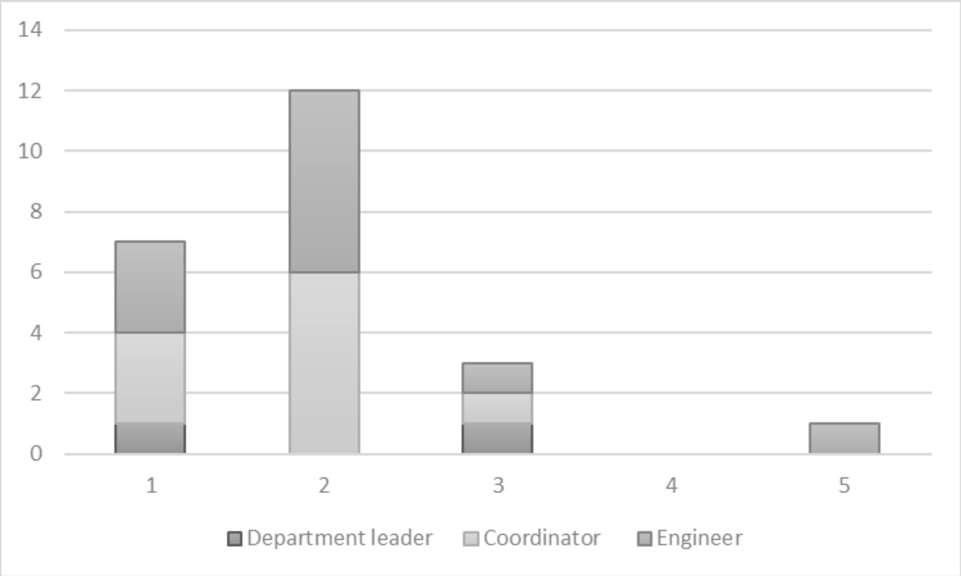


Q8. How do you experience working with temporary hired resources?

	1	2	3	4	5
Hull and Steel	1	6	1	0	0
Machinery, Piping and HVAC	3	2	1	0	0
Interior	0	1	1	0	0
Electrical	3	3	0	0	1
Sum:	7	12	3	0	1

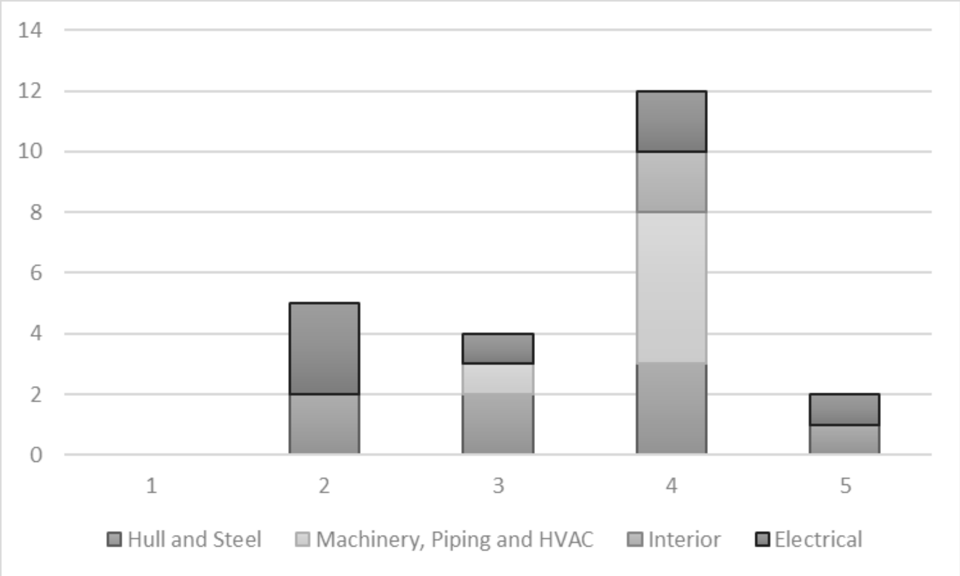


	1	2	3	4	5
Department leader	1	0	1	0	0
Coordinator	3	6	1	0	0
Engineer	3	6	1	0	1
Sum:	7	12	3	0	1

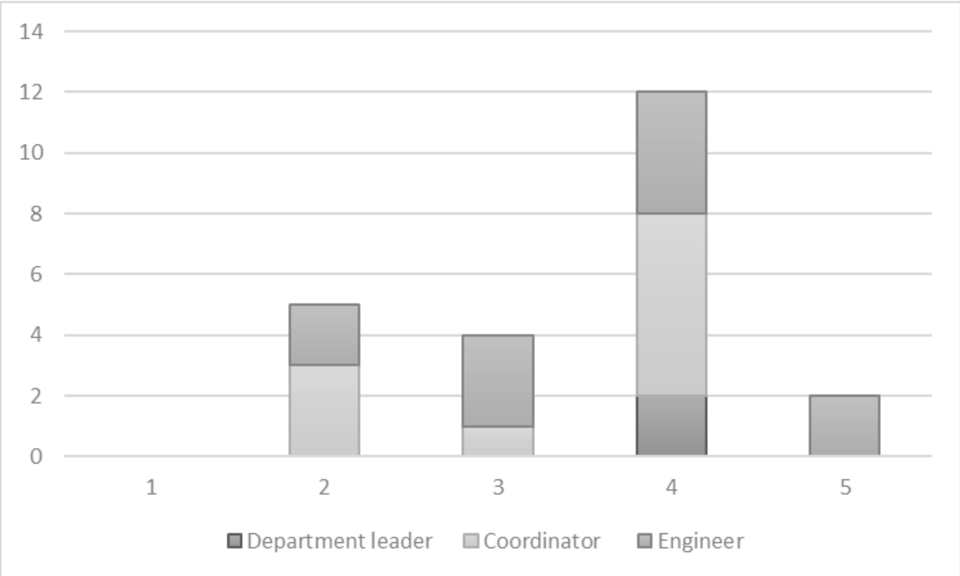


Q9. How do you experience working with permanent resources?

	1	2	3	4	5
Hull and Steel	0	2	2	3	1
Machinery, Piping and HVAC	0	0	1	5	0
Interior	0	0	0	2	0
Electrical	0	3	1	2	1
Sum:	0	5	4	12	2

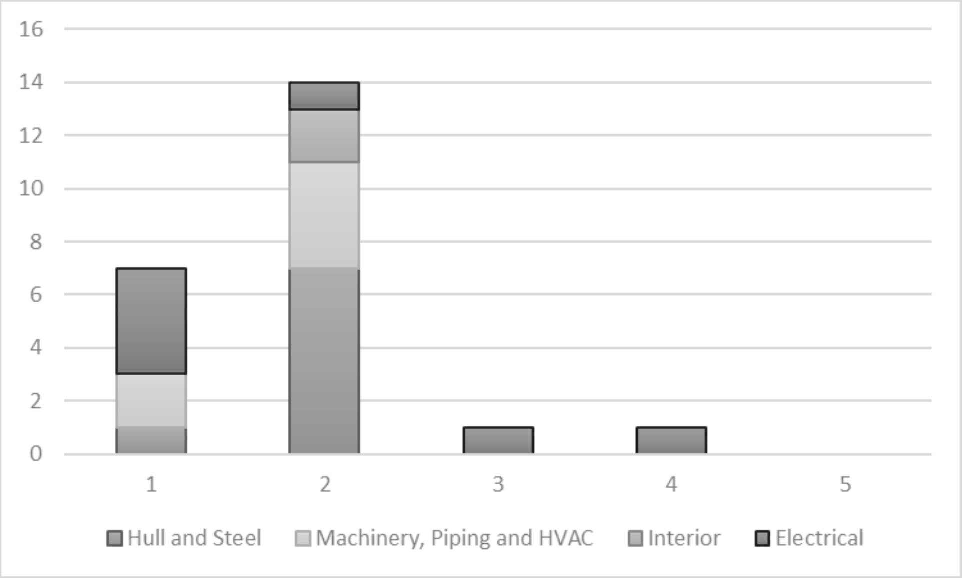


	1	2	3	4	5
Department leader	0	0	0	2	0
Coordinator	0	3	1	6	0
Engineer	0	2	3	4	2
Sum:	0	5	4	12	2



Q10. How do you experience the amount of resources?

	1	2	3	4	5
Hull and Steel	1	7	0	0	0
Machinery, Piping and HVAC	2	4	0	0	0
Interior	0	2	0	0	0
Electrical	4	1	1	1	0
Sum:	7	14	1	1	0



	1	2	3	4	5
Department leader	1	1	0	0	0
Coordinator	4	6	0	0	0
Engineer	2	7	1	1	0
Sum:	7	14	1	1	0