



Master's degree thesis

LOG 950

Waste in shipbuilding supply chains; A lean perspective; A case study of Ulstein Verft AS

Ragnar Olsvik Hovind

Number of pages including this page: 132

Molde, 21.05.2012



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Preface

This master degree thesis is the final stage of the Master of Science in Logistics degree at Molde University College, and has been written during the winter and spring 2012. This thesis has been a part of the *Lean shipbuilding II* research program between Molde Research Institute and Ulstein Verft, and has been carried out in collaboration with Ulstein Verft AS and GS-Hydro Norge AS.

The thesis has been completed with guidance from supervisor, Associate professor Bjørn Guvåg, and co-supervisor Karolis Dugnas, Research scientist at Molde Research Institute. I would like to sincerely thank both for valuable guidance, comments, discussions and advices during this research.

Furthermore, I would like to thank Ulstein Verft AS for the opportunity of writing my master thesis with the shipyard and to learn about the intriguing industry of shipbuilding. I particularly appreciate the time and readiness of the interviewees in Ulstein Verft to provide information. In addition, I would like to specifically express my gratitude to Planner Odd-Sverre Volle who served as my contact person in Ulstein Verft, for the time and willingness to provide information and organise my interviews and visits to the shipyard.

Finally, I would like to thank GS-Hydro Norge AS, and particularly Logistics manager Idar Brunvoll and distribution coordinator Cato Bjerkevold for their time and effort of providing information and their enthusiasm in participating in this thesis.

Molde 21.05.2012

Ragnar Olsvik Hovind

Summary

The purpose of this thesis has been to highlight, in a lean perspective, where and why waste occurs in two different supply chains both serving Ulstein shipyard with components. The first supply chain consists of GS-Hydro, supplying B- and C-components to Ulstein Verft, while the other supply chain consists of Brunvoll, supplying A-components to Ulstein Verft. This thesis is a part of the *Lean shipbuilding II* research program with Ulstein Verft and Molde research institute, and is the first study to investigate where delays and interruptions occur in the supply network of a shipyard.

Therefore, an exploratory-explanatory, qualitative case study approach was selected. Evidence was mainly collected through open-ended interviews, observations, and archival records and documentations. The theory has been centred on lean, supply chain management (SCM) and lean SCM.

The findings suggest that waste in the flow of materials from GS-Hydro to Ulstein Verft is related to excessive inventory, excessive transportation and waiting. This is caused by the lack of collaboration and coordination between the two firms. The analysis on the information flow between Brunvoll and Ulstein Verft revealed three features in the procurement process as having large impact on lead time and increased the complexity of the information flow; competitive bidding, high level of customisation and change orders, and waiting. The sources of this were mainly the concurrent engineering nature, high level of transactional contracting and lack of coordination between the two firms. For the internal flow of materials within the shipyard, wastes identified were related to excessive inventory, excessive transportation and waiting. This mainly caused by lack of planning, control and coordination. The actual findings corresponded with previous findings in the theory.

The thesis concludes that lean SCM principles can be applied to reduce and eliminate waste in the supply chains serving Ulstein shipyard or other Norwegian shipyards, but emphasises the importance of taking the lean SCM principles of continuous flow, pull, collaboration and value stream thinking, and develop specific tools and methods tailored to the Norwegian shipbuilding industry, rather than directly copying tools and techniques from other industries as a means to eliminate waste in the supply chains.

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List of abbreviations

ATO	Assembly-to-order
CODP	Customer order decoupling point
CONWIP	Constant work in progress
ERP	Enterprise Resource Planning
ETO	Engineer-to-order
GSCF	Global Supply Chain Forum
IT	Information technology
JIT	Just-in-time
LCI	Lean Construction Institute
MFM	Møreforskning Molde (Molde Research Institute)
MTO	Made-to-order
MTS	Made-to-stock
MUC	Molde University College
NNVA	Non-value adding, but necessary activity
NVA	Non-value adding activity
OSV	Offshore service vessel
PPC	Percentage Plan Complete
SCM	Supply Chain Management
TPS	Toyota Production System
UPS	Ulstein Production System
VAA	Value adding activity
VSM	Value stream mapping

1. Introduction

1.1. *Background*

The Norwegian shipbuilding industry is recognised for its high quality, high delivery reliability and competence in building complex and highly customised specialised vessels such as offshore service vessels (OSVs) and seismic vessels. This competence has developed over the years as the high costs of labour in Norway have made it difficult for the Norwegian shipyards to compete with shipyards in low-cost countries in building standardised low-cost vessels (NOU 2005).

However, the industry has over the last years struggled to remain profitable and competitive due to several challenges. Firstly, before the financial crisis, the Norwegian shipyards experienced an order boom causing problems for the shipyards to finish projects on time due to lack of capacity, of both labour and supply and low supplier reliability. This resulted in costly delays and low margins for the shipyards (Aslesen 2007; Hervik et al. 2011). Secondly, during the financial crisis the shipyards experienced a decrease in orders for new vessels. This combined with increasing competition from shipyards in low-cost countries, resulted in pessimistic outlooks for the Norwegian shipbuilding industry in the years during the recession, with many of the shipyards not receiving new orders (Hervik et al. 2010).

Although Hervik et al. (2011) report an increase in order levels and the margins for the shipyards in Møre and Romsdal for the years after the recession, the future prospects for the shipbuilding industry are somewhat mixed. On one hand, the current economic climate regarding the debt crisis of several EU countries, the US and Japan is a source of uncertainty regarding the funding of new ships. On the other hand, however, the discoveries of new oil fields of the coast of Norway, as well as in Brazil, Australia, of the coast of West-Africa and Brunei have resulted in optimism for the future of the Norwegian shipyards building offshore service vessels that are capable of serving the new challenges in current markets, such as the increasing complexity in subsea operations. In addition, Hervik et al. (2011) point to how the offshore service industry is currently renewing their fleet, as well the offshore industry will have to increase their capacity as a result of the new oil field discoveries. Consequently, the future prospects

for the Norwegian shipbuilding industry are mixed between optimism regarding the new oil fields and pessimism regarding the international economic climate.

The challenge for the Norwegian shipyards, however, is to maintain a quality, technological and innovative advantage while reducing costs and lead time for building a vessel, in an industry with frequent change orders, global supply chains and the competition from shipyards in low- cost countries, particularly as shipyards in low- cost countries are starting to investigate the possibility of building same type of vessels as the Norwegian shipyards (Hervik et al. 2011, 2010).

In order to address these challenges, Ulstein Verft AS (hereafter referred to as Ulstein) in cooperation with the Norwegian research council's innovation program MAROFF, the shipyards STX Europe and Kleven Maritime as well as Molde University College (MUC) and Møreforskning Molde (MFM) engaged in a research- and development project named *Lean shipbuilding- innovative shipbuilding in a Norwegian context* from 2006 to 2009. Inspired by the concept of lean construction, the goal was to tailor lean thinking to the project-based production of the Norwegian shipbuilding industry by enhancing the understanding of the Norwegian shipbuilding industry in a lean context, as well as developing lean methods and tools to the industry.

As a part of this initiative, Ulstein started implementing the Last Planner system for planning and control in 2006. The Last Planner is a planning tool divided in different levels, hierarchically organised. In contrast to traditional planning tools where the master plan often dictates the weekly working plan through a "push" approach, the Last Planner uses a "pull" approach where the weekly work tasks are assigned based on what activities which are actually feasible to complete. This is decided by the Last Planner (weekly work plan), while the roles of the other planning levels are to facilitate and make ready for the completion of the activities. There are seven preconditions, or flows, that have to present to ensure the feasibility to complete an activity. These are materials, information, personnel, equipment, prior work, space and external conditions. Furthermore, the executing level is responsible to carry out analysis with respect to plan and actual completion, often using percentage plan complete (PPC), to understand reasons for failure to complete tasks and to take corrective actions (Mossman 2005).

After the implementation of the Last Planner, Ulstein has experienced increased transparency in the projects with respect to flows required to complete an activity and increased knowledge of sources of variability and uncertainty in the projects (Toftesund 2007).

Currently, Ulstein in cooperation with MUC, MFM and FAFO are continuing the work to develop a new concept for shipbuilding based on lean principles in a new research project entitled *Lean Shipbuilding part II*. The aim is to increase productivity and reduce the costs of building ships in Norway. The research project has two main focus areas:

- **Project logistics**

The concept is developed to emphasise that project based production has its own logistics, both concerning the physical flows and organisational aspects in a value chain perspective.

- **Social logistics**

The concept is used to emphasise the social cooperation required in a project based production setting, with the basis of the mutual dependency between activities and functions.

Within the project logistics focus area there are three targets; (1) to develop and test methods to improve the internal flows in the shipyard of information, equipment, personnel and particularly materials, (2) to develop and tests methods to improve the external flow of materials and components to the shipyard and (3) to identify bottlenecks with respect to external production, as a basis of developing efficient organisational solutions.

This thesis is a part of the *Lean shipbuilding part II* research project within the project logistics focus area. The purpose and scope of the thesis will be described in the next section.

1.2. Purpose and scope of study

The ultimate goal of the lean shipbuilding research at Ulstein described above is to develop the Ulstein Production system (UPS), a production system based on lean principles and techniques tailored for the specific characteristics and facilities of Ulstein (Toftesund 2007). The first step towards the UPS has mainly been related to planning and control with the implementation of the Last Planner system. In addition, research has been conducted on work-time utilisation and warehouse management at Ulstein. The findings from the work-time utilisation study indicated that only 27 percent of the time was actually value adding, while the warehouse management research highlighted challenges in the warehouse such lack of space and excessive workload for the warehouse personnel (Ugland and Gjerstad 2010; Longva 2009).

The current research project “*Lean Shipbuilding part II*”, focusing on the concepts of projects logistics and social logistics as described above, is the second step towards the UPS. Longva (2009) describes that the ultimate vision for Ulstein for the material flow within the shipyard is that required materials should be transported to production workers just-in-time and possibly as work packages which include drawings, tools and components for whole work operations.

As a part of this, this thesis will focus on the flow of materials into production. More specifically, this study will investigate both the external flow of materials to the shipyard, and the internal flow of materials within the shipyard.

Furthermore, since this is the first study investigating the flow of materials after the introduction of Lean Shipbuilding at Ulstein, the purpose of this study is to contribute to the understanding of what in the value stream that delays and interrupts the flow of materials, and why these delays and/or interruptions occur. The research problem for this study will be described in the next section.

1.3. Research problem

Mossman (2007) put forward that project logistics create no value in itself, except for the assembly or processing work, but is rather a process of aligning the operations needed to deliver a structure or building.

Reflecting on this, one may argue that even though project logistics creates no value in itself, aligning the activities and operations required to deliver a ship is crucial to obtain a continuous flow of materials, with the result of shorter lead times and lower costs.

As outlined above, this is the current focus of the research at Ulstein. In addition, when GS-Hydro, a supplier of standard components changed from several regional to one central warehouse in 2011, this added further interest to what activities in the value stream that delay the flow of materials. Particularly as this, from Ulstein's point of view, resulted in materials were received later on the delivery route with more variability.

Polat and Ballard (2003) put forward that the main purpose of supply chains is to maximise operational efficiency, profitability and competitive advantage of the partners involved by fulfilling the needs of the end- customer, and the supply chain performance can be measured with metrics such as time, cost and quality. Mentzer et al. (2001) describe how a supply chain consist of all the parties (three or more) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer.

Although a supply chain consists of more than two parties, within the boundary conditions of this thesis only Ulstein and a first tier supplier will be considered.

The research problem of this thesis is to investigate the flow of materials in a lean perspective of two different supply chains serving Ulstein, with a particular focus on what is delaying the flow of materials in the two supply chains and the sources of these delays. One can expect that delays occur due to non-value adding activities, constraints or bottlenecks, or other structural arrangements in the supply chains. The research question is therefore:

What causes delays in the flow of materials in two different supply chains serving the same shipyard, and what are the underlying sources of these delays?

The supply chains are different with respect of the type of components flowing through the value stream. The first supply chain consists of Ulstein and GS-Hydro. The components supplied by GS-Hydro are mainly standardised and include for instance pipes, tubes and valves. For each vessel a vast number of these components are required, with each component having a relatively low unit value. The materials flowing in this value stream can therefore be described as high-volume–low-value components. The volume and type of components Ulstein orders from GS-Hydro varies from project to project, depending on the size and type of vessel, rather than direct specifications from the client. Due to the current nature of this value stream, the main focus will be on the flow of materials from Ulstein places an order to the components are received, stored and used at Ulstein. Within this, some consideration will be made to how GS-Hydro manage their suppliers (tier 2 suppliers) as well as the impact of GS-Hydro’s change from regional to a central warehouse on the flow of materials will be discussed.

The second supply chain consists of Ulstein and Brunvoll. Brunvoll is a supplier of thrusters to Ulstein, and the components flowing in this value stream can be described as low-volume-high-value components. In addition, the thrusters are complex, and can be highly customised with respect to the specifications from the client. In addition, each thruster is also an independent project at Brunvoll. As the components flowing in this value stream require more detailed engineering and specifications compared to the value stream consisting of GS-Hydro, and since Brunvoll is not an active participant in this thesis, the main focus will be on the information flow from Ulstein initiates contact with Brunvoll, and the flow of materials within the shipyard. The Brunvoll- Ulstein supply chain link will be evaluated in terms of Ulstein’s build no.295.

Consequently, there are clear differences in the two value streams in terms of complexity and size of the components, lead time and the location and production system of the suppliers.

Due to these differences, one may expect differences in the performance of the two supply chains and also differences in waste. The two supply chains will therefore be compared with respect to waste and sources of waste.

1.4. Outline of thesis

This thesis is divided into five main chapters: the introduction, the literature review, the methodology, case study findings, and the discussion and conclusion.

The first chapter will introduce the background, the purpose of the study as well as the research problem and limitations of the study.

The literature review is focusing on lean theory and supply chain management (SCM), including the concepts of lean principles, lean construction and shipbuilding, as well as concepts within SCM, and lean SCM. This chapter will provide the theoretical background for the case study and discussion.

Following this, the methodology chapter describes how the research problem will be aimed to be solved through an exploratory-explanatory case study, and the data collection methods used.

The case study findings will describe the findings in the current state of the two supply chains. In both cases the current state will be mapped and described and the waste identified will be discussed.

Finally, in the last chapter the sources of waste in the two supply chain will be discussed and compared, before the conclusion will summarise the findings of this thesis and the corresponding managerial implications and further studies will be outlined.

1.5. Limitations

This thesis is based on a qualitative research, as requested by Ulstein. Consequently, the findings are not supported by a quantitative analysis of the value streams. This means that statements and perceptions from selected employees along with observations and some archival records will be used as evidence to support the findings, instead of quantitative evidence such as statistical calculations or mathematical models. The archival records that are used in the analysis of the value streams are used in the sense of indicating where delays may occur, rather than for thorough scientific analysis. The result is a qualitative understanding and indication of where and why delays occur in the flow of materials in the value streams, which is also in coherence with the purpose of the study.

Similarly, with respect to the discussion concerning the impact of GS-Hydro's change to a central warehouse, the thesis will not conduct a quantitative analysis or go into other details about the ideal location and number of warehouses, but rather highlight the impact the change has had on the flow of materials from a qualitative perspective based on the supply chain partners' views.

Another limitation of the thesis is that Brunvoll is not participating in the research. Brunvoll is not participating due to lack of time and resources available, as a result of high order levels and time consuming implementation of a new ERP system. To deal with this, Brunvoll is treated as a "black box", and the value stream is only considered from Ulstein's view. As a consequence, the analysis of this value stream lacks to some degree a holistic perspective.

2. Literature review

This section will review the relevant literature for this research. The first part will give a brief introduction to lean philosophy, including lean production, lean wastes and lean principles. Following this, some lean tools will be outlined, before the concept of lean construction will be discussed. After that, this chapter will go into more detail on more specific literature for this thesis. This will include a review of peculiarities of the shipbuilding industry, and how the concept of lean can be applied to shipbuilding. This will be followed by a discussing of the supply chain management (SCM) concept, and how SCM can be related to construction and shipbuilding including what is currently being considered as waste in construction supply chains. Lastly, important factors to achieve lean SCM will be discussed.

2.1. *Lean philosophy*

Lean philosophy is a production philosophy originating from the Toyota production system (TPS), with a focus on eliminating and reducing non- value adding activities. It gained particular interest from the rest of the world as a result of performance gap between Toyota and other car manufacturers (Holweg 2006). Lean philosophy offers a way to do more with less; *“less human effort, less equipment, less time and less space- while coming closer and closer to providing customers with exactly what they want”* (Womack and Jones 2003, 15).

Furthermore, lean thinking provides a method to specify value, line-up value creating activities in the best sequence, use pull- techniques and achieve continuous improvement (Womack and Jones 2003). Further elements of a lean philosophy are discussed below.

2.1.1. Lean production

From its origin in the TPS, the term lean production was first coined by Womack et al. (1990) in the book *“The machine that changed the World”* to describe the philosophy of the TPS. Although lean production originated from the TPS, the fundamental principles of lean production is not culturally bound to Japan, but rather universally applicable (Holweg 2006; Womack, Jones, and Roos 1990).

Lean production is a business philosophy which spreads across all areas of production, including the supply chain, with the focus on eliminating non-value adding time

without compromising quality or on-time delivery (Womack, Jones, and Roos 1990). It is also defined as a method of manufacturing that focuses on shortening the time between customer order and the delivery by eliminating sources of waste, with waste being defined as anything that does not add value to the end product, while using less of everything compared to traditional mass production; less human effort in the factory, less manufacturing space, less investment in tools, less engineering hours, and less inventory in a warehouse (Liker and Lamb 2000; Womack and Jones 2003).

Shah and Ward (2007, 791) define Lean production as *“integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability”*.

It is important to emphasise that Lean philosophy is not about copying the principles and tools of Toyota, but rather developing principles that are suitable to the specific organisations, for instance a shipyard, and diligently practicing them to achieve high performance that continues to add value to customers and society (Liker 2004).

Correspondingly, Picchi (2001) put forward that lean thinking can be viewed from three levels; philosophy, system and techniques, where the philosophy view is a conceptual aspect, the system view is a coordination aspect and techniques is an operational aspect. He emphasises that the philosophy behind the systems and techniques is the most important element, particularly because direct applicability of techniques from one industry to another is limited due to specific characteristics of different industries (Picchi 2001).

2.1.2. Lean principles

Furthermore, Womack and Jones (2003) put forward lean thinking as a cyclic route to seek perfection, centred around four principles seeking a fifth:

1) Specify value

Value should be defined by the end customer, in terms of product specification meeting the requirements of the end customer at a specific time and price.

2) Identify value stream

Identify all the activities necessary to bring the product to the market, and eliminate activities that do not add value to the end product.

3) **Create an uninterrupted flow**

Make the value adding activities flow through the value stream to the end customer without obstacles such as delays and inventories.

4) **Establish pull**

The reduced lead time from the first three principles should facilitate for only producing to a signal from a downstream customer.

5) **Seek perfection**

The previous principles should allow for continuous improvement with the aim of maximising value for customers while eliminating waste.

Hines, Holweg and Rich (2004) argue that value is often seen equal to cost reduction, and thus there has been a tendency of lean thinking to focus on waste and cost reduction. However, as Womack and Jones put value in the first principle, they argue that lean has moved away from a “shop-floor-focus” on solely waste elimination and cost reduction, to focus on both enhancing the value for customers and the removal of wasteful activities (Hines, Holweg, and Rich 2004).

In lean, activities can be categorised into three categories (Hines and Rich 1997):

- **Value-adding activities (VAA)**

Value adding activities are activities producing value to the end product. The aim is to create a continuous flow of value adding activities.

- **Non-value adding, but necessary activities (NNVA)**

Non-value adding, but necessary activities are activities not adding value to the end-product, but are necessary for the value adding activities to occur. These should be minimised, as complete elimination would often require major changes in the system, which may not be feasible in the short-term.

- **Non-value adding (NVA)**

Non-value adding activities are pure waste, because they do not add any value to the end-product. These should ideally be eliminated completely.

Both NNVA and NVA activities are considered waste in lean. However, Koskela (2000) point out that some NNVA, such as planning and accounting, might produce value for internal customers, and should thus not be reduced without considering

whether more non-value adding activities would occur in other parts of the value stream. The waste aspect in lean will be further elaborated in the next section.

2.1.3. Waste

A fundamental aspect of lean production is the identification, elimination and prevention of waste, with waste being defined as anything that does not add value from the customers' (either internal or external) perspective. In addition to the original seven sources of waste in lean described below, two additional sources of waste have been added later; "design of goods and services that fail to meet the user's needs" and "unused employee creativity" (Hines and Rich 1997). However, only the original seven described below will be considered in this thesis.

- **Overproduction**

Overproduction is generally considered to be the most serious source of waste because it discourages a continuous flow of goods and services, and is likely to inhibit quality and productivity. Overproduction refers to producing too much, too early or "just in case".

- **Waiting**

Waiting occurs when time is not used efficiently, and this waste occurs when goods are not being moved or worked on. This affects both workers and materials, both spending time waiting.

- **Excessive transportation**

Every movement of goods can be considered waste, so the aim is usually to minimise transportation, rather than total removal. In addition, excessive movement and double handling of goods increases the risk of goods being damaged.

- **Excessive inventory**

Reducing excess inventory is critical as it tends to increase lead time, preventing fast identification of problems and increase space requirements. Unnecessary inventory can also relate to having material available too far in advance of when it is needed in production, thus increasing holding costs and likelihood for damaged goods.

- **Inappropriate processing**

This source of waste involves processing materials with overly complex machinery or equipment, or with unnecessary steps.

- **Unnecessary motion**

This source of waste involves employees' motion during their work, such as stretching and bending. These motions are tiring for the employees, and should be avoided or minimised, because they are likely to lead to lower productivity and often quality problems.

- **Defects (rework)**

Producing defect parts is considered waste as it requires rework and quality inspections which are wasted handling, time and effort.

Koskela (2000, 58) argue that there are three root causes of these non-value adding activities:

- 1) **The structure of the production system**

The flow of material and information is determined by the structure of the system, thus the amount of waste is related to the design of the system. Similarly, the site layout determines the flow of materials, and thus the amount of waste, between workstations.

- 2) **The way production is controlled**

This affects waste in at least two ways; (1) the control principles used may produce waste and deficiencies or (2) ignorance, in conforming to the control principles may produce waste.

- 3) **The inherent nature of production**

Waste exists in the inherent nature of production such as machine breakdowns, accidents and human error.

The TPS house, illustrated in figure 1, can be used to summarise lean production and the TPS. However, it is important to stress again that the purpose of lean production is not to copy the tools and principles of the TPS, but rather to develop tools and principles that are suitable to a specific organisation.

The basic idea of the TPS house is that every component has to be in place to keep the house steady. The goals are showed in the roof of the house; provide best quality at the

lowest cost, with the shortest lead time with best safety and high morale through shortening the production flow by eliminating waste.

Of the two building pillars, Just-in-time (JIT) ensures that the components are delivered when they are need, in the right amount at the right place, while built-in quality ensures that products are produced with the right quality with no defects. JIT and built-in quality are mutually reinforcing, creating a JIT flow leads to increased quality and without inventory buffers the JIT systems will fail if there are frequent quality problems that interrupt the flow (Liker and Lamb 2000; Liker 2004).

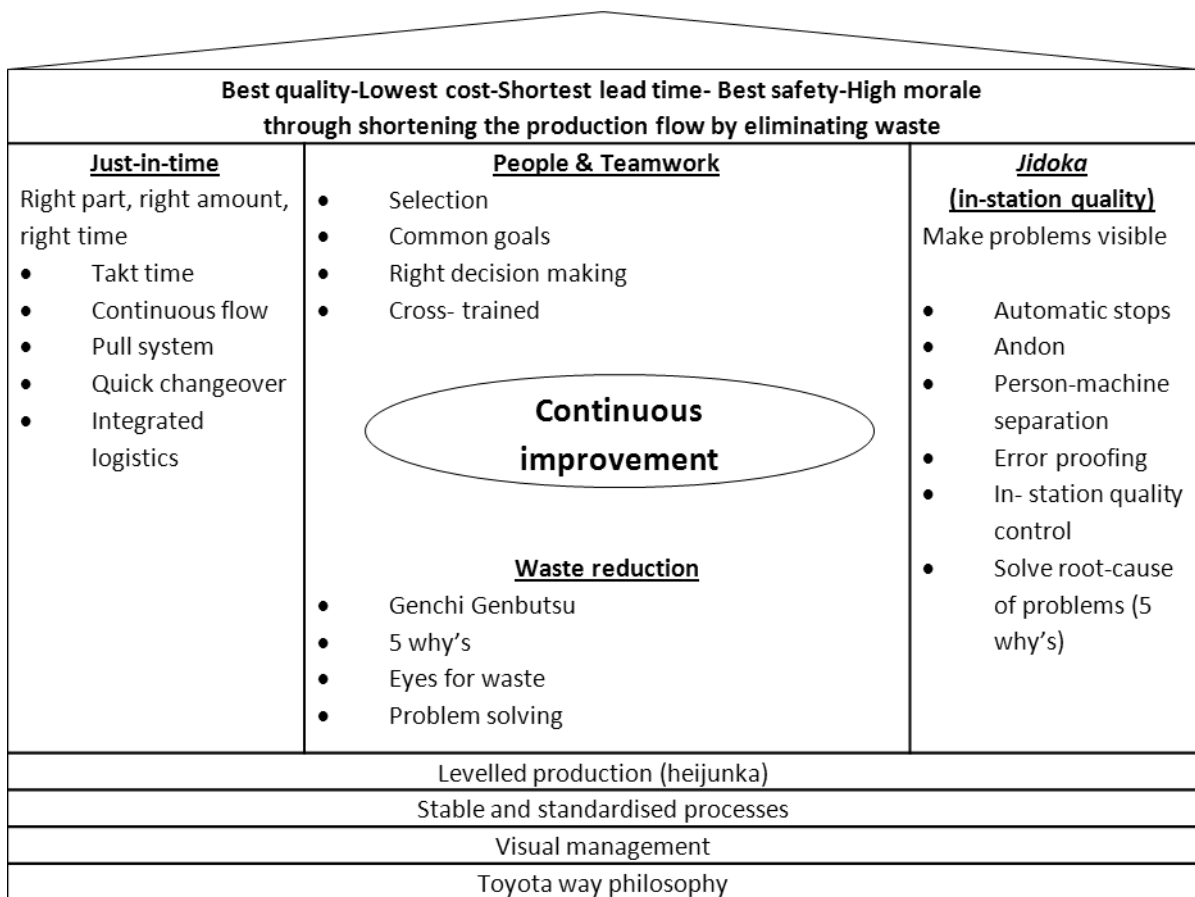


Figure 1: TPS House (based on Liker (2004))

2.2. Lean tools

In this section, the lean tools of value stream mapping (VSM) and 5S will be described. Although there are several lean tools, only these two are considered in this thesis. VSM is selected as this is a tool aiming to highlight non-value adding activities in the value streams, thus highly relevant for this thesis. 5S is selected because this is a tool aiming to organise the workplace to facilitate for a better flow and also as it was put forward by Longva (2009) as a way of improving warehouse management at Ulstein.

2.2.1. Value stream mapping

Value stream mapping (VSM) is a method to visualise and analyse the value streams by creating a map of the flow of materials from the supplier to the end customer, and the flow of information between the parties in the value stream. VSM facilitates for the identification of waste and the root causes (Kocakülâh, Brown, and Thomson 2008).

The purpose of VSM is to highlight sources of waste and eliminate them by implementing a future-state value stream, with the aim of having a value stream where the processes are linked to their customers by either continuous flow or pull, with each process being as close as possible to producing only what its customers require when they require it (Rother and Shook 2009).

There are four phases in VSM; 1) Selecting a product family, 2) create current state map, 3) create a future state map and 4) implementing. These four stages are described below (Rother and Shook 2009).

1) Selecting a product family

This is setting the boundary conditions for the value stream map, as drawing all product flows on one map is considered too complicated. A product family is a group of products that flow through similar processing steps using common equipment in the value stream.

2) Create current-state map

Using measurements such as cycle time, value-creating time and lead time, the current-state map highlights waste in the value stream and serves as the basis for developing a future state map.

3) Create future-state map

A future-state map is created where the waste from the current-state map is eliminated or at least reduced and the materials are pulled through the value stream in a smooth flow.

4) Implementation

The difference between the current- and the future-state map serves as a road map to start implementing the performance improvements (Arbulu and Tommelein 2002).

2.2.2. 5S

While VSM is often considered to be the basic tool for management to start implementation of a lean philosophy, the 5S tool is a method for keeping the workplace clean and organised, as a foundation for further improvements (Kocakülâh, Brown, and Thomson 2008). It was originally developed by Toyota to describe the proper methods of housekeeping, as a well organised workplace is necessary for stability. The 5S's, sort, straighten, shine, standardise and sustain, refer to the words included in the process of making the workplace clean and organised, and thus eliminate waste resulting from a poorly organised working area (Kocakülâh, Brown, and Thomson 2008; Liker and Lamb 2002).

1) Sort

Refers to the process of separating needed items from what is not needed, and removing the unneeded materials and tools.

2) Straighten

Involves defining a specific place for the needed items within the area they are needed, in order to facilitate for a continuous workflow and to minimise motion.

3) Shine

Focuses on cleanliness, and ensures that the workplace is kept organised, clean and ready for inspection.

4) Standardise

Focuses on maintaining and monitoring the first three Ss. These should enable standardisation of the best practice for the workplace.

5) Sustain

Maintaining a stabilised and organised workplace is an on-going process of continuous improvement.

2.3. *Lean construction*

This section will introduce the concept of lean construction. First, the history of construction and lean construction will be outlined, before the elements and peculiarities of construction will be described. Lastly, lean construction will be compared and contrasted with traditional construction.

2.3.1. History

Construction is a very old industry, with many of its cultures and methods having their roots in periods before scientific analysis. Nevertheless, after the Second World War, there have been many initiatives trying to understand construction industries and the problems within construction industries, as well as trying to develop corresponding solutions and improvement methods. Among these solutions and improvement methods, Koskela (1992) recognises strategic initiatives such as industrialisation, computer integrated construction and total quality management. Operational and tactical techniques that have been developed include project planning and control tools, organisational methods, project success factors and productivity improvement methods (Koskela 1992). Furthermore, Picchi (2001) suggest that construction has been one of the first industries to discuss lean philosophy outside a manufacturing environment .

On the other hand, the construction industries have rejected several ideas from manufacturing due to the belief that construction is different from manufacturing. More specifically, ideas from manufacturing have been rejected due to the fundamental differences between unique and complex construction projects in highly uncertain environments and mass production. However, Howell (1999) argue that waste in construction with a traditional project management approach arises from the same activity-centred focus as in manufacturing, namely by focusing on optimising each activity. Moreover, the boundary between construction and manufacturing is not clear. For instance, there is confusion whether a supplier of standard off-the-shelf products such as pipes and tubes to a shipyard is part of the construction or the manufacturing industry (Segerstedt and Olofsson 2010).

Nevertheless, lean philosophy focuses on improving the entire value stream, rather than individual processes and activities. The concept of lean construction has been

developed based on the principles of the Toyota production system, to tailor lean thinking to the peculiar characteristics of construction.

2.3.2. Elements of construction

There are particularly three essential elements of construction that differentiates construction from traditional manufacturing; (1) One-of-a-kind nature of projects, (2) site production and (3) temporary multi-organisations (Koskela 1992). However, Ballard and Howell (1998) argue that there are other types of production that possesses one or more of these characteristics, and therefore the uniqueness of a project is a relative matter.

Similarly, Koskela (1992) emphasises to what extent construction is not unique, and suggests actions in order to reduce the uniqueness of construction projects such as using standardised work flows and components and modularisation.

Nevertheless, a characteristic that clearly differentiates construction from traditional manufacturing is the “*fixed-position manufacturing*” characteristic. Fixed-position manufacturing means that the manufactured products become too large to be moved through work stations, so that the work stations have to be moved through the product (Ballard and Howell 1998).

The Lean Construction Institute (LCI) summarises lean construction as a “*production management based project delivery system emphasizing the reliable and speedy delivery of value. It challenges the generally accepted belief that there is always a trade between time, cost and quality*”(LCI 2012).

Similarly, Ballard and Howell (2004, 2) put forward that lean construction “*conceives a construction project as a temporary production system dedicated to the three goals of delivering the product while maximising value and minimising waste*”.

Koskela (1992, 16) has elaborated eleven principles from lean thinking which are applicable to lean construction:

- 1) Reduce share of non-value adding activities.**
- 2) Increase output value through systematic consideration of customer requirements.**

There are two types of customers for each activity; the next activity and the final customer, and value is generated by fulfilling customer requirements.

3) Reduce variability.

There are two reasons for reducing process variability: First, any deviation from target value causes a loss of value to customer, and second, variability increases the volume of non-value adding activities.

4) Reduce the cycle time.

Benefits of reduced cycle time include faster delivery to customers, reduced need to forecast future demand and decreased disruptions due to change orders.

5) Simplifying by minimising the number of steps and parts.

The construction process can be simplified by reducing the number of components in a product and reducing the number of steps in a material and information flow.

6) Increase output flexibility.

Increased flexibility can be realised by modularised product design, reduce difficulty of setups and changeovers and training a multi- skilled workforce.

7) Increase process transparency.

Make the production process transparent and observable to facilitate for control and improvement to all the employees.

8) Focus control on the complete process.

Avoid sub- optimisation and optimise the total workflow by engaging in long- term co-operation with suppliers and by letting self-directed teams control their processes.

9) Build continuous improvement into the process.

The effort to reduce waste and increase the value in the construction process must be carried out on a continuous basis.

10) Balance flow improvements with conversion improvement.

Both the flows and conversions have to be addressed. The potential for flow improvement is normally higher than conversion improvement and require lower investments, but flow improvements takes longer time to implement compared to conversion improvements.

11) Benchmark

Includes knowing the organisation's strength, weaknesses, threats and opportunities, knowing the industry leaders and competitors and create a competitive advantage by combining existing strengths with external best practices (Koskela 1992).

He argue that most of these principles address the elimination of non-value adding activities, but points out “*it is also possible to directly attack the most visible waste just by flowcharting the process, then pinpointing and measuring non-value adding activities*” (Koskela 2000, p. 58).

Ballard and Howell (1998) argue that the lean revolution is essentially a conceptual revolution, as the focus has shifted from solely to be on the conversion process, to also include the flow and value processes. They put forward that implementing lean in construction has two parts; (1) Minimising uniqueness of construction to take advantage of lean techniques developed in manufacturing, and (2) develop lean techniques suitable for dynamic construction.

Furthermore, they point to that implementing lean in construction projects does not imply making construction manufacturing by standardising products or using lean tools explicitly. Instead, implementing lean means developing standard procedures to plan and manage construction projects, thus adopting a “project-as-production-system” approach to construction, while understanding the principles offered by lean, to maximise value and minimise waste (Ballard and Howell 1998).

On the other hand, Jørgensen and Emmitt (2008) argue that many lean construction publications are not built on solid theoretical ground because the management books on which these publications are based on do not refer to scientific research methods for validating the results. The lack of empirical evidence within the field of lean construction is therefore a weakness of lean construction concept. In addition, they point to the lack of a common definition of the concept of lean construction as a weakness of lean construction (Jørgensen and Emmitt 2008).

2.3.2.1. Traditional construction vs. Lean construction

Ballard and Howell (2004) suggests that there are four roots of the emergence of Lean construction as a new approach to construction projects; the success of the TPS, dissatisfaction with project performance, efforts to establish a theoretical background to project management and the failure of traditional thinking and practice to explain facts. The method of managing construction projects based on lean principles is fundamentally different from the traditional approach to managing construction projects. The most fundamental difference between lean and traditional construction is

related to scheduling. While lean construction is based on a pull work schedule, traditional construction uses a push work schedule. This is a clear difference, as a pull system schedule work based on actual downstream demand, while a push system schedule work based on system status (Ballard and Howell 2004).

Production processes can be viewed in three different ways; (1) a process of converting inputs to outputs, (2) as a flow of materials and information through time and space and (3) as a process of generating value to the end customer. However, while the process of converting inputs to outputs has been dominating view in the construction industry until very recently, the flow concept is applicable to construction industries because production in construction is of assembly-type, where different material flows are connected to the end product (Koskela 2000; Ballard and Howell 2004).

In particular, the flow principle is important in lean construction because it focuses on eliminating non-value adding activities, to ensure a continuous flow of value adding activities (Koskela 2000).

2.4. *Lean shipbuilding*

This section will outline the concept of lean shipbuilding, which is a concept tailoring lean thinking to shipbuilding. First, however, the characteristics of shipbuilding will be outlined, with a particular focus on the Norwegian shipbuilding industry. Following this, the concept of lean shipbuilding will be described and the applicability of lean thinking to Norwegian shipbuilding will be discussed.

2.4.1. Shipbuilding

The characteristics of shipbuilding vary across countries and sectors, usually due to the degree of complexity and the level of customisation of the ships. For instance, shipbuilding in Norway is recognised by a high level of complexity. The characteristics below are highly relevant for the Norwegian shipbuilding industry, and can also be, particularly consistent production facilities and fixed position manufacturing, related to shipbuilding in other countries (Dugnas and Oterhals 2008; Liker and Lamb 2002; Aslesen and Bertelsen 2008; Longva 2009):

- **One-of-a-kind production**

Ships are engineered-to-order products, with typically significant differences in designs and specifications between different ships. Although some small series of ships may occur, each ship is customised to the owner's specific requirements. However, shipbuilding is similar to mass production in terms of repeatable standardised processes such as welding and production line for pipe fabrication.

- **Consistent production facilities**

In contrast to construction, each shipbuilding project takes place within the same production facilities at the shipyards. The established production infrastructure also ensures a higher degree of repetitiveness in the flow of materials, compared to traditional construction.

- **Fixed position manufacturing**

Shipbuilding is in similar fashion to construction characterised by fixed position manufacturing, as the ships are too complex to move around, with workstations moving through the ship.

- **Temporary organisations**

Due to the project driven nature of the shipbuilding industry, temporary organisations are created to manage specific projects. There is, however, less randomness in shipbuilding projects' organisation compared to construction.

Dugnas and Oterhals (2008) points out additional characteristics that differentiate Norwegian shipbuilding industry from traditional construction industries. These are outlined below.

- Design, SCM and production activities are integrated and carried out simultaneously – it is rather a rule than an exception.
- Significant prefabrication and pre-outfitting of units and modules off-site.
- Advantage of supply network within the Norwegian Maritime Cluster.
- Significant customisation and innovation- also during construction phase (it is common with change orders).

In addition, the industry is cyclical industry highly volatile with the economic climate. In economic booms, the industry is typically capacity constrained (critical lead times

and lack of workforce), while in recessions the industry has typically excess capacity (Dugnas and Oterhals 2008; Hervik et al. 2009).

There are typically four key production phases in the Norwegian shipbuilding industry; (1) Hull fabrication, (2) Primary outfitting, (3) Final outfitting and (4) Testing. The two first phases are normally outsourced to shipyards in low-cost countries, while the final outfitting and testing is performed at the shipyards' facilities (Dugnas and Oterhals 2008).

Furthermore, the shipyards rely on a complex network of suppliers of components, with an increasing part of the production being performed by trade contractors. It is therefore clear that shipbuilding is a highly complex, multi-phase and multi-actor process including several different operating, several disciplines and a wide range of suppliers. This makes the shipbuilding process similar to the construction process (Aslesen and Bertelsen 2008). Consequently, as lean principles are already being widely applied to construction industries, it can be argued that lean principles are also applicable to the shipbuilding industry. This will be discussed in the next section.

2.4.2. Application of lean principles to shipbuilding

As a result of the characteristics of the shipbuilding industry, Dugnas and Oterhals (2008) argue that shipbuilding can be treated similarly to construction with regards to transferring lean principles to shipbuilding. Furthermore, they point to how the characteristics described above serves as a background for analysis to define how lean principles can be applied to shipbuilding.

In similar fashion, Liker and Lamb (2000) argue that lean thinking is applicable to shipbuilding due to particularly two points. First, the basic principle of giving customers what they want with shortened lead times and less waste applies to any industry. Secondly, they point to leading shipbuilding models which have much of the same underlying philosophy as the TPS at work in building ships. Particularly, they point to Japanese shipyards that use modular designs, highly standardised processes and JIT deliveries of raw materials. In addition, Liker and Lamb (2002) point to be process of continuous improvement as being applicable to any process.

Nevertheless, even though shipbuilding can resemble construction in some areas, it is clear that shipbuilding differs from construction. Therefore, it should be emphasised

that application of lean principles to shipbuilding in Norway is not about copying lean tools and techniques from lean manufacturing or lean construction (or lean shipbuilding in Japan), but rather developing own tools and techniques tailored to the specific needs, including strategy, organisational culture and facility layout, of the shipyards aiming to apply lean principles (Dugnas and Oterhals 2008).

2.5. Supply chain management

In this section the origins of supply chain management (SCM) will be outlined, SCM will be defined and the concepts of SCM will be described. Furthermore, this section will describe construction SCM and typical waste in construction supply chains. Lastly, this section will discuss how the SCM concept relates to the shipbuilding industry.

2.5.1. Origins and definitions

The term supply chain management (SCM) first emerged in the literature in the mid-1980's. However, the concepts which SCM is based on are significantly older, and include managing inter-organisational operations, systems integration research and information sharing (Cooper, Lambert, and Pagh 1997).

Similarly, Vrijhoef and Koskela (2000) point to how SCM emerged from manufacturing industries, particularly the JIT delivery system of the TPS, which aimed to regulate supplies to the Toyota factory in the right amount, right time and right place. In addition, they point to the work of Deming (1982), who argued that working with suppliers in a long-term relationship of trust and loyalty would improve the quality and reduce the cost of production (Vrijhoef and Koskela 2000).

Furthermore, Mentzer et al. (2001) point to the influence of Forrester (1958) and how his identification of key management issues such as interrelationships between different functions within a company and between different companies, are referred to within the concept of SCM.

Mentzer et al. (2001, 4) define a supply chain as *“as a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer”*. They point to how different authors define SCM either in operational terms involving the flow of materials and products, as a management philosophy or in terms of a management process (Mentzer et al. 2001).

There are many different definitions of SCM. In this thesis, however, the definition of SCM from the Global Supply Chain Forum (GSCF) will be used. They define SCM as (Lambert and Cooper 2000, 66):

“Supply Chain Management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders.”

Other stakeholders in this definition relate to other involved parties in the supply chain such as suppliers and the focal firm. In this respect, an important aspect of SCM is to create value for all involved parties within the supply chain, with a focus on satisfying end-customers’ needs through collaboration and coordination. Furthermore, it views supply chains as an integrated value-generating flow rather than a set of independent activities.

In contrast, the traditional way of managing the supply chain focuses on the conversion view of production. The waste arising from supply chains which are not integrated or streamlined include unnecessary variability, excessive inventory and lack of control (Lambert and Cooper 2000).

2.5.2. Concepts

Building on the previous section, this section will describe the concepts of supply chain lead time, the two flows in a supply chain; materials and information, the four supply chain structures, make-to-stock, make-to-order, assemble-to-order and engineer-to-order and ABC-classification of components.

2.5.2.1. Supply chain lead time

The supply chain lead time is the time required for a material to flow through the processes and activities in the supply chain, from origin to end-customer.

The lead time depends on various factors such as the complexity of the products (Arbulu and Tommelein 2002). Koskela (2000, 58) argue that supply chain lead time is comprised by four elements; (1) processing time, (2) inspection time, (3) wait time and (4) move time. He argues that only the processing time adds value to the end- product, while the other elements are non-value adding activities.

Furthermore, Koskela (2000, 60) put forward that benefits of compressing the lead time are:

- Faster delivery of the product or service to the customer
- Reduced need to forecast future demand
- Decrease of disruption of the production process due to change orders
- Easier management because there are fewer customer orders to keep track of

2.5.2.2. Flow of materials and information

Within a supply chain there are three flows; material, information and capital. However, for this thesis only the material and information flows are considered.

Material flow refers to the flow of physical goods from origin through the processes and activities in the supply chain to the end-customer as a final product, while information flow refers to the flow of information between the involved parties in a supply chain (Harrison and Hoek 2008). Figure 2 illustrates a generic supply chain in manufacturing where materials flow downstream in the supply chain, while information flows upstream.

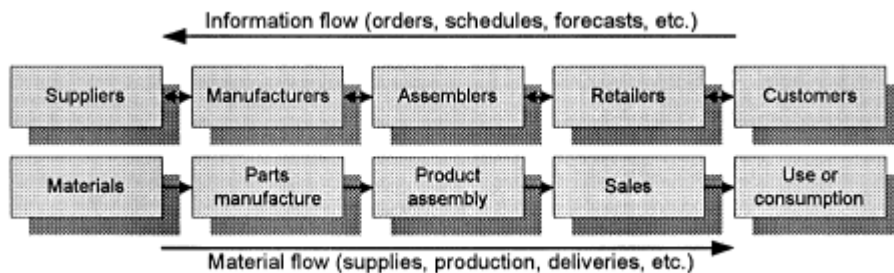


Figure 2: Generic configuration of a supply chain (Vrijhoef and Koskela 2000)

2.5.2.3. Supply chain structures

There are mainly four supply chain structures (in some form or another) for a supply chain; make-to-stock, make-to-order, assembly-to-order and engineer-to-order. One important element related to the supply chain can structures is the customer order decoupling point (CODP). The CODP is a stock holding point that separates the part of a supply chain that responds directly to the customer from the part of the supply chain that uses forecast planning (Gosling and Naim 2009). The four supply chain structures are described below (Gosling and Naim 2009; van Weele 2010).

- **Make-to-stock (MTS)**

Make-to-stock production is characterised by standard products being manufactured and stocked, with customers being serviced from an end product inventory. The decoupling point is located as finished goods at the supplier.

- **Make-to-order (MTO)**

Products are manufactured from raw materials or components inventory after an order from a customer has been received and accepted. The decoupling point is located at purchased goods.

- **Assembly-to-order (ATO)**

Only systems elements and subassemblies are in stock at the manufacturing centre and final assembly takes place based on a specific customer order. The decoupling point is located at finished goods in a supply centre.

- **Engineer-to-order (ETO)**

All the production activities from design to assembly and even purchasing of required materials are related to a specific customer order. The decoupling point is located at the design stage.

2.5.2.4. ABC- classification of components

A traditional method for classifying component or inventory is an ABC classification system, where components are classified as either A, B or C components (Arnold, Chapman, and Clive 2008; Ramakrishnan 2006).

- **A-components**

A-components are strategically important components, which counts for a small number of total quantities, but a large proportion of total value. In a project environment, A- components are typically ETO.

- **B- components**

B-components can be categorised between A and C components, in terms of both unit value and quantities required. In a project environment, B-components are typically MTO non-strategic, but project specific items.

- **C- Components**

C-components are “bits and pieces” or consumables, which counts for a large number of total quantities, but a small proportion of total value. In a project environment, C- components are typically MTS non-project specific components.

2.5.3. Supply chain management in construction

As discussed above, construction industries differ from traditional manufacturing. Consequently, construction supply chains have to be managed differently compared to manufacturing industries. According to Vrijhoef and Koskela (2000, 3), a construction supply chain in terms of structure and function can be characterised by three elements:

- It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The construction site is set up around one single product.
- It is, usually, a temporary supply chain producing one-off construction projects through repeated reconfiguration of project organisations. It is therefore recognised by instability, fragmentation and particularly separation between design and construction.
- It is a typical make-to-order supply chain, with every project creating a new product or prototype. Although there is usually little repetition, the processes can be very similar for projects of a particular kind.

As a response to these characteristics, Vrijhoef and Koskela (2000) have proposed that SCM has four specific roles in construction. The four roles are described below and illustrated in figure 3.

- **Role 1: Focus on the interface between the supply chain and the construction site**

The focus is on improving the flow of materials to the construction site through cooperation with suppliers.

- **Role 2: Focus on the supply chain**

This includes developing specific supply chain by considering a trade-off between transportation, inventory and production costs.

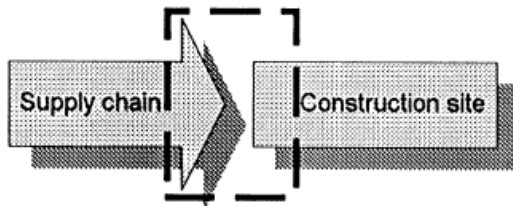
- **Role 3: Focus on transferring activities from the construction site to the supply chain**

This role focuses on transferring on-site activities off the construction site, by for instance prefabrication or modularisation, to reduce on-site activities.

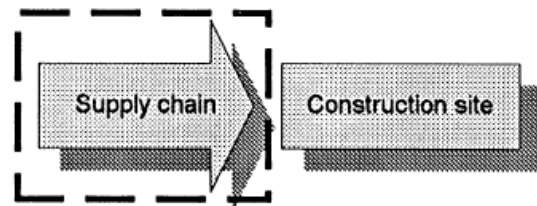
- **Role 4: Focus on the integrated management of the supply chain and the construction site**

The goal is to replace the usually temporary chains with permanent supply chains, through for instance standardising procedures and activities.

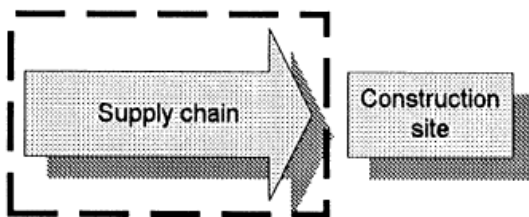
Role 1: focus on the interface between the supply chain and the construction site



Role 2: focus on the supply chain



Role 3: focus on transferring activities from the construction site to the supply chain



Role 4: focus on the integrated management of the supply chain and the construction site

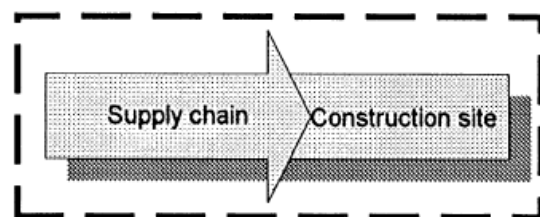


Figure 3: The four roles of SCM in construction (Vrijhoef and Koskela 2000).

Hamzeh et al. (2007) propose that the construction industry is characterised by high variations in supply and demand for resources such as material, equipment and services. The uncertainty causes inefficiencies and unresponsiveness within a supply chain with the result of supply-demand mismatches leading to increased lead time, poor utilisation of resources, increased supply chains costs and unsatisfied customers.

Along the same lines, Cox and Ireland (2002) suggest that construction supply chains are contested, fragmented and highly adversarial due to the conflicting nature of demand and supply. This has resulted in complicated structures of power between actors at each state of the supply chains (Cox and Ireland 2002).

Moreover, Ireland (2004) put forward that construction supply chains are often characterised by adversarial and opportunistic actors. In contrast to researches who propose a SCM approach of cooperation and partnerships between supply chain actors in response to this (for instance DETR (1998) and Vrijhoef and Koskela (2000)) he argue that such SCM approaches can only be implemented in certain power regime circumstances. In his paper, he concludes that SCM approaches are only possible in construction supply chains with power regimes with extended buyer-dominance or buyer-supplier interdependence. In addition, the regularity of demand is a significant variable determining whether proactive SCM approaches can be applied or not (Ireland 2004).

2.5.4. Waste in construction supply chains

Zimmer et al. (2008) put forward that most of the effort in implementing lean in construction has focused on field operations, while lean focuses on the entire value stream. Therefore, they argue that waste is still evident in the supply chain. Particularly, members of the supply chain often aim to maximise their own profit, while ignoring the effect on downstream members of the supply chain, which leads to waste in terms of ineffective supplier relations and transactions. Furthermore, they state (Zimmer et al. 2008, 382):

“These inefficient supply chains, along with incorrect design information, are bottlenecks which are inhibiting flow in the construction process, causing a “road block” for further value generation.”

Vrijhoef and Koskela (1999) conducted three case studies on construction supply chains to give insight to the waste and problems in these supply chains, and the causes of these wastes and problems. Their findings showed that time buffers had a large impact on the total lead time. The underlying cause of time buffers was separate planning in the supply chain due to inter-organisational barriers.

Furthermore, they drew three main conclusions from their case studies; (1) Waste and problems exist, even in normal situations, but this is not seen or ignored, with each actor

focusing on its own business, (2) the root cause of the waste is usually not found in the activity the waste is encountered, but in an earlier activity performed by another actor, often at a higher organisational level and (3) waste is caused by myopic control in the supply chain, with each actor optimising its own activity without considering the impact of downstream activities in the supply chain. The result is that a low proportion of the total lead time is value-adding time, while the majority of the total lead time is wasted time (Vrijhoef and Koskela 1999).

In their research on pipe supports, Arbulu and Tommelein (2002) found that causes of waste in the supply chain are mainly related to the time materials and information are waiting to be processed. Particularly, they point to the batching effect as a cause of waiting time. In their case, they put forward two examples of the batching effect. (1) Design information is sent from engineers to supplier in large batches, and (2) the completed materials are shipped in large batches from the supplier to the construction site. In addition, waste is often occurring on the interface between activities, processes or organisations.

Polat and Ballard (2003) evaluated the supply chains of cut and bent rebar for Turkish construction projects. Their results showed that wasted time amounted to up to three quarters of the total lead time. The main causes of this wasted time were inaccurate data transfers, lack of coordination between supply chain partners, lack of data format standardisation, infrequent deliveries due to high cost of shipping and priority changes. They concluded that these causes often resulted in interrupted materials and information flows.

Additionally, the material flow in a construction project is considered of major importance because project delays are often caused by lack of materials (Elfving, Tommelein, and Ballard 2004).

2.5.5. Supply chain management in shipbuilding

As outlined above, the Norwegian shipbuilding industry can be identified as ETO, where each ship being design and engineered one-of-a-kind, with rare exceptions where two identical “sister” ships are built. Mello and Strandhagen (2011) point to other characteristics of ETO operations, including high level of customisation, different components are required in different volumes and some components are highly customised while others are standardised.

Further, they point to how Norwegian shipbuilding also have some of the features of MTO operations, such as fluctuating demand cycles, project-specific components demands and uncertain production conditions.

Due to the complexity, multi-phased and multi-actor setup of the Norwegian shipbuilding industry, Aslesen and Bertelsen (2008) emphasise the importance of managing the coordination of multiple parties in the supply chains, particularly as each party can be expected to pursue its own agenda.

Similarly, Mello and Strandhagen (2011) discuss that a critical issue for SCM in shipbuilding is to efficiently integrate and coordinate the network of suppliers, subcontractors and shipyard resources. Moreover, they point to how attempts to developing collaborative relationships in a shipbuilding setting often are filled with frustration with the lack of trust, and that the lack of trust can be a result of adversarial relationship, low-volume and infrequent demand for many items and a price-competitive procurement approach,

Correspondingly, Dugnas and Uthaug (2007) found that shipyards report a significant stronger relationship with the suppliers than vice versa. They suggest that this can mirror the satisfaction with the relationship, where the shipyards are very satisfied with the supply conditions, while the suppliers feel they have no influence, and due to the frequent sourcing from the shipyards making the demand for new orders uncertain and variable for the suppliers.

In addition, they point to how some equipment now is procured directly from ship owners and how the development of a few large suppliers for the shipyards have changed the role of smaller suppliers to the shipyard.

Following in the lines of Vrijhoef and Koskela, it is clear that the supply chain of a Norwegian shipyard is a converging supply chain directing the materials to the construction site. In contrast to other construction projects, such as construction of buildings, shipbuilding is recognised by fixed production site, i.e. the shipyard.

Consequently, it can be argued that supply chains for Norwegian shipyards are to a lesser degree characterised by temporary supply chains if compared to other construction projects. This is particularly because the materials are flowing to the same location for each project. The supply chains are, however, temporary in terms of the partners involved in the supply chains for each project and the amount and type of

materials and information flowing in the supply chain, as these may differ depending on each project.

In addition, the supply chain for a Norwegian shipyard is also characterised by different partners in the supply chain have different supply chain structures for their upstream supply chain. For instance, a supplier of standard components may produce and manage its upstream suppliers based on a MTS or MTO supply chain structure. One issue for the management of shipbuilding supply chains is therefore how to integrate suppliers with a MTS/MTO supply chain structure into the ETO shipbuilding project. This issue of MTS and MTO components in a project environment will be discussed below, and compared to ETO components in a project environment.

2.5.5.1. B and C components in project environment

As described above, B and C components have in a project environment typically a MTO or MTS upstream supply chain structure.

Although B and C components are different in a theoretical perspective, no clear difference between these components with respect to the external flow of materials to the shipyard will be made in this thesis. This is because GS-Hydro, in contrast to Ulstein who view this as two different types of components (B and C), view these as similar components mainly supplied from their inventory, and are thus handled similarly by GS-Hydro, with the same lead time.

In terms of the internal flow after Ulstein receive the goods, the components are viewed and treated differently, particularly with respect to project specificity.

Nevertheless, in this thesis both B and C components are considered as standardised components with relatively low unit value, high volumes per project and short lead time. The main difference is how Ulstein classify B components as project specific items, and C components as consumables (non-project specific items).

Sanderson and Cox (2008) studied a supply chain delivering electrical cables, which are standard components, typically MTS or MTO, to a major UK shipbuilder. They argue that in a one-off or low-volume project environment, where there are typically significant differences in design and specifications between different ships, it is almost impossible to predict the parameters of demand (type, quantity and timing) based on past experience. They concluded that electrical cables used in shipbuilding have both features of a functional and innovative product. Most interestingly, however, is how a

supply chain of standard components such as electrical cables have the features of innovative products. These features are unpredictable demand pattern and a high margin in forecasting requirements. This is a result of building of the ship commences before the design is completed, and thus both the design and build schedule of a vessel are subject to on-going change (Sanderson and Cox 2008).

Furthermore, Sanderson and Cox (2008) discuss how the mixed characteristics of end customer demand is visible for standard components such as electric cables, with the demand is highly volatile and unpredictable, while the end customer is also price sensitive.

Tommelein et al. (2008) propose that finished goods inventory have zero lead time, and thus components can be shipped quickly to customers as well as it serves as a protection, or buffer, against uncertainties of customer demand. In addition, finished goods inventory allows for batch optimising, thus lowering the shipping and handling costs.

Although finished goods inventory can compensate for the lack of information and predictability of demand in one-of-a-kind construction projects, it disregards a holistic value chain perspective, important in both SCM and lean thinking. The lack of demand information also requires the supplier to hold a large product assortment at finished goods inventory, in order to maintain a high service level, thus creating waste in terms of excessive inventory.

However, in a project environment (such as Norwegian shipbuilding) some B (MTO) components have a long manufacturing lead time from manufacturer (second tier supplier), thus finished goods inventory at the first tier supplier can be seen as an important link between manufacturer and the construction site.

A further issue in this respect is whether the supplier should have one central warehouse serving all customers directly or several regional warehouses within a specific geographical area (for this thesis, say Norway).

Warehouses have particularly three roles within a distribution system; transportation consolidation, product mixing and service, and the aim is to provide the highest possible service at lowest possible cost (Arnold, Chapman, and Clive 2008).

It is generally considered that by adding more warehouses inventory and material handling will increase, while transportation costs decrease if the regional warehouses are replenished directly from a supplier (Arnold, Chapman, and Clive 2008). However,

if the regional warehouses have to be replenished from a central warehouse, it seems likely that transportation costs will increase as well.

On the other hand, the service level have to be considered and a regional warehouse has the advantage of being closer to the market, thus being able to serve the customer with a shorter lead time compared to a central warehouse. With respect to the location and number of warehouses there is therefore an important trade-off between cost and service level (Arnold, Chapman, and Clive 2008).

Although finished goods inventory in itself can disregard a holistic value chain perspective, in a Norwegian shipbuilding context it can be considered important as a link between the manufacturer and the shipyard and as a buffer protecting against uncertain demand. An important issue is still, however, to minimise excessive inventory, material handling and transportation to obtain a streamlined flow between a MTS supplier and an ETO project.

Arbulo et al. (2003) put forward how kanban can be utilised in construction supply chains, both to manage the on-site material flow and as a means to integrate MTS suppliers to a ETO project. A similar approach was suggested by Arbulo et al. (2005). This will be described in more detail later.

2.5.5.2. A-components in project environment

In terms of strategic components, ETO, these are recognised by high unit value, low volume and long lead time as customer orders are processed through engineering, detailing, fabrication and delivery, hence classified as A-components in a project environment.

The long lead time in combination with high uncertainty and variability in construction projects, can result in many design decisions having to be made early in the process, based on weak assumptions. This may again lead to suboptimal solutions, quality defects and rework. Consequently, compression the lead time in the delivery process of strategic components can have major impact on the project performance (Elfving, Tommelein, and Ballard 2002).

In a study on the delivery process of ETO products, Elfving et al. (2004) found several causes that increased the delivery lead time. In the design phase the causes included changes due to design errors, low level of design standardisation and non-sequenced “push” driven design, while causes in the procurement phase included serial

competitive bidding, large document batches and changes in product specifications. The component lead time and capacity constraints were the main causes of delays in the manufacturing phase.

Similarly, in an earlier study, the same authors described the information flow in the supply chain for ETO components as often being fragmented, complex and uncertain, while the material flow is often characterised by frequent change orders and long lead times. Particularly they point to the supply chain partners' lack of system perspective, as well as a lack of an overall coordination mechanism as major sources of delays and long lead times in the supply chain because it generates a lot of unnecessary work (Elfving, Tommelein, and Ballard 2002). They point to a vicious circle, where longer manufacturing lead times cause more engineering uncertainty and more engineering uncertainty causes more waste in the delivery process which again leads to longer lead times (Elfving, Tommelein, and Ballard 2002).

Accordingly, Forsman et al. (2011) studied the delivery process of a ETO component from a system perspective. Their findings suggest that improvements in construction supply chains are hindered by the partners' lack of a system view. Particularly they point to the fragmented information flow is a result of information needs are not met, lack of competence and lack of standardisation of the interface between the supplier and the customer. They therefore put forward a more standardised interface between the customer and the supplier as a solution to improve the information flow in the value chain.

Correspondingly, Azambuja and Formoso (2003) propose that most of the problems occur on the interface between parties in the supply chain, due to the ineffective information flows, lack of cooperation and poor coordination of the supply chain members. Particularly, they point to the lack of planning in the flow of materials between the supplier and the on-site activities as a major source of waste on-site in terms of inventories and unproductive workers. In addition, they emphasise the importance of correct positioning of large ETO components before installation, because poor position may affect the execution of other activities. As a result, they suggest a more formal planning to coordinate the flow of materials, as well as greater integration between suppliers and construction site (Azambuja and Formoso 2003).

Furthermore, Elfving et al. (2003) specifically question the true value of procuring power distribution equipment (ETO components) through competitive bidding. Their findings indicate that competitive bidding have a negative impact on delivery and

labour time. In terms of delivery time the impact was 2-3 months, while in terms of labour time they estimated that the cost of the bidding practice in itself amounted to 10 per cent of the value of the component. Particularly, they point to how competitive bidding increases fragmentation of the process and reinforces adverse goals, which leads to local optimisation rather than systems (or supply chain) optimisation.

In addition, they point to how document batch sizes have a major impact on the process lead time, and thus the largest lead time reduction in the delivery process of ETO components can be realised by reducing the document batch size and need for approvals. Interestingly, they conclude that the largest opportunity for reducing ETO lead time lies with improved document flow and not in reduction manufacturing lead time.

In addition, in a Norwegian shipbuilding context, the final decision with respect to selection of suppliers for strategic components is made by the client/ship owner, thus further complicating the competitive bidding process and information flow for ETO components.

2.5.5.3. Comparison of MTS, MTO and ETO

Tommelein et al. (2008) suggest that there are two types of construction supply chains. First, a construction supply chain may be part of existing, longer-lived supply chains that operate regardless of whether or not any specific projects exist. Second, a construction supply chain may be established for the purpose to meet one project's or several projects' needs.

In a Norwegian shipbuilding context, one can argue that MTS and MTO components belong to the first type of construction supply chains. This is due to that shipbuilding is fixed-site production, and normally there is at least one ship being built, thus there is a constant need for standard components, with each type of components, such as pipes, often being supplied from a limited number of suppliers.

By comparison, it can be argued that ETO components in a Norwegian shipbuilding context belong to the second type of construction supply chains. The reason for this is the low volume of components required for each project, as well as each type of components, such as thrusters, is not necessarily procured from the same supplier for each project.

Nevertheless, due to the fixed-position and that at least one ship is normally being built, the internal flow of materials is permanent, regardless of type of components and supplier.

Furthermore, Wegelius-Lehtonen and Pahkala (1998) suggest that even though products and components are different from project to project, the information and material delivery processes are almost the same in every construction project. They point to how material flows are most important for standard components, while information flows are most important for ETO components. In terms of material flows, they argue that the logistics costs as a percentage of the purchase price of standard components are higher compared to ETO components.

2.5.5.4. Internal logistics

Previously, during the first Lean shipbuilding in Norway research program, the concept of project logistics was used to describe the flow of parts and components within the shipyard (Dugnas and Oterhals 2008). Currently, however, within the *Lean Shipbuilding II* research program, the concept has been broadened to also cover external value streams, and thus the concept is currently used to describe all the flows of materials related to a specific project.

Nevertheless, the flow of components and parts within the shipyard is still an important aspect of SCM in shipbuilding and current meaning of project logistics. In this thesis, this flow of materials will be referred to as the internal flow of materials.

In a study on warehouse management at Ulstein, Longva (2009) discusses how the material flow at shipyards is characterised by limited space for storing materials at the work site. The use of time buffers when setting delivery dates for strategic components to reduce the risk of late deliveries increases the requirements for storage space further. Additionally, the different requirements in terms of materials, equipment and suppliers for different projects results in reduced possibilities to standardise materials and engage in closer cooperation with suppliers (Longva 2009). On the other hand, as outlined above, due to the fixed position and that there is usually at least one ship being built, shipyards can utilise the same infrastructure for material handling for all projects. As a result, it can be argued that shipyards have the possibility of standardising the internal flow of materials, at least to a certain degree.

Furthermore, because of the limited space available in the vessel and the insufficient coordination of deliveries and production, the warehouse function is a focal point in the shipyard because it serves as a buffer between suppliers and production to ensure timely deliveries of materials into production (Longva 2009).

2.6. *Lean supply chain management in construction*

Supply chain management is the traditional term for managing supply chains, and the concept of lean supply chain management arises when fundamental lean principles such as continuous flow and pull are included (Zimmer et al. 2008). Similarly, Wincel (2004) argue that the concepts of Lean and SCM intersect in terms of profitability and quality objectives as well as customer satisfaction.

Furthermore, Lamming (1996) argues that in contrast to traditional supply chain management, where the focus is on managing relationships with suppliers and customers, in lean supply the entire flow from raw materials to end-customer is considered as an integrated whole. Therefore, the traditional interfaces between companies are seen as artificial, only created as a result of the economic arrangements of assets. A fundamental principle of lean supply is that waste in one activity is not limited to that activity, but impacts the whole supply chain. Lamming (1996, 5) states:

“This is a fundamental point, since lean supply does not recognise the traditional positions of customer and supplier, which tend to obscure the central quest for the removal of waste.”

The purpose of lean SCM in construction is to accomplish supply management with minimal amounts of waste in construction projects. The focus is on developing relationships among the partners in the supply chain. Through coordination and collaboration the aim is to improve the total flow of materials in a construction project.

The rest of this section will describe and discuss elements considered important in order to achieve lean supply chain management in construction and shipbuilding.

2.6.1. Pulling to site demand and JIT

A central idea in implementing lean is to create a “pull” system. A pull driven approach means that materials are delivered when they are needed in the quantities needed (Tommelein 1998). By comparison, a push driven approach relies on forecasts, where the materials are pushed downstream in the supply chain. This creates waste in terms of overproduction and excessive inventory. Through the establishment of pull in the supply chain these wastes can be reduced, and material can flow through all the activities in the supply chain without excessive inventory (Tommelein, Ballard, and Kaminsky 2008). The most common term used in a pull system is Just-In-Time (JIT). In addition to the meaning of JIT that materials arrive in the right amount, at the right time, in the right place, it can also be described as the state in which value flow through the activities with minimum delays and waste (Kocakülâh, Brown, and Thomson 2008). In similar vein, Zimmer (2006) explains how the JIT aspect of lean construction involves delivering only what materials that are ready for installation, in the amounts needed, at the time needed, with the materials ideally are brought straight to the point of installation without interruptions such as storage or inspection.

Arbulu, Ballard and Harper (2003) put forward a kanban strategy to manage materials on site and to the process of receiving, store, control and distribution of MTS products to assembly areas. Kanban in a lean approach to pull materials and parts through the value stream on a Just-in-time basis and there exist two types of Kanban: 1) Transport kanban which signals a need to replenish materials from suppliers and 2) Production kanban which initiates production (Arbulu, Ballard, and Harper 2003).

2.6.2. Information sharing and collaboration

Effective communication is essential to achieve a lean supply chain, as information must flow smoothly between organisations to optimise flow and generate value for end-customer (Zimmer 2006).

Furthermore, Chen (2003) point out that the performance of a supply chain is dependent on how the actors coordinate their decisions, and argue that coordination is not possible without sharing of information.

Simply put, the value of information is the resulting improvement of a supply chain’s performance after additional information is available to decision makers in the supply chain. The element of information sharing is particularly complicated when the supply

chain consists of independent parties, because when one party has superior information he may either withhold the information to gain an advantage or share the information to improve cooperation (Chen 2003).

Based on the work of Ian MacNeil, an advocate for relational contracting, several authors have discussed the relationship between lean construction and relational contracting (Ballard and Howell 2005; Matthews and Howell 2005; Colledge 2005). Colledge (2005) described how in a relational contracting agreement the contract assume less prominence than the relationship itself, and the mechanisms for delivery of a project focuses on trust and partnerships. The general agreement on the relationship between relational contracting and lean construction is that the traditional forms of contract (discrete, transactional) and the associated business structures do not facilitate the pursuit of the lean ideals. However, it is emphasised that substantial and long-lasting improvements in project deliveries with enhanced value generation and/or waste reduction cannot solely be accomplished by changing contracts and incentives. Changing to relational contracting can instead facilitate the pursuit of the lean ideals, thus changing how the work is done (Ballard and Howell 2005). Figure 4 illustrates the relationship between type of contracts, project type and production systems.

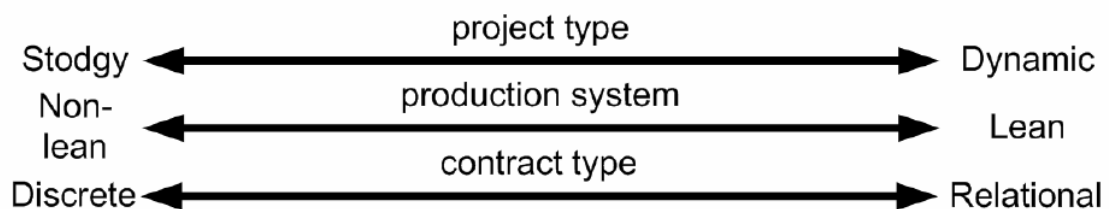


Figure 4: The spectrum of contract correlated with types of production systems and projects (Ballard and Howell 2005)

Moreover, information flow can be considered as a means to integrate the supply chain by improving coordination and collaboration. From this view, the information flow can be improved by means of design and implementation of mechanism that ease the transparency and information sharing between the parties in the supply chain (Azambuja et al. 2006).

In their research about commitments involved in the information sharing between supply chain partners, Azambuja et al. (2006) argue that most causes of the inefficiency

in construction supply chains are caused by managerial issues, such as lack of integration of managerial processes and poor management of commitments among supply chain members. According to Denning and Medina- Mora (1995) the basic element of a coordination process is a closed loop that connects two parties; one of them (the performer) promise to satisfy a request from the other (the customer). This commitment loop is illustrated in figure 5.

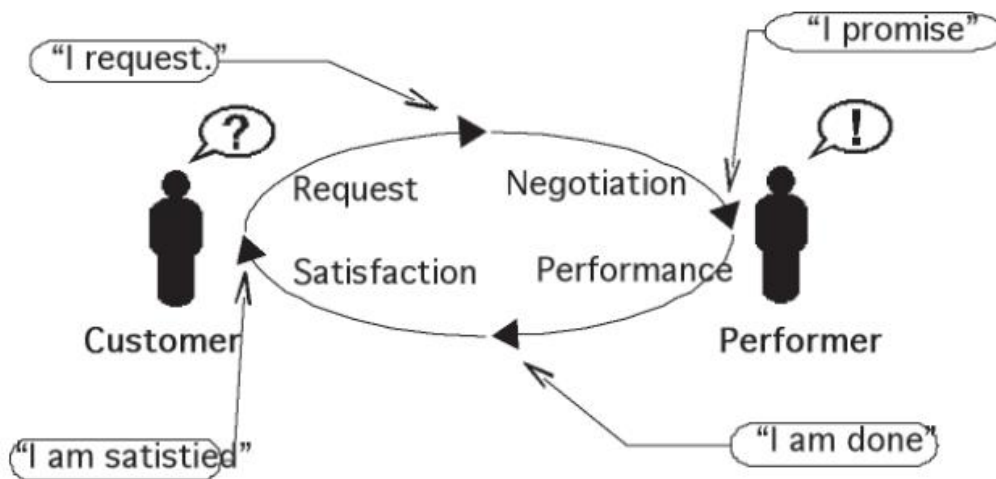


Figure 5: The commitment loop (Denning and Medina- Mora 1995)

Azumbuja et al. (2006) identified four classes of failures to complete the commitment loops:

- **Lack, error or lateness in request formulation by the customer**
For instance, no explicit request was made from customer or the customer was not providing enough time for the completion of the task.
- **Lack of explicit declaration of commitment by the performer**
The performer does not make an explicit promise to fulfil the request. A promise should at least include what and when it is to be delivered.
- **Lack of explicit declaration of its conclusion by the performer**
The performer does not notify the customer that the task is completed.
- **Lack, error or lateness in declaration of customer's satisfaction**
The commitment loops can only be closed when the customer explicitly expresses his satisfaction with the performance of the performer.

Based on their findings they conclude that a large part of the information flow problems in MTO supply chains can be traced back to poor management of commitment loops among people and firms. Finally, they point to how the possible solutions to information flow problems are not expensive, with many of the problems being avoidable by making supply chain members aware of the importance of managing commitments both within one organisation and between companies (Azambuja et al. 2006).

As a mechanism to improve the information flow, several authors have pointed to the use of information technology (IT) systems. Koskela (2000) point out how IT systems can help improve the delivery of a construction project and it can improve the communication between the actors in a construction project.

Correspondingly, Zimmer (2006) argues how IT systems can be used to coordinate parties in the supply chain with real time information, which will also enable the use of transport kanban to send electronic signals to suppliers to replenish materials.

Additionally, Pinho, Telhada and Carvalho (2007) emphasise the importance of reliable and real time information regarding needs of materials, equipment and workforce in construction projects. Consequently, they suggest the use of a web-based system where all actors in the supply chain can have access to relevant information through a common portal.

Although not explicitly discussed by the authors, it can be argued that such a web-based portal is mainly applicable to MTS and MTO components due to the limited amount of specifications required. Suppliers can then get access to real time demand and indications for future demand, while the customers can get access to information such as availability of components and lead time.

In comparison, due to the high level of specification and engineering, such a portal for ETO components would be more suitable for monitoring the suppliers' progress to ensure on time delivery.

2.6.3. Planning delivery and material management

The cost of material may add up to more than half of the total cost in a construction project. Consequently, the design and implementation of material management systems in construction projects is critical to obtain efficient construction projects, as poor management of materials may lead to delays and increased cost. Particularly, this delays and extra expenses may be incurred if; (1) materials required on site are not available when needed, (2) materials delivered on site are not the right materials or (3) large amounts of materials are accumulated on site (Arbulu, Koerckel, and Espana 2005).

Thomas, Riley and Messner (2005, 808) define material management as:

“The allocation of delivery, storage, and handling, spaces and resources for the purpose of supporting the labour force and minimising inefficiencies due to congestion and excess material movement”.

It seems clear that good management of materials is related to how well deliveries and handling of materials are managed. Ideally, these should be controlled in the same fashion as site activities, and thus be planned and scheduled accordingly. Lack of planning and scheduling may have detrimental impacts on project performance, as out-of-sequence deliveries of materials to site, double handling of materials, poor site layout and other sources of waste, may result in delays and increased costs of a construction project.

Consequently, Arbulu, Koerckel and Espana (2005) presented a systematic approach to link production level workflow with materials supply, illustrated in figure 6. They concluded that the management of supply can be incorporated into workflow management practices on site, by pulling materials to the site based on demand on a JIT basis.

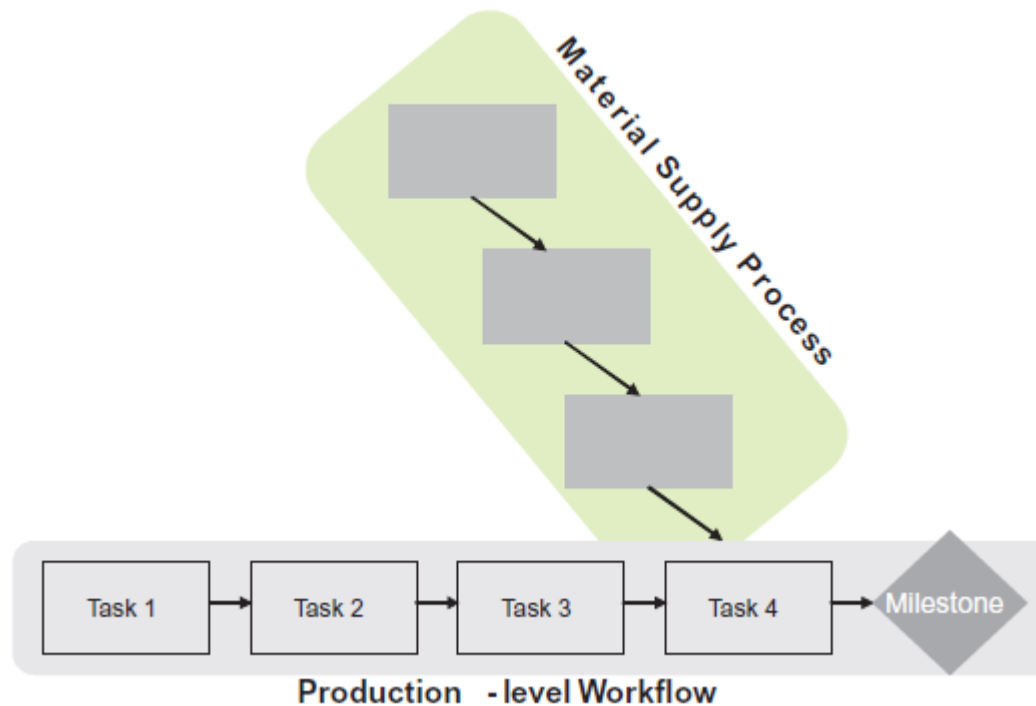


Figure 6: Integrating production level workflow with materials supply (Arbulu, Koerckel, and Espana 2005)

More specifically, they propose a particular approach of materials management of different supply chain structures:

- **MTS materials**

They suggest a method of physical control systems using kanban techniques, where replenishment points are driven by minimum and maximum levels of inventory.

- **MTO and ETO materials**

They suggest an approach of materials management systems to pull materials through the value stream with either appropriate work-in-progress levels in the supply chain (CONWIP) or each step in the supply chain (pure pull). These options are illustrated in figure 7.

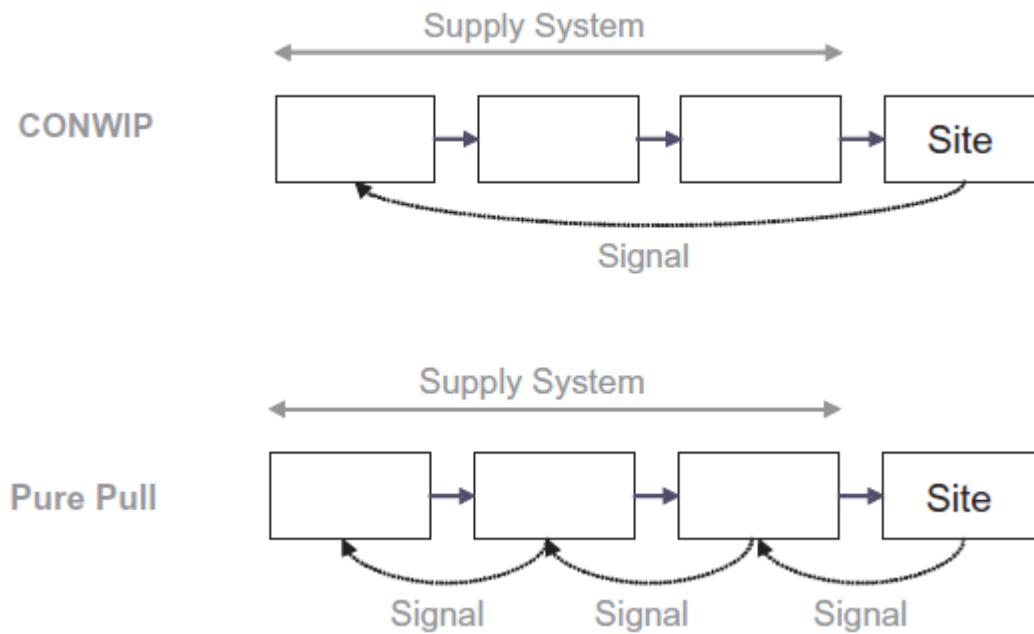


Figure 7: Material management approaches for MTO and ETO materials (Arbulu, Koerckel, and Espana 2005)

A similar approach to use kanban techniques to handle the delivery of MTS components is proposed by Arbulu et al. (2003). Particularly, they point to how kanban techniques can support the reduction of material inventories and paperwork required to procure components, as well as simplifying the site materials management of MTS components by eliminating waste and reducing information processing.

Moreover, material planning includes quantifying, ordering and scheduling, and it is considered that material planning is particularly important in order to increase productivity and to ensure timely completion of projects. Therefore, a failure to properly plan the material supply is likely to result in lower productivity, with the consequence of failing to deliver a project on time (Kasim 2011).

Thomas, Riley and Messner (2005) divide the storage of materials in a construction project into three areas, with according material management principles, also applicable to shipyards:

1. Semi-permanent storage area

These are the areas where materials are stored prior to being used in a project. For shipyards, this can relate to the warehouse, or other storage areas in the shipyard. Material management principles include marking stored materials and storing materials to facilitate easy access and retrieval.

2. Staging area

These are the areas from where materials are lifted into the facility. Within shipyards, this can related to areas besides the dock. Material management principles include reserving the staging areas for material deliveries.

3. Workface

This is the area where the work takes place. For a shipyard, this relates to either on the ship or in the pre-fabrication areas. Material management principles include keeping materials stored at a minimum and preassembly of components.

In addition, they point to principles for managing supplier relations and deliveries including sequencing deliveries with the work plan and aligning the delivery rate with actual work rate (Thomas, Riley, and Messner 2005).

The Last Planner System is a widely adopted tool within lean construction, aimed at improving planning and controlling the production process. Consequently, linking the materials supply and management with the last planner system, should make it possible to improve the flow of material to a construction site. This is discussed by Ala-Risku and Kärkkäinen (2006) in their article *Material delivery problems in construction projects: A possible solution*. This will, along with the last planner system will be discussed in the next section.

2.6.4. The Last Planner System

As mentioned above, the last planner system is a tool to improve planning and control in the production process. After it was first introduced by Glenn Ballard in 1993 it has become one of the most important tools within the lean construction concept. The last planner system aims to create an even workflow by planning the weekly work and carefully monitoring the plan performance, and thus through proactive planning the work can flow across production units in the best achievable sequence and rate (Bertelsen 2002; Ballard 2000).

Mossman (2005, 1) describes the last planner system as:

“A system for collaboratively managing the network of relationships and conversations required for programme coordination, production planning and project delivery”.

Within the Last Planner system the aspects of pulling production, reducing variability and improving flow reliability are included, and the idea is to make the planning more realistic by allowing the last person in the process (the Last Planner) to plan and decide work tasks to be executed (Sterzi, Isatto, and Formoso 2007). Mossman (2005) argue how the last planner system creates conversations and decision making at the right levels of the of the project and at the right time to create trust among the *last planner* and higher project managers, by allowing the last planners to plan and decide work tasks.

Koskela (2000) describes seven preconditions for the completion of a construction task. This has also been referred to as the MakeReady checklist by Mossman (2005, 2007). The seven preconditions, which Mossman call the seven flows, are: (1) Materials, (2) personnel, (3) information, (4) equipment (tools), (5) external conditions, (6) space and (7) preceding work (Koskela 2000; Mossman 2007). Figure 8 shows an illustration of the seven preconditions.

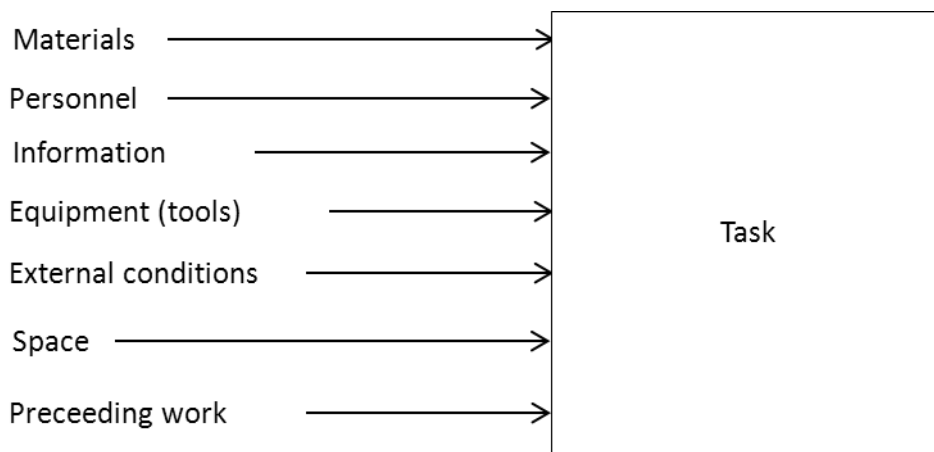


Figure 8: The 7 preconditions for a construction activity (adapted from Koskela 2000)

Furthermore, Mossman (2007) explains how bringing information, equipment, materials and personnel to the workplace creates no value in itself. Value is only created when they all come together at the workplace.

Ballard (2000) proposes four levels of planning in the Last Planner system:

- **Master schedule**

This is the strategic plan with major milestones for the entire project. It refers to what *needs to be done*.

- **Phase scheduling**

This is a more detailed plan of the master schedule, and is created by the team that manages and work in each phase. It refers to *should be done*.

- **Look ahead plan**

In this plan the workflow is arranged in the best achievable sequence and rate by checking the seven prerequisites. It also serves as a logistical plan. It refers to what *can be done*.

- **Weekly work plan**

The weekly work plan contains a list of assignments and work tasks the last planner has committed to be complete within the coming week. It refers to what *will be done*

In the last planner system, the percentage plan complete (PPC), is used as a measure on how much of the weekly work plan that has actually been completed (Ballard 2000).

The Last Planner system is illustrated in figure 9.

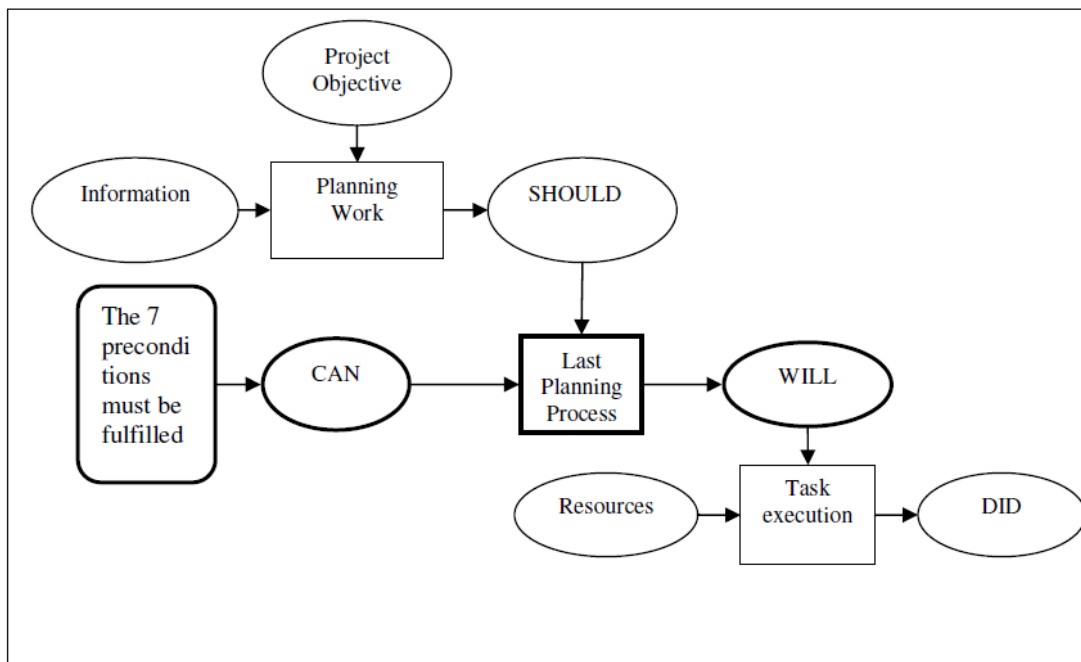


Figure 9: The last planner system (Dao and Follestad 2009)

However, Ala-Risku and Kärkkäinen (2006) suggest that there are two material flow management challenges in the Last Planner System: (1) The last planner must have access to information concerning materials availability for individual project tasks and

(2) materials should be readily available without excessive inventory on-site. Particularly, they point to giving information to the last planner about material availability is a challenge as materials are often not registered in any inventory control system, but have to be visually controlled to ensure availability. Therefore, materials are often ordered well in advance to ensure availability when needed, thus creating large inventory buffers on site. This results in problems for materials handling on site and increases the risk of damaged materials. Consequently, they argue that continuous planning on single construction task level, such as the Last Planner, places two requirements for materials deliveries: (1) transparency of inventory levels on-site and other stages in the supply chain and (2) short response times along the supply chain (Ala-Risku and Kärkkäinen 2006).

They propose a solution in two parts. First, in order to increase visibility of inventory levels on site and other stages in the supply chain, they suggest a tool based on shipment tracking for site inventories and short-term storages most critical for the project tasks. Second, in order to ensure availability of materials without excessive inventory, they propose the use of the near-term schedule from the Last Planner system as a means of communication between project site and materials suppliers (Ala-Risku and Kärkkäinen 2006).

2.6.5. Variability and reliability issues in construction supply chains

Bertelsen (2005) suggest that the complex nature of construction often results in great variability in the flows of work, information, crew, materials and space. Sources of variability include late delivery of material and equipment, design errors and change orders (Abdelhamid and Everett 2002).

Similarly, Arbulu and Ballard (2004) point to how variability is omnipresent in any production and supply system, and how supply chain variability creates waste and can potentially impact the on-time delivery of a project. Particularly, they point the matching of supply and demand, and how any type of variability of either demand or supply can negatively impact project performance.

Moreover, variability can be described as the opposite to reliability, the lower the variability the higher the reliability in the system. In a perfect situation, demand and supply are perfectly reliable (zero variability), and materials and information flow

continuously. More realistic, however, is that either demand or supply or both have some variability. When supply is more reliable than demand, inventories accumulate on site, while when demand is more reliable than supply WIP increases and project delays may occur due to lack of resources (Arbulu and Ballard 2004).

Furthermore, Arbulu and Ballard (2004, 4) state: *“Any type of variability in both demand and supply will be critical to the effective project management and will impact the total production system performance increasing cost and time and reducing quality and safety”*.

Accordingly, variability is ever present in construction supply chains, and is particularly recognised by poor workflow reliability between production processes as a result of demand and supply variability. Arbulu, Koerckel and Espana (2005) report that workflow reliability has been repeatedly measured at levels from 30-60 %, and argue that improving workflow reliability is synonymous with increasing the accuracy of site demand.

Consequently, improving the workflow reliability is the equivalent to reducing variability, and thereby reducing the share of non-value adding activities in the production processes and the corresponding supply chains.

3. Methodology

This chapter will describe the methodological approach for this thesis. The first part will outline the research design, before the selected case-study approach will be described. Following that, the data collection methods used will be summarised, before the validity and reliability issues will be discussed and the research model described.

3.1. Research design

Research is conducted to obtain information regarding a specific research question, and the selected research design should be closely linked with the purpose of the research. The purpose of the research can either be of an exploratory, explanatory, descriptive or predictive nature. Exploratory research is conducted when the purpose is to explore a little known phenomenon, while explanatory research is conducted when the purpose is to explain a phenomenon (Ellram 1996; Yin 2003; Marshall and Rossman 1999).

The purpose of this thesis has an exploratory-explanatory nature. This combined character is due to the twofold research problem. First, the thesis aims to explore what activities in the value streams that delay the flow of materials and differences between the two supply chains, thus making the exploratory research design appropriate. Secondly, the thesis aims to explain the underlying reason for these delays and differences, thus making the explanatory research design appropriate. Furthermore, as the thesis aims to explore the applicability of lean supply chain management approaches to a Norwegian shipyard based on the evidence from the two value streams assessed, an exploratory-explanatory research approach was considered suitable.

3.2. Case study research

Yin (2003, 13) defines a case study as an empirical inquiry that “*investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly defined*”.

Building on this definition, he discusses how a case study approach appears suitable when the variables tend to be vague, the researcher has little or no control over other events and the researcher investigates a contemporary phenomenon.

Furthermore, he put forward six key sources of evidence applicable to case studies; documentation, archival records, interviews, direct observation, participant observation and physical artifacts. The use of these sources in this thesis will be further discussed in the next section.

There is also a distinction between single case study and multiple case studies. Multiple case studies occur when the same study contain more than one case. However, Yin (2003) argue that single and multiple case studies are variants from the same methodological framework.

For this thesis a case study approach has been chosen. This approach is considered appropriate as it allows for investigation of non-value adding activities and sources of these within a real-world environment and as multiple sources of evidence will be used. In addition, although the selected approach is a single case study of the flow of materials to and within Ulstein shipyard, the two different supply chains evaluated in this thesis will be treated as two different cases, thus enabling for comparison between the two.

It should be noted, however, that the purpose of this thesis is to enhance the understanding of what activities in the value stream that delay the flow of materials and why these delays occur, rather than an in-depth and detailed quantitative analysis of the two supply chains.

3.2.1. Data collection

Data collection refers to the process of collecting the empirical evidence or information through one or more data collection methods, and serves as a basis for analysis.

Data can be categorised as either *qualitative* or *quantitative* techniques, and collected through for example questionnaires, interviews, observations and experiments. Qualitative data are typically descriptive data and the results are often expressed verbally to create an understanding of the phenomenon in question, while quantitative data are precise measurements and mathematical analysis with the results often expressed in numerical and quantifiable terms. In addition, data can be either of *primary* or *secondary* character. Primary data refers to data collected for the purpose of the specific research, while secondary data is existing data collected primarily for other purposes (Ellram 1996).

In this thesis, qualitative methods for data collection have been applied. The data consists of primary data collected from interviews and (direct) observation and secondary data such as archival records, documentation and data collected for other research projects. An overview of the data collection methods applied in this thesis can be seen in table 1. The reason for selecting a qualitative methodology was mainly that

the qualitative research and data collection methods were considered more suitable for the purpose of this research. When considering that the purpose of the study to study is to contribute to the understanding of what in the value stream that delay and interrupt the flow of materials, and why these delays and/or interruptions occur, as well as the time frame for this study a qualitative approach was found suitable. In addition, this is the first research paper conducted with Ulstein regarding supply chain management and the flow of materials to and within the shipyard. Therefore, a qualitative approach was selected as it was considered the most suitable to obtain a holistic perspective of the two supply chains and to be able to compare the two supply chains, within the time frame of this thesis.

On the other hand, it was considered early in the research process to have a more quantitative approach to this thesis, involving physically following and mapping the flow of materials in the two supply chains. This method could have resulted in more quantitative measurements of waste by identifying lead time, cycle time, processing time, non- value adding time and similar. There are, however, several reasons why this method was not selected. The first and most important reason is the lack of access to data from Brunvoll did not make it possible to map the whole value stream from Brunvoll to Ulstein, and as this could have been a feasible method for mapping the GS-Hydro- Ulstein value stream, the comparison would then have been made on different grounds. Furthermore, it was considered only to map the internal flow within the shipyard from when the thrusters arrived to installation, but this was not feasible within the time frame of this thesis. The thrusters were expected to be delivered in late April and in June, but the delivery dates were uncertain in the beginning of the research process, thus this method was not considered feasible within the time frame of this thesis.

Second, it was considered that through this method, a holistic perspective of the two supply chains would not be covered in the same degree as with a qualitative method.

In addition, the lack of access to quantitative data, such as the manufacturing time at Brunvoll, and cycle time and storage time at Ulstein, also favoured a qualitative methodology. However, some quantitative archival records were used to support and validate the qualitative data.

Table 1: Overview of data collection methods used

	Qualitative data	Quantitative data
Primary	- Interviews - Observation	
Secondary	- Documentation - Other research projects	- Archival records

The main source of primary information for this study was interviews. Interviews are one of the most important sources of information in a case study, and in a case study interviews are typically guided conversations rather than structures queries, where the researcher explores a few general topics to uncover the interviewees' views and perceptions of the topics in question, while allowing for the interviewees to structure their own response. The most common type of case study interviews are open-ended interviews, where interviewees are asked both about facts and opinions concerning the topic (Marshall and Rossman 1999; Yin 2003).

For this study, open-ended interviews were selected. The main reason for this is that it allowed for flexibility in the interviews, which was considered important to obtain an understanding of the current situation and the issues in the supply chains, in order to answer the research problem. The interviews were conducted with employees in different positions within Ulstein and GS-Hydro. The interviews with employees at Ulstein were carried out in two rounds. The first round of interviews was mainly used to obtain an overview and understanding of the current situation. The second round of interviews were more in-depth targeting the issues identified in the first round of interviews. The interviews at Ulstein related to GS-Hydro were mainly conducted with a project manager and purchasers, while the interviews related to Brunvoll were conducted with a purchaser. For the interviews related to the internal flow of materials, interviews were conducted with the internal logistics manager and other employees in the warehouse function. In addition, informal conversations with employees working in warehouse were also conducted to obtain an overview of the current situation.

The interviews with GS-Hydro were conducted in a single round, and the employees interviewed included purchasing director, logistics manager, distribution coordinator and warehouse manager. Similarly, these interviews were open-ended to allow for flexibility to obtain an understanding of the current situation. Even though the actual

interviews with GS-Hydro were conducted in a single round, GS-Hydro was visited in the beginning of the research process to discuss the purpose and methodology of the thesis, and the current situation for GS-Hydro

Furthermore, direct observation was also used a source of primary information, particularly to obtain an understanding of the actual processes and activities within in the shipyard. The observations were mainly done on the first visit to Ulstein, by walking around the premises accompanied by the internal logistics manager who explained the processes and activities.

In terms of the secondary data used in this thesis, two main sources were used; archival records and documentation. The archival records used are mainly related to historic orders from Ulstein to GS-Hydro in 2010 and 2011, and were obtained from both parties. These archival records were used for the analysis of the supply chain. In addition, the archival records also included some historic figures concerning transportation costs for March 2012.

The documentation used is related to the correspondence between Ulstein and Brunvoll for project no. 295. For each project, Ulstein log all correspondence, both of a technical and commercial nature, with Brunvoll (or other A-component suppliers) in a database. The documentation used for this thesis was the correspondence of a commercial nature between Brunvoll and Ulstein for build no. 295. The reason for not including the technical correspondence in the analysis is mainly due to the large quantities of data combined with that it was considered that a large proportion of the data would not be relevant for this thesis. Therefore, the commercial correspondence was the most relevant and interesting for this study, and the technical correspondence was important to know of, instead of going into details.

For future reference, the figures and tables which are not specifically referenced to, mainly in the case findings and discussion parts, are created for this thesis specifically, either based on the archival records obtained from either Ulstein or GS-Hydro or as an illustration.

In addition, information from other research projects, particularly Longva (2009), were used mainly to obtain an overview and understanding of the flow of materials through the warehouse within the shipyard.

3.2.2. Validity and reliability

Validity and reliability are two important aspects in order to evaluate the quality of a research, particularly for research of a qualitative nature, because there is no coherent set of methods for a qualitative research and qualitative research may be subject to a lack of objectivism (Peräkylä 2004).

Yin (2003) describe three different concepts addressing the validity in research; (1) Construct validity, (2) internal validity and (3) external validity. Construct validity is concerned with establishing the correct operational measures for the concepts being studied. Internal validity is related to testing causal relationships between variables, while external validity is related to applicability and generalisation of the findings.

This thesis has attempted to construct validity through the method of triangulation. Triangulation is a concept constructing validity by applying multiple sources of evidence, as findings and conclusions based on several sources of evidence are more precise and convincing than using a single source of information, particularly in a case study research design (Yin 2003). In this thesis triangulation has been attempted by using multiple sources of evidence, including interviews, observation and archival records. Furthermore, in the case of the link between GS-Hydro and Ulstein, interviews were conducted with employees in both firms, which allowed for opinions and perceptions from both sides, which again should strengthen the validity of the study. Similarly, interviews were conducted with employees in different positions in both Ulstein and GS-Hydro, and thus information was obtained from different employees with different perceptions and opinions about the topic, again a source of strengthened validity.

This was also the case with the interviews concerning the Brunvoll-Ulstein supply chain link. However, Brunvoll was not participating, thus the interviews were conducted with employees at Ulstein. For the information flow, interviews were conducted with one of the purchasers, again in two rounds. Triangulation is then constructed with two different rounds of interview combined with the documentation of the correspondence between Brunvoll and Ulstein. Ideally, interviews should have been conducted with Brunvoll as well, to obtain a perspective from both sides. However, as this was not possible, it was selected to evaluate the information flow from Ulstein's perspective.

Furthermore, the first round of interviews with Ulstein was written down, while the second round of interviews with Ulstein and the interviews with GS-Hydro were recorded, after approval of the interviewees, to avoid misinterpretations and/or information being lost.

In terms of the reliability of a research, this is concerned with the replication of the study, and whether the same results would be achieved if the case study was conducted all over again. The goal of reliability is therefore to minimise bias and errors in the study. An important aspect to ensure reliability of a study, is to document the procedures undertaken in the study, thus allowing for other researchers or reviewers to conduct a similar research or examine the reliability of the research (Yin 2003), which is the aim of this methodological framework chapter and the information in the appendices. Some of the interview guides used for the interviews and extracts from the archival records and correspondence can be found in the appendices (appendix II and III).

3.3. *Research model*

The research model in figure 10 illustrates the focus and expected findings of this thesis. Ulstein, as the focal firm are linked with the two suppliers, Brunvoll and GS-Hydro. The components from GS-Hydro have (relatively) high-volumes, low-unit price and short lead time, while the components from Brunvoll have (relatively) low-volumes, high-unit price and long lead time. Based on this nature of the two supply chain links and the literature, it is expected that the main flow impacting the supply chain performance is the material flow for the GS-Hydro- Ulstein link and the information flow for the Brunvoll- Ulstein supply chain link.

Furthermore, based on the literature discussed above and findings from other researchers the two last columns in the figure represent the expected findings in this thesis.

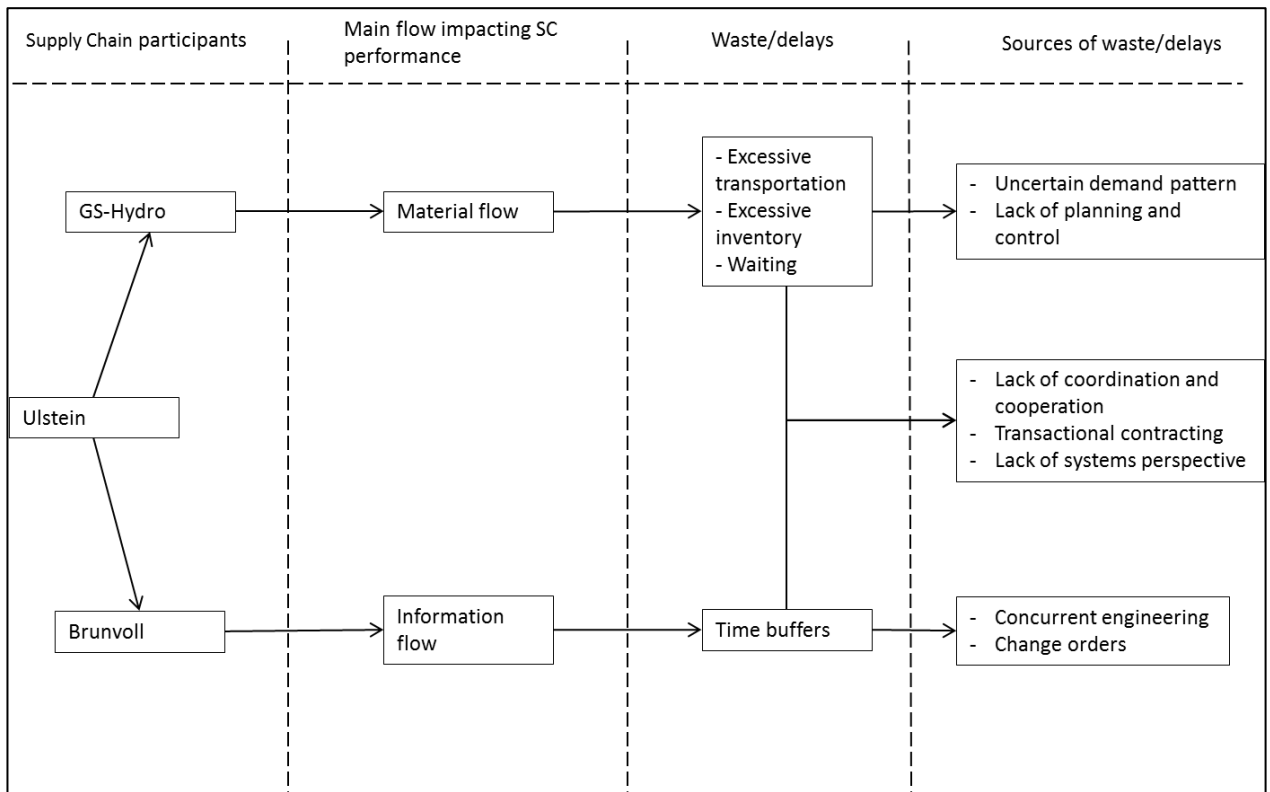


Figure 10: Research model

4. Case study findings

As another step towards the Ulstein production system, a production system based on lean principles and tailored to the specific characteristics of Ulstein, this case study is aiming to enhance the understanding of waste and delays in the two value streams.

The intention of this case study is therefore to investigate the two supply chains from GS-Hydro and Brunvoll supplying B-and C-components and A-components, respectively, to Ulstein, in order to identify what type of waste that is interrupting a continuous flow in the current situation. In figure 11 the supply chains are illustrated, where Ulstein is the focal firm, the ship owner is the first tier customer, while Brunvoll and GS-Hydro are first tier suppliers. Further upstream (tier 2 and 3 suppliers) there is a wide network of different suppliers, not considered in this thesis.

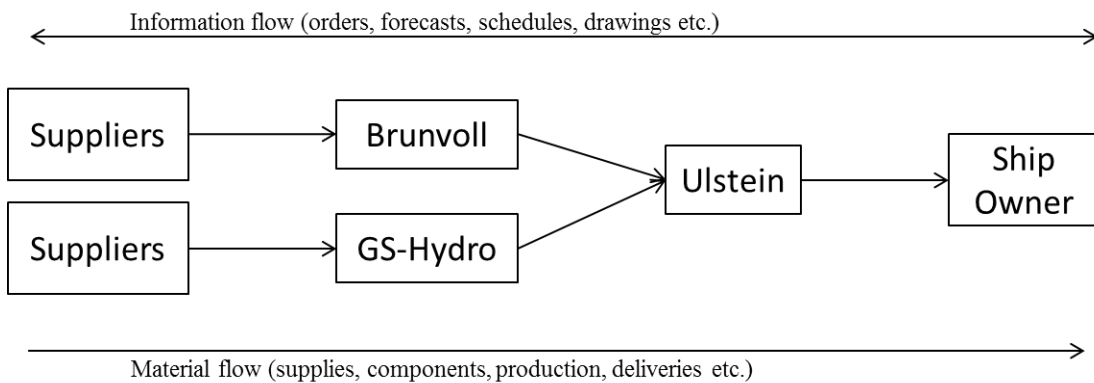


Figure 11: Supply chain configuration

This chapter will put forward the findings from the case study which will describe the current situation, including how the two value streams are currently configured and what is interrupting a streamlined flow of materials in the two supply chains.

Building on the findings outlined in this chapter, the sources of waste and delays, and the managerial implications for the supply chain participants will be discussed in the subsequent chapter.

4.1. Value stream from GS-Hydro to Ulstein

From the research model described previously, and by following the argument of Wegelius-Lehtonen and Pahkala (1998), the main focus of this supply chain is the physical flow of materials, particularly due to the short lead time and the relatively standardised components flowing in the value stream.

According to a VSM approach described above, the first step is to selecting a product family and setting the boundary conditions. In terms of this value stream the product family is defined as all the components supplied from GS-Hydro to Ulstein, which Ulstein categorises as B and C components, where B components are project-specific and C components are consumables. On the other hand, GS-Hydro's consider these as similar components, with both being supplied mainly from their finished goods inventory.

In terms of other boundary conditions, the value stream analysis is limited to the flow of materials from GS-Hydro to Ulstein and internally within the shipyard (focal firm and tier 1 supplier), even though other parties exist both further upstream and downstream in the supply chain. For future reference, the term external flow is used here to describe the flow from GS-Hydro to Ulstein, while the term internal flow is used to describe the flow of materials within the shipyard, after Ulstein receives the materials. The focus of this supply chain and the boundary conditions are illustrated in figure 12 (in comparison to figure 11).

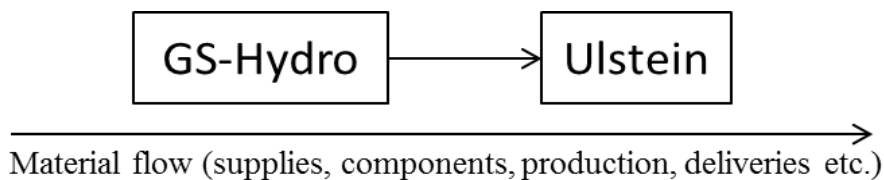


Figure 12: Focus and boundary condition of GS-Hydro- Ulstein supply chain link

4.1.1. Flow

Following a VSM approach, the next step is to create a current state map of the processes the materials flow through in the value stream and this can be linked with the lean principle of identifying the value stream, in order to highlight waste and serve as a basis for improvement. Therefore, this section will describe the current value stream from GS-Hydro and Ulstein within the boundary conditions outlined above. It should be noted that the analysis of the current state does not consist of quantitative measurements such as cycle time and value creating time, mainly due to lack of data and the choice of having a more qualitative analysis, as described above.

Before the flow of materials is described, the ordering procedure from Ulstein to GS-Hydro should be outlined. The B-components are typically ordered through a tendering process including several suppliers, with the main criteria being price, but also delivery date is considered. Upon agreement an estimate of the requirements for a project is allocated in storage at GS-Hydro, and the components are ordered, based on the agreement, by the foremen at Ulstein when the components are required in production on a daily or weekly basis.

The C-components are ordered by the workers in the warehouse at Ulstein by manually scanning barcodes located at each components storage space in the warehouse, which electronically generates the order. The scanning is typically done on a daily basis based on visibly low inventory levels, stockouts in the shelves or anticipated upcoming usage. The quantities that are to be replenished are determined by the workers and are typically based on the experience of the workers or in some cases informal communication about short term requirements from the foremen.

An order from Ulstein to GS-Hydro can be served by GS-Hydro from two locations; the central warehouse at Frogner or the regional warehouse in Ålesund.

When the orders are served from the central warehouse, the orders have to be received at GS-Hydro before the cut-off time for next day delivery at 15:00. The orders are then registered and released for picking based on the requested delivery date. The order release system at GS-Hydro is setup so that orders are released to be delivered on the requested delivery date from the customers, regardless of how far in advance the order is placed. In addition, the order release system prioritises orders based on the strategic

significance of the customer for GS-Hydro, thus ensuring that the orders from strategic customers (including Ulstein) are picked first. The materials are picked from four different picking areas; automated picking, general picking area, tubes and pipes.

The orders to the same regions are then consolidated and shipped in bulk, leaving Frogner around 17.30 (day 0). For the Møre region the goods are transported by Transferd, to their terminal in Ålesund. Here, the orders are received around 04.00 (day 1) where they are sorted and distributed, leaving the terminal on fixed delivery routes around 08.00 (day 1) in part load to each customer by Transferd. The customer should receive the materials around 12.00 (day 1), thus the lead time from order is released for picking at GS-Hydro to the components are received at Ulstein is less than 24 hours. This flow is illustrated in figure 13.

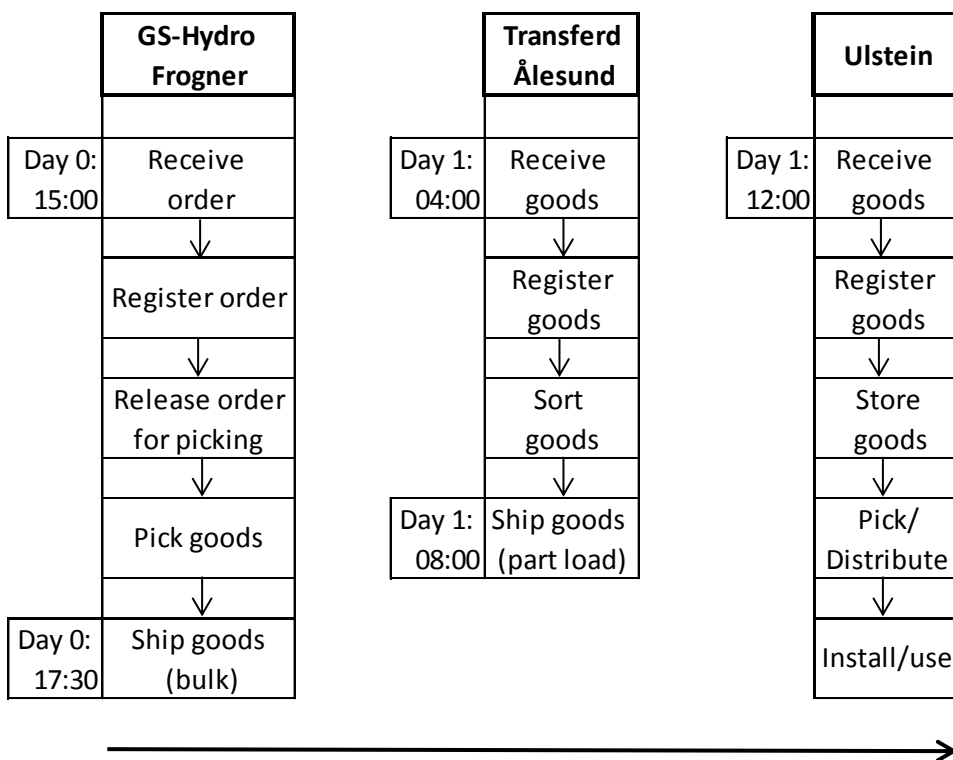


Figure 13: Current state flow: Deliveries directly from GS-Hydro Frogner

For the orders served from the regional warehouse in Ålesund, these are normally orders for components required by Ulstein the same day. These are picked at the regional warehouse when the order is received, and delivered to Ulstein typically within 3-4 hours. However, the replenishment to the regional warehouse is done from the

central warehouse at Frogner with an internal order either on a one-out, one-in basis, or when inventory reaches a minimum level at the regional warehouse. These components thus have to go through the same processes as components shipped directly from central warehouse to customers, before they are received, registered and stored at the Ålesund warehouse and later picked and shipped to the customers. This flow is illustrated in figure 14.

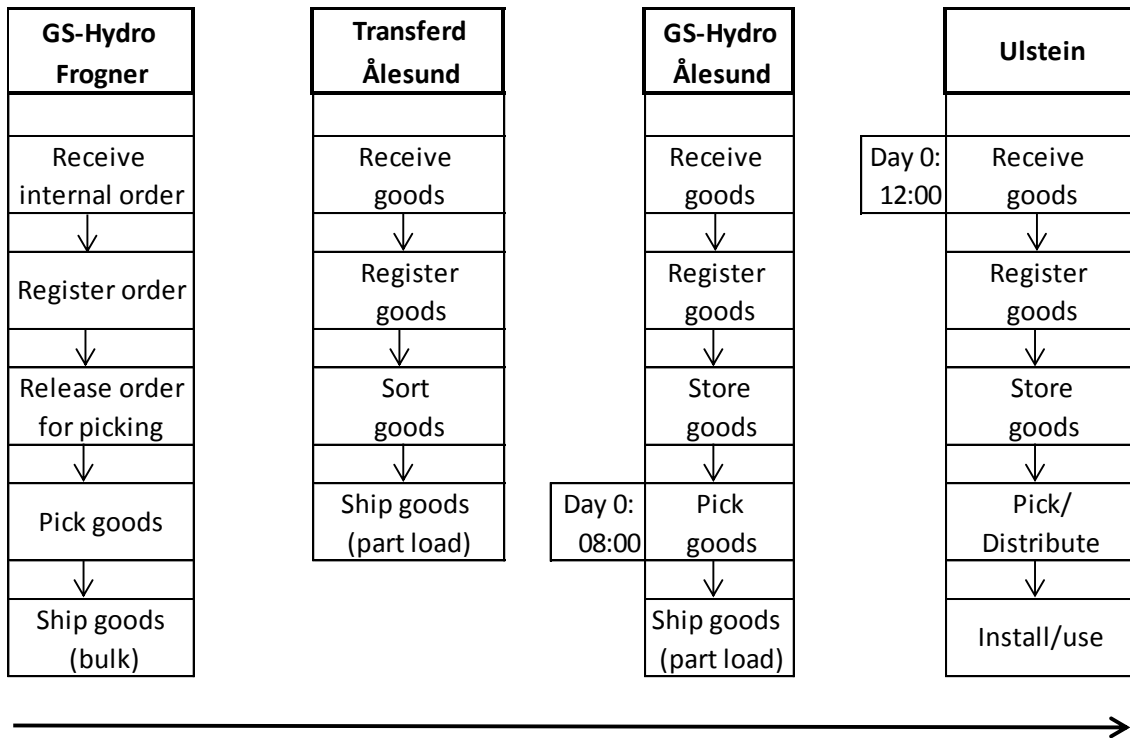


Figure 14: Current state flow: Delivery from GS-Hydro Ålesund

The archival records used to obtain an overview of the value stream did not differ between B-and C-components, thus the supplier location the different materials are shipped from are difficult to evaluate. However, the interviews revealed that C-components are normally delivered the day after the order is sent, thus indicating that C-components are normally shipped from the central warehouse at Frogner. It should also be noted that although C-components are not project specific, they are ordered for the ship that at the time is in the docking hall, mainly for book-keeping purposes.

In the case of Ulstein ordering prefabricated (MTO) components from GS-Hydro, a manufacturing lead time is added to the lead time. In addition, GS-Hydro can also provide components not in their inventory, and in this case the lead time will vary with the delivery lead time from the sub-supplier. However, it was reported that the majority

of components Ulstein order from GS-Hydro is held as finished goods inventory at GS-Hydro.

In terms of the flow of materials within the shipyard, this was evaluated from a more general perspective regarding B-and C-components, rather than for components specifically from GS-Hydro. This was mainly due to difficulties in differing on suppliers in the internal flow, but also as a more general perspective was desired. From the figures 13 and 14, it is clear that the processes after the components are received are similar regardless of from where the components are shipped.

When the components arrive at the shipyard they are received in the warehouse, where the components are registered and stored. As no formal planning is made for the arrival of incoming trucks, this is conducted as soon as possible after the arrival of trucks. The components are registered in the ERP- system within 24 hours unless deviations occur.

Both B- and C- components flow through the same receiving and registration processes, but are treated somewhat differently after this. C-components are stored at fixed locations in the warehouse with the main location being within the warehouse. In addition, there is also a separate storage location for C-components within the docking hall. B-components, on the other hand, do not have a fixed storage location and storage location is decided based on where it is available space, and when the warehouse personnel expect the components to be used. In addition to the warehouse, there are additional tents used for storage placed within the shipyard. The storage location is registered in the ERP-system with rack and shelf if located in the warehouse, and with tent number if stored in one of the tents.

The actual storage lead times are not known for either B- or C-components as withdrawal from storage is not registered. As a result, the components are typically treated as used when the ship is delivered to the client. For the internal picking and distribution, the components, both B and C, are typically picked by installation workers as they require them. Larger components, which workers are unable to carry, are transported to the building site by warehouse workers often based on a “*need it now*” request from the foremen or installation workers, as no formal planning is made for the internal distribution.

Although not within the boundary conditions of the value stream analysis, it is worth mentioning the order and delivery process from supplier (tier 2) to GS-Hydro. The lead time for these materials differs significantly. For components stored at finished goods inventory at supplier, the lead time is only the transportation time from suppliers, mainly located outside Norway. However, many of GS-Hydro's suppliers make-to-order, thus the lead time is increased with the manufacturing lead time. Particularly, pipes are produced to order at the suppliers mainly located in Asia and the lead time can vary from 4 to 12 months depending on the availability of raw materials and market fluctuations. The orders from GS-Hydro to suppliers are typically based on historical data and forecasts. For their strategic components, such as pipes, GS-Hydro has consolidated the purchasing on a global level to obtain better conditions and to better cope with forecasts errors and demand uncertainties. The components MTO by the supplier are typically received at GS-Hydro's central warehouse two months before shipped to customer, but this may vary.

Clearly, there is also a flow of information between the different departments of sales, purchasing, engineering, production, planning and warehousing at Ulstein. However, as the main focus of the internal flow has been physical flow of materials, the information flow has not been analysed or mapped explicitly. Nevertheless, the internal information flow is clearly impacting the flow of materials, and this is taken into consideration in the analysis of the flow of materials.

4.1.2. Waste

As described above, there are seven original sources of waste in lean thinking; overproduction, waiting, excessive transportation and inventory, inappropriate processing, unnecessary motion and defects (rework). Since the focus of this value stream is mainly the physical flow of materials, the waste aspect here is related to activities, processes or structural arrangements that causes delays and/or interruptions in the flow of materials.

In this case, particularly three lean wastes were identified consistently throughout the flow of materials in this supply chain: (1) Excessive transportation, (2) excessive inventory and (3) waiting.

4.1.2.1. Excessive transportation

In lean theory the aim is to minimise transportation, as every movement of goods can be considered waste. In this value stream, excessive transportation was evident in both the external flow of materials to Ulstein, and in the internal flow of materials within the shipyard.

In terms of the external flow, particularly the use of the regional warehouse in Ålesund results in increased transportation. Figure 15 shows the share of total tonnage ordered by Ulstein from GS-Hydro that is supplied from the different GS-Hydro locations in 2010 and 2011. In 2010 and 2011, 55 % and 34% respectively, of the total tonnage was supplied from GS-Hydro's regional warehouse in Ålesund.

From the description above, it is clear that the regional warehouse in Ålesund has to be replenished from the central warehouse on the same route as direct deliveries to Ulstein, and thus the use of the regional warehouse clearly increases the transportation of materials in the delivery process. In addition, the location of the regional warehouse in Ålesund in relation to the Transferd terminal and Ulstein, increases the time and complexity of the transportation (see map in appendix V).

Correspondingly, figure 16 shows the share of total orders served from different GS-Hydro locations in 2010 and 2011. This was in 2010 and 2011, 64 % and 51 %, respectively from Ålesund. Although this further emphasises that the extra transportation is delaying the flow of materials, there is a trend that both a larger share of the total tonnage and a larger share of the total orders are supplied from the central warehouse at Frogner since the change to a central warehouse in 2011.

However, a major part of this waste is the extra handling in the delivery process. For instance, the materials shipped from GS-Hydro Ålesund to Ulstein have to go through the processes of receiving, registering, storing and picking three times, both at GS-Hydro's central and regional warehouses and Ulstein's warehouse, in addition to the receiving, sorting and shipping at the Transferd terminal outside Ålesund, before they can be used in production. This additional handling is also increasing the risk for materials being damaged, lost or delayed in the delivery process.

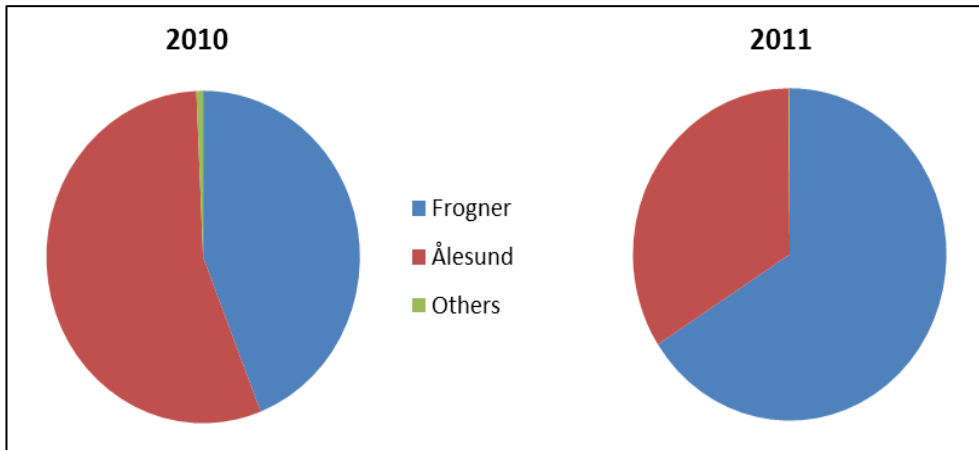


Figure 15: Share of annual total tonnage from GS-Hydro location in 2010 and 2011

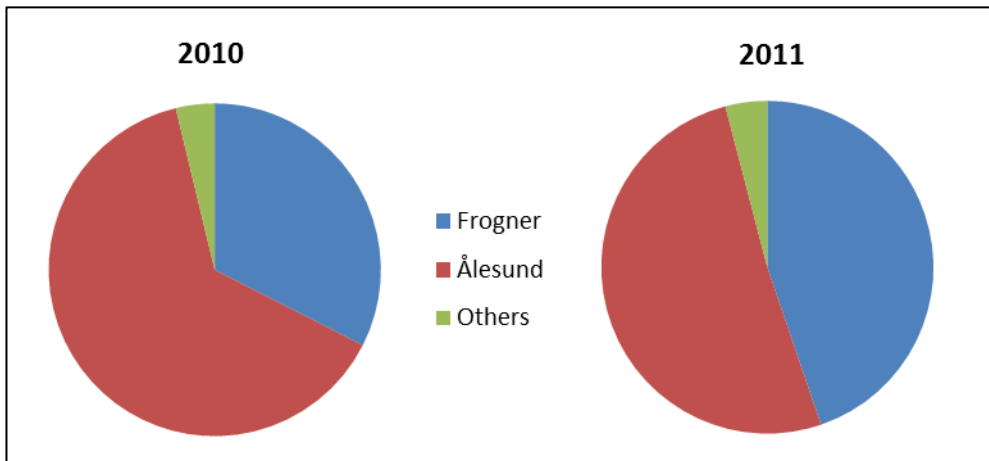


Figure 16: Share of annual orders served from GS-Hydro location in 2010 and 2011

In addition, the findings also indicate that the use of a regional warehouse in Ålesund also has a large impact on transportation costs. In the current situation, it was informed in the interviews that Ulstein often order from GS-Hydro in the morning what they require in production later the same day. Due to the location of the central warehouse, this cannot be serviced from Frogner, and in the current distribution system there is no delivery route able to serve these urgent orders. As a result, in 2010 and 2011, 92% and 77%, respectively, of the orders supplied from Ålesund, were sent by couriers typically being 3-4 times more expensive than using the fares negotiated by GS-Hydro with Transferd.

More specific, figure 17 shows the tonnage and net price for transportation with both Transferd and couriers for the shipments from GS-Hydro to Ulstein in March 2012. Of

the 52 shipments, 26 were sent with couriers counting for 9 % of the total tonnage, while counting for nearly one third of the total transportation costs. This gives a transportation cost per kilo with couriers more than four times higher compared to transportation with the distributor Transferd. This adds up to a potential saving of 22% for the transportation costs for the orders from GS-Hydro in March 2012 if all the components were shipped with Transferd.

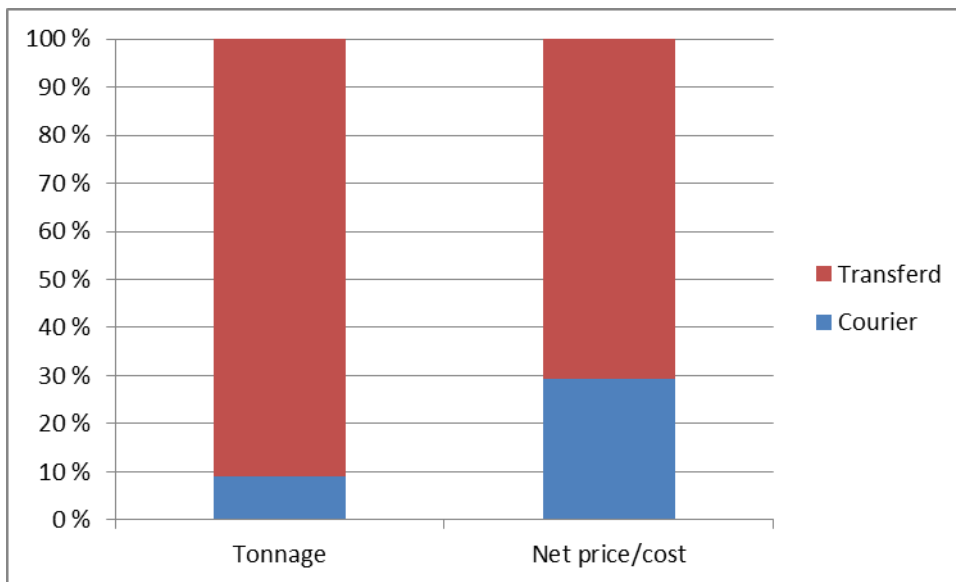


Figure 17: Tonnage and net price for transportation from Ålesund in March 2012

As a result, it seems obvious that the extra handling and transportation is not adding value the materials, but rather delaying the flow of materials in this supply chain link. It should also be noted that in the current situation Ulstein has free shipping from GS-Hydro, thus the cost saving potential for Ulstein is difficult to estimate, as the extra shipping costs is typically indirectly transferred to the customer(s), for instance through higher prices. There is, however, clearly a large cost saving potential in a value chain perspective.

In terms of the internal flow, excessive transportation was also reported for B-components, mainly with respect to double handling and moving the components. The findings suggest that this is particularly due to the lack of fixed storage location and the uncertainty of when arriving components are required in production. For instance, it was reported that it is not unusual that a required component is stored behind another components, thus resulting in extra moving and handling of the components in front to get access to the components required in production.

4.1.2.2. Excessive inventory

The second lean waste consistently identified in the supply chain is excessive inventory. As described above, excessive inventory refers to having too much inventory or having materials available too far in advance before it is needed in production. Lean theory suggests that excessive inventory tend to increase lead time, prevent fast identification of problems and increase space requirements, as well as increasing inventory holding costs.

In terms of the external flow, excessive inventory was evident both at the central warehouse at Frogner and at the regional warehouse in Ålesund. For the central warehouse the excessive inventory is particularly related to having the “wrong” inventory. The interviews suggested that as little as 10% of the finished goods inventory counts for up to 90% of the sales for GS-Hydro. The rest of the inventory is typically categorised as slow-moving items resulting from ordering too much or wrong components from suppliers, as this is based on historical data and forecasts, due to lack of access to actual demand information.

Similarly, it was reported that having fresh and fast-moving inventory, with the right components is the main challenge for GS-Hydro, and therefore the warehouse often exists of excessive inventory in terms of slow- moving items or even non-moving, outdated items.

The findings suggest that the main impact on the flow of materials of having inventory that is outdated and not adjusted to the actual customer demand is when components are not in finished goods inventory at GS-Hydro. In that case, GS-Hydro has to acquire the components from their suppliers which increase the lead time. For GS-Hydro this can also lead to loss of sales, as Ulstein may go to another supplier for the components. In addition, excessive inventory also impact the cost perspective as this imply that unnecessary capital is tied up in the system.

Regarding the warehouse at Ulstein excessive inventory was evident for both B- and C-components. For B- components, these are procured specifically to the requirements of a project, so the excessive inventory is mainly related to having materials available too far in advance. For instance, a safety margin of 1-2 weeks was reported as not unusual. However, it can be argued that such a safety margin is necessary in the current situation due to the time constraints in a project. Therefore, and more importantly, is the impact

this have on the internal flow of materials. Particularly, as the warehouse personnel is not informed when arriving components are required in production, this put pressure on storage space, which again leads to extra handling and moving as described above and concerning waiting which will be described below.

For C- components, this is mainly related to having too much inventory available, often of the “wrong” components. Especially, this is typically caused by inconsistent and unclear, or lack of, communication from production to the warehouse personnel about upcoming requirements, resulting in orders often being based on experience and guessing. However, due to the low unit value of these components and the fixed and separated storage space, excessive inventory of C- components is not considered have a large impact on inventory holding costs or interrupting the flow of more critical components. Therefore, more importantly is to have the right inventory in terms of both volume and type of components to reduce the risk of stockouts, which can have a larger impact on project performance.

4.1.2.3. Waiting

The third lean waste delaying the flow of materials identified consistently in the supply chain link between GS-Hydro and Ulstein is the time materials are waiting to be processed or the time workers are waiting to process the materials.

In terms of the external flow of materials, the interviews revealed that one of the main challenges for the warehouse at GS-Hydro is that the majority of daily orders are received and released for picking between midday and 4 p.m. during a day, as the cut-off to send order for next day delivery is at 3 p.m. In other words, workers are waiting for orders to come in from customers and be released for picking, putting additional pressure on workers to ensure timely delivery. Particularly, as having a central warehouse requires transporters to have a fixed departure time from GS-Hydro to be able to deliver the materials to the different regions within 24 hours.

This has been overcome by GS-Hydro by having double shifts of workers during this period. However, it was reported that not having time to complete orders, due to large batches of orders to be picked before the truck leaves the central warehouse, is the main reason for not being able to deliver the materials on time the next day. As a result of having a central warehouse not in close proximity to customers, a missed shipment will

result in a one day delay of the materials, as it has to be sent the next day. Nevertheless, GS-Hydro reported that only 2-3 % of domestic orders are typically not shipped on time, and as GS-Hydro prioritise the orders based on strategic significance of the customers (A, B and C) these are orders normally to non-strategic customers. Ulstein is a strategic customer for GS- Hydro, and thus the orders from Ulstein have first priority.

This waste is also related to the excessive inventory in the supply chain described above, thus resulting in materials are waiting in finished goods inventory before they are shipped to the customers, both tying up capital and storage space and increasing the risk of materials becoming obsolete. No direct measures were found or reported, but the interviews at GS-Hydro revealed that the time materials are held in finished goods inventory at either the central or regional warehouse varies greatly. For instance, up to 90% of the inventory are slow moving items as described above, thus indicating that materials are sitting idle not producing any value in the warehouses before usage. Similarly, the interviews revealed that materials with long lead time from manufacturer (tier 2 supplier), such as pipes, are typically held in finished goods inventory at central warehouse for around 2 months often being allocated to customers. This is mainly due to the long lead time from manufacturers, combined with the uncertain demand from customers.

Regarding the waiting in the warehouse at Ulstein, the storage time was not accurately measured because information was not available from Ulstein, since the warehouse does not register when materials are withdrawn from storage. However, the interviews indicated that components are often held in the warehouse for a longer period of time after arrival before the components are requested in production. For B- components, this was mainly related to materials arriving too early at the shipyard, while for C-components this is typically caused by lack of information available about upcoming requirement, thus resulting in the wrong components or excessive quantities being purchased.

Furthermore, deviations were reported in both the external and internal flow of materials as being time consuming, thus delaying the flow of goods.

In the external flow, deviations were reported in both at the central and regional warehouse, mainly in terms of picking errors. Although picking errors were less than

1% of total orders picked at the central warehouse in 2011 and mainly related to wrong quantities, this was reported as very time consuming to handle. In addition, due to the location of the central warehouse, one picking error can have a major impact for the customer, as the component can typically not be delivered until the next day. Picking errors happen more often in the regional warehouses, and is clearly interrupting a streamlined flow of materials, but due to the proximity to the customer, this have less impact on the customers' production compared to picking errors at the central warehouse.

For the internal flow of materials, deviations particularly occurred in the receiving process. Deviations are related to for instance wrong quantities, wrong components, incomplete deliveries, and incomplete or lack of paperwork. In addition, deviations were also reported regarding the arrivals of incoming trucks. In the current situation, the arrival of incoming trucks is not planned at the warehouse, but the warehouse personnel have access to information regarding the confirmed delivery date. However, both the interviews and the archival records showed that the actual delivery date and confirmed delivery date deviated (largely) in many cases.

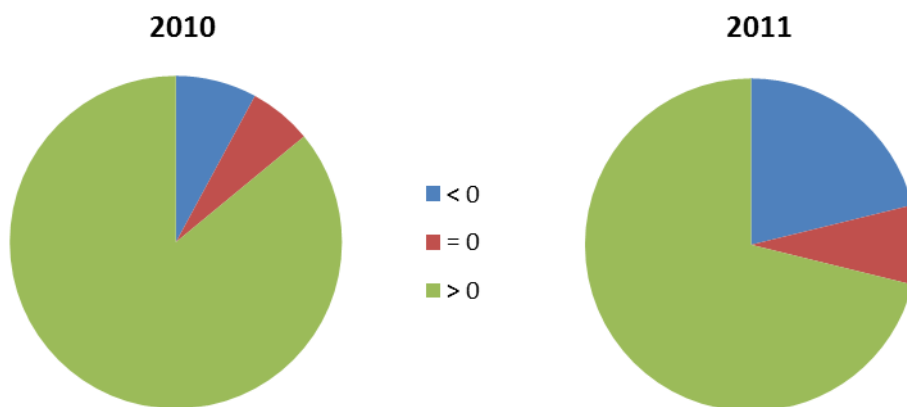


Figure 18: Deviations confirmed delivery from actual delivery

In figure 18, the deviations between confirmed delivery dates and actual delivery dates are illustrated for shipments from GS-Hydro in 2010 and 2011. Less than zero means that the materials are delivered before the confirmed date in the ERP system, higher than zero means that the materials are delivered after the confirmed date, while equal to zero means the materials are delivered on the day they were expected.

Clearly, the figure shows that 86% and 79% of the orders where delivered later than the confirmed delivery date in the ERP system, while only 8% and 6% were delivered on

the same day as confirmed date registered in the ERP system, in 2010 and 2011 respectively. However, this does not necessarily indicate that the deliveries from GS-Hydro are delayed. These deviations may also be caused lags in the registration, wrong date in the ERP system or that delivery dates in the ERP system are not updated after changes from the purchasing department. This is an example of how the poor information flow internally, impacts the flow of materials.

Therefore, the main point to draw from these deviations is the impact it has on the warehouse personnel and thus indirectly on the flow of materials. For instance, this information is the only available information the warehouse personnel have concerning the incoming trucks. As a result of this information it not reflecting the actual delivery date, it is difficult for the warehouse personnel to do any planning, particularly for B-components, with respect to the receiving process and allocation of storage location. As described above, C- components from GS-Hydro are normally delivered the day after they are ordered by the warehouse personnel, thus arrivals are expected.

Consequently, the interviews revealed that this inability to plan incoming deliveries, leads to peaks in in the workload for the workers, thus incoming materials are waiting to be processes due to lack of capacity to receive, register and store many deliveries at the same time.

Furthermore, this in combination with lack of available data about when components are needed in production leads to poor utilisation of the storage location as components are stored where it is space available, rather than being based on when components are needed in production. In addition to the double handling described above, this also results in workers having to spend time searching for components within the storage locations. Some searching was suggested to also be related to incomplete information from production workers requesting materials from the warehouse.

As it is mainly the same workers handling inbound and outbound components this creates further pressure on the workload for the warehouse personnel, thus leading to more materials waiting to be processed or moved within the shipyard.

In addition, since C-components are typically ordered based on usage, stockouts can be relatively normal and caused by a sudden peaks in demand for components. As these are ordered with delivery next day from GS-Hydro, the waste of waiting for C-components is also related to the time waiting for incoming materials from supplier due to stockouts at Ulstein's warehouse, which in some cases can delay the production.

4.2. Value stream from Brunvoll to Ulstein

Again, by referring to the research model outlined above, and the argument of Wegelius-Lehtonen and Pahkala (1998), the main focus of this supply chain link is the flow of information, primarily due to the comparable long lead time, ETO nature of the components flowing in this value stream and the relatively low logistics costs compared to purchase price of these components.

In similar fashion as the GS-Hydro supply chain link, this value stream analysis is limited to the supply chain link including Brunvoll and Ulstein (tier 1 supplier and focal firm). In terms of product family, the materials flowing in this value stream are thrusters, categorised by Ulstein as strategic components (A- components), with a high unit value and low quantities per project.

The focus and boundary condition are illustrated in figure 19 (in comparison to figure 11).

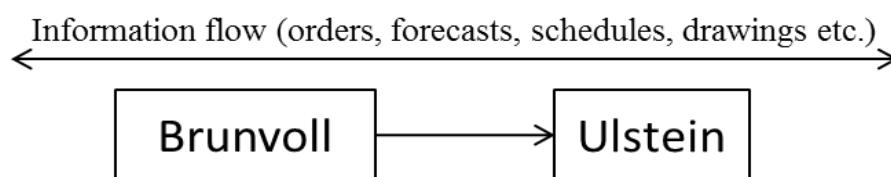


Figure 19: Focus and boundary conditions

4.2.1. Flow

As discussed previously, the information flow in a supply chain link between an ETO supplier and a construction project is often characterised by high level of fragmentation, complexity and uncertainty, while the material flow is characterised by a high level of change orders and long lead times.

Again, by following a VSM approach, the next step is to create a current state map in order to highlight waste and improvement opportunities. However, in relation to the focus and boundary conditions described above, for this supply chain link this means creating a current state map of the information flow, with less focus on the material flow. For this value stream, the material flow is mainly considered for the internal flow, as data was not available for the manufacturing phase at Brunvoll. The information flow is analysed for Ulstein's project no. 295, and includes delivery of three thrusters from

Brunvoll. This section will describe the current state of the information flow in the external flow between Brunvoll and Ulstein, as well as the material flow in terms of the internal flow at Ulstein.

Clearly, there is also a flow of information between the different departments at Ulstein. However, this information flow is not explicitly analysed, but rather discussed in relation to the internal flow of materials.

Although Brunvoll may get indications from the sales department at Ulstein at an earlier stage in the project about potential upcoming orders, the procurement procedure considered here starts with a tendering process. In the tendering process Ulstein initiates contract with Brunvoll with a request for quotation (RFQ). The RFQ is based on the specifications from the engineering department, which again is based on the order and specifications from the client (ship owner). A RFQ is typically sent to at least 2-3 different suppliers. A supplier is selected mainly based on price, but also delivery date and specifications impacts the supplier selection. Within this tendering process, information flowing between the supplier(s) and Ulstein include technical information and documentation as well as negotiation both on a technical level, in terms and specifications and on a commercial level in terms of price, delivery date, and potential options to change the order. When agreement is reached with the preferred supplier, the final part of the tendering process includes sending a recommendation to the client and obtaining approval from the client for purchasing from the selected supplier.

When approval is obtained from the client, the next process is the actual purchasing process where the order is placed with the supplier, in this case Brunvoll. Additional information flowing between Ulstein and Brunvoll in this process include decisions whether to implement options or not and technical documentation and drawings.

The next process in the value stream is the production of the thrusters at Brunvoll. In the supply chain link between Ulstein and Brunvoll, this is the process where materials start flowing, since suppliers further upstream are not considered. The actual flow of materials in the production at Brunvoll is, as mentioned previously, not analysed since Brunvoll is not participating in the case study. However, there is a flow of information between the two parties during the production phase, including for instance drawings and documentation, both of a technical and commercial nature, change orders, and a

monthly update from Brunvoll on the progress and current schedule. The processes and flow of information between the involved parties is illustrated in figure 20.

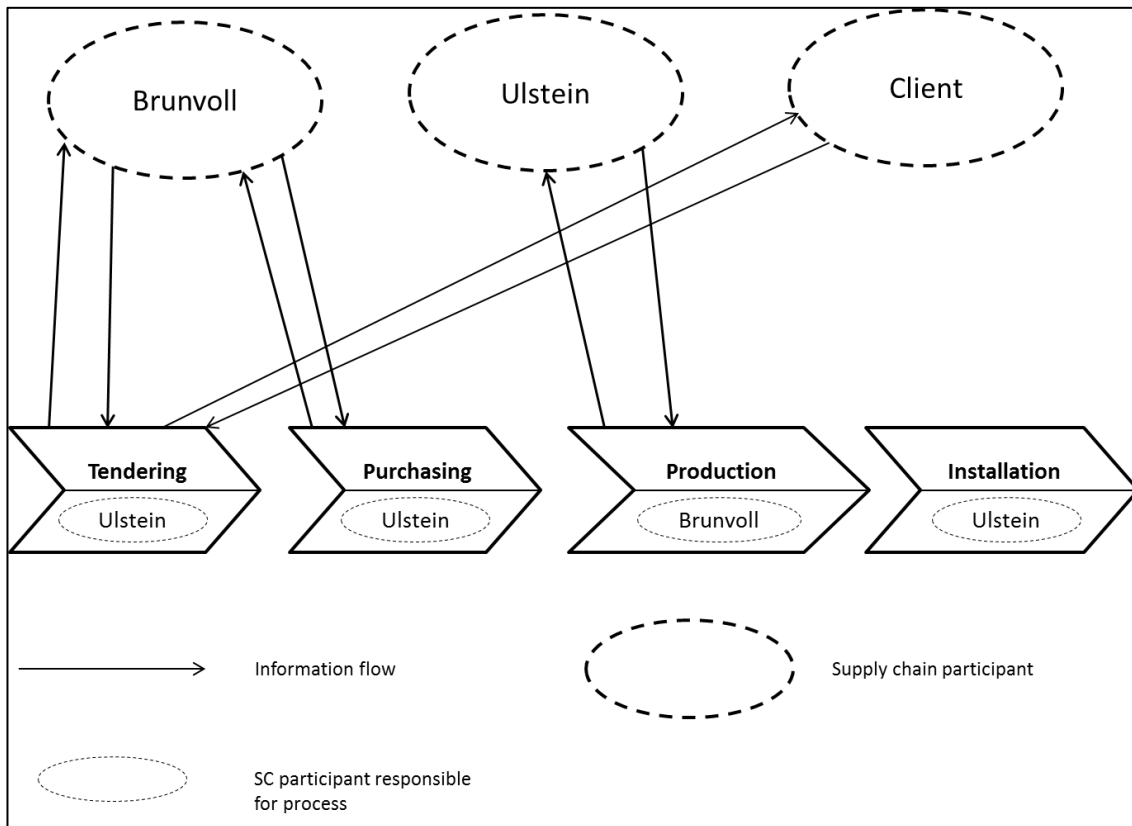


Figure 20: Map of value stream processes and information flow

The main focus of the value stream after the production process is the (internal) flow of materials, from when Ulstein receives the components until the components are ready to be installed. This flow is showed in figure 21, where the black boxes in the Brunvoll column is only an illustration of the material flow before Ulstein receives the components.

It should be noted that in some instances thrusters are delivered for primary outfitting to the shipyard constructing the hull in a low-cost country. However, for this study the delivery of thrusters to build no. 295 to Ulstein shipyard is evaluated.

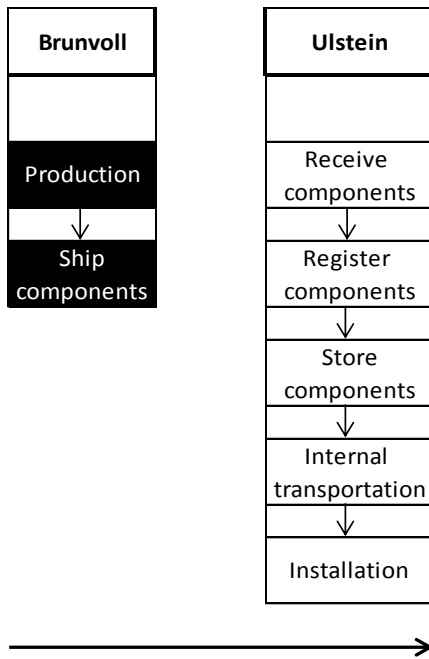


Figure 21: Internal flow of components

More specifically, build no. 295 is scheduled to be delivered to the client 30. November 2012. In terms of the procurement of thrusters for this project, Ulstein’s purchasing department initiated contact with Brunvoll with a RFQ the 2. March 2011.

The order consists of delivery of three thrusters, and the current schedule is to have two thrusters delivered on the 20. April 2012 and the last one on the 1. June 2012. The lead time from the RFQ was sent to suppliers to the current planned delivery is therefore 408 and 449 days. The manufacturing lead time is calculated as the time from the order is sent to the original delivery date and is 334 and 347 days for the different thrusters (table 2). Clearly, this is the largest contributor to the total lead time, but the actual manufacturing process is not evaluated in this thesis due to the lack of access to data. However, from the interviews it was clear that Brunvoll’s manufacturing lead time was similar to other suppliers in the market, and the manufacturing lead time varies in the industry depending on the market environment and the types of thrusters.

Table 2: Dates and lead times (days) on thrusters from Brunvoll for build no. 295

RFQ issued	Supplier selected	Order sent	Original delivery date	Scheduled delivery date	Lead time RFQ-original	Lead time RFQ- Scheduled	Manufacturing lead time
02.03.2011	08.04.2011	26.04.2011	30.03.2012	20.04.2012	388	408	334
			13.04.2012	01.06.2012	401	449	347

4.2.2. Waste

Waste is, as discussed above, anything that is not adding value to the end-product, and can be processes, activities or other structural arrangements. With respect to the supply chain link between Brunvoll and Ulstein, where the main focus is on the information flow, it can be argued that waste is more related to arrangements which increase the complexity, fragmentation and uncertainty of the information flow, rather than directly impacting the material flow, particularly as the manufacturing phase is not analysed. Instead, the waste may have a more indirect impact on the lead time and the delivery process.

From the analysis of the information flow, particularly three features in the procurement process were identified as having a large impact on the lead time and the complexity of the information flow; (1) competitive bidding, (2) high level of customisation and change orders and (3) waiting for information in terms of documentation and decisions. First, when considering the actual lead time from contact was initiated to the current scheduled delivery dates, the process of competitive bidding, here calculated as the time from the RFQ was sent to Brunvoll to Brunvoll was selected as preferred supplier, amounted to 36 days, or 8.8 % (8% for latest delivery) of total lead time.

In addition, it took another 18 days, or 4.4 % (4 % for latest delivery) of total lead time from Brunvoll was selected as supplier to the order was sent to Brunvoll. This time included obtaining approval from the client (ship owner).

Consequently, in this case the process of competitive bidding and obtaining approval from client amounted to 54 days, or 13.25 % (12 % for latest delivery) of total lead time. The findings are summarised in table 3. Without the opportunity to evaluate the whole process in detail, it is not clear how much of this is actually adding value to the end product. However, it is clear that the process of competitive bidding is a large contributor to the total lead time, particularly when viewing the supply chain from Ulstein's perspective. In addition, the tendering process clearly increases the complexity of the information flow, as at least 2-3 suppliers are involved in the process.

Table 3: Impact of competitive bidding on lead time

Lead time RFQ- Scheduled	Days RFQ- supplier sel.	% of lead time	Days supplier selection-order	% of lead time	Days RFQ- order	% of lead time
408	36	8,8 %	18	4,4 %	54	13,2 %
449	36	8,0 %	18	4,0 %	54	12,0 %

The second feature of the information flow impacting the lead time was the high level change orders. For the thrusters for build no. 295, the contract with Brunvoll included 2 options to change the order. One option was to change a super silent tunnel thruster to a combined azimuth/tunnel thruster, while the second option was regarding an extraction of the control panel and control system from the delivery scope from Brunvoll. In addition, there was a change order to increase the power of the thrusters.

As the two options were included in the contract, Brunvoll was aware of the potential changes early in the process. This, in combination with the relatively early implementation of the two options, suggests that the options had relatively limited direct impact on the lead time. However, the options increased the complexity of the information flow, thus indirectly impacting the lead time. This impact will be further discussed below.

In terms of the change order, this was included relatively late in the project. This resulted in 48 days delayed delivery of the combined azimuth/tunnel thruster because Brunvoll was waiting for an engine from a supplier. During the interviews it was made clear that this delay impacts the production plans and the project progress, as the work that can be done in the area where the thruster is to be installed is limited.

The third and probably the most important contributor to the lead time within the scope of this study was the time parties in the supply chain were waiting for information in terms of documentation and decisions. This was made more evident due to the two options and the change orders, which added to the complexity of the delivery process.

In terms of the documentation, this is an important part of the information flow in the supply chain, both in terms of commercial correspondence and technical documentation. The flow of technical documentation is important because Brunvoll is dependent on input from Ulstein to complete their drawings/components and vice versa.

The findings suggest that most of the waiting for information in terms of technical documentation was related to when either Brunvoll or Ulstein was waiting to receive technical documentation from the other party. For instance, the delayed delivery of technical documentation from Ulstein to Brunvoll resulted in a 20 days delay in the delivery date for the tunnel thruster. Furthermore, the interviews with Ulstein indicated that the information flow is fragmented and complex, as a large proportion of the information is sent on requests and after reminders from the party requiring the documentation. The documentation is often sent to the party “shouting loudest” and often sent when Brunvoll has made the documentation rather than when it is actually required. In addition, due to the large amount of documents, gathering all the required information and documentation was reported as one of the main challenges in the procurement process.

In terms of the impact of waiting for decisions has on lead time, this was related to the time Brunvoll was waiting on a decision from Ulstein. In this case this was mainly related to decision of whether or not to implement the two options. The decisions to implement the two options were made 31 and 23 days after the original deadline, for option 1 and 2 respectively (see table 4).

Although the direct implications on lead time and delivery date of this waiting for decisions to be made are not documented, it seems clear that it is adding extra time to the delivery lead time. It is, however, a difficult question whether this is adding value to the end product or not. On one hand, although not directly adding value to the end product, the longer decision time may be necessary and result in a better decision regarding the requirements of the client. On the other hand, the interviews gave the impression that the additional decision making time was not always necessary. In that case, the extra time does not add value to the end product, and should have been eliminated.

Table 4: Dates and decision time (days) for implementing the two options

	Original Deadline	New Deadline	Implementation confirmed	Revised order based on option	Days, original-new deadline	Days, original deadline-confirmed implementation
Option 1	16.05.2011	29.05.2011	17.06.2011	23.06.2011	13	31
Option 2	16.05.2011	29.05.2011	09.06.2011	14.06.2011	13	23

In terms of the internal flow, the thrusters for build no. 295 were not delivered to the shipyard in time to specifically analyse the internal flow of the components. The internal flow of A-components was therefore evaluated from a more general perspective. The interviews revealed particularly three wastes delaying the flow of strategic components; (1) excessive inventory, (2) excessive transportation and (3) waiting.

The excessive inventory for A-components refers to having the components available too far in advance. However, as withdrawal of components from storage is not registered, there was no precise information available concerning the storage time for A-components. Instead, it was reported based on experience from employees in the warehouse function that the thrusters are typically installed within 1-2 weeks after they are received at the shipyard. This view was supported from the purchasing function, who reported that the thrusters are typically stored for at least a few days before installation.

On the other hand, it can be argued that a safety margin may be necessary for strategic components in a Norwegian shipbuilding context due to the potential large impact on production plans a delayed delivery can have. However, in the current situation at Ulstein this excessive inventory results in excessive transportation and waiting within the shipyard.

After arrival and registration of strategic components at the shipyard, the components should ideally be transported directly to the staging or installation area. However, the interviews suggest that this is not always possible due to space limitations, too early deliveries and/or it is unclear when the components are required in production. As a result, components can in some instances be stored where employees can find space until further notice when the components are needed in production, resulting in double handling and excessive transportation within the shipyard.

Moreover, the findings suggest that delays in the internal material flow occur in terms of time components are waiting to be processed or moved, for instance due to peaks in the workload for the warehouse personnel responsible for receiving and moving the components or that the components are received too far in advance before they are required in production. For instance, there is currently no scheduling of incoming trucks, often causing different trucks and components arriving at the same time. This

can result in components waiting to be registered and moved to storage/production location. There is, however, a plan for when A-components are needed in production. Nevertheless, the interviews did not suggest that these plans were used explicitly to plan the transportation from the warehouse to the installation areas, and thus the requirements are often communicated to the warehouse on a “required immediately” basis. As a result there are often peaks in the workload of the warehouse personnel, which may result in components waiting to be moved to production areas.

5. Discussion and Conclusion

5.1. *Thesis discussion*

There are, according to Koskela (2000), three root causes of non-value adding activities; (1) the structure of the production system (value stream), (2) the way production (value stream) is controlled and (3) the inherent nature of production. Similarly, it has been argued that waste and delays in construction supply chains are caused by lack of planning, coordination and collaboration due to high organisational barriers, with each partner in a supply chain focusing on its own processes and financial gains, without considering the impact on upstream or downstream parties in the supply chain.

Based on the case findings described above, this section will discuss what the sources of the waste and delays in the two supply chains appear to be. First, the sources of waste in the link between GS-Hydro and Ulstein will be debated. Second, the sources of waste and delays in the link between Brunvoll and Ulstein will be discussed, before the two supply chain links will be compared and contrasted.

5.1.1. Sources of waste GS-Hydro- Ulstein

Clearly, in the current situation, there are considerably amounts of non-value adding time, inventory and other processes and structural arrangements which are hindering a continuous flow of materials in the supply chain link between GS-Hydro and Ulstein. One could argue that this is due to the nature of Norwegian shipbuilding with its unique projects, concurrent engineering, high level of change orders and uncertain demand pattern for components. However, the findings suggest that although this has an impact on how the supply chain is and should be configured; it is not the main source of delays in the delivery process of components from GS-Hydro to Ulstein. Particularly, even though shipbuilding is project-based production, this supply chain is relatively permanent as evident from figure 22. The figure shows the number of orders per month from Ulstein to GS-Hydro in 2010 and 2011, and although number of orders and volumes vary, the figure illustrates that materials are flowing consistently through the supply chain.

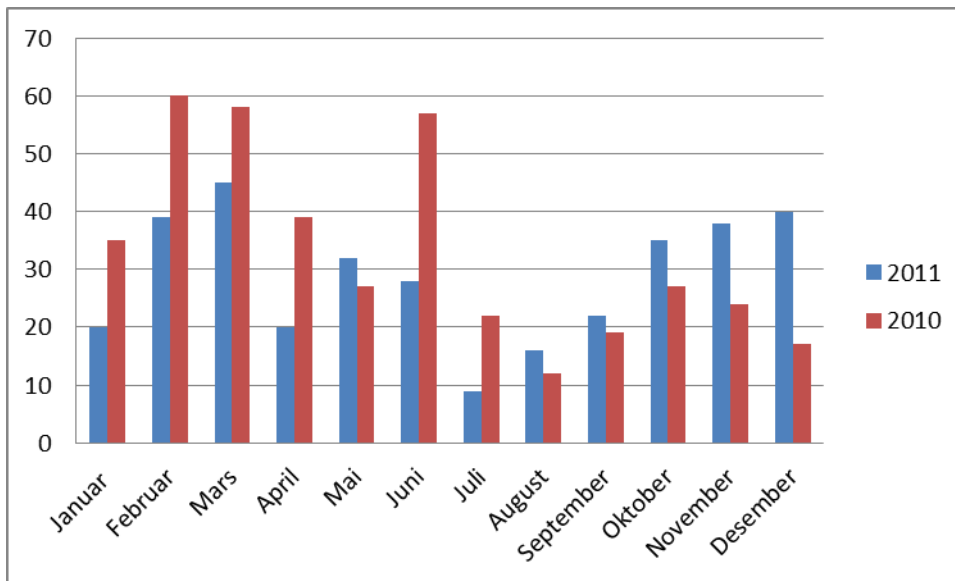


Figure 22: Number of orders per month in 2010 and 2011

Consequently, the waste in the supply chain cannot be explained by the one-of-a-kind nature of shipbuilding with corresponding temporary supply chains. Instead, the findings suggest that one of the main sources of delays in the supply chain link between GS-Hydro and Ulstein is the lack of coordination and cooperation in the interface between the two parties. This is particularly evident in terms of the sharing of demand information. For instance, the interviews revealed that GS-Hydro does not have any information about demand, neither type of components or volume, until the order is received from Ulstein. For larger deliveries of B-components (typically pipes) to a project, GS-Hydro receives an estimated demand for the whole project. However, the actual delivery of these components is typically communicated on a shorter term, and pipes for a whole project are normally delivered in some large batches.

There are several examples on how this lack of coordination and collaboration impacts the delivery process in this value stream. First, due to the long lead time for some of the components (especially pipes) from suppliers to GS-Hydro as described above, GS-Hydro has to procure based on forecasts which are based on historical data and some input from sales personnel (if available).

This is where the one-of-a-kind production impacts the supply chain. Considering the one-of-a-kind nature of shipbuilding in Norway, the historical data are not accurate to predict future demand as typically no ship is exactly the same as another and different types of ships require different amounts of for instance pipes, i.e. an uncertain and fluctuating demand pattern. Figure 23 shows the tonnage per month shipped from GS-

Hydro to Ulstein in 2010 and 2011, and illustrates the uncertain and variable demand pattern, while also confirming the permanency of the supply chain.

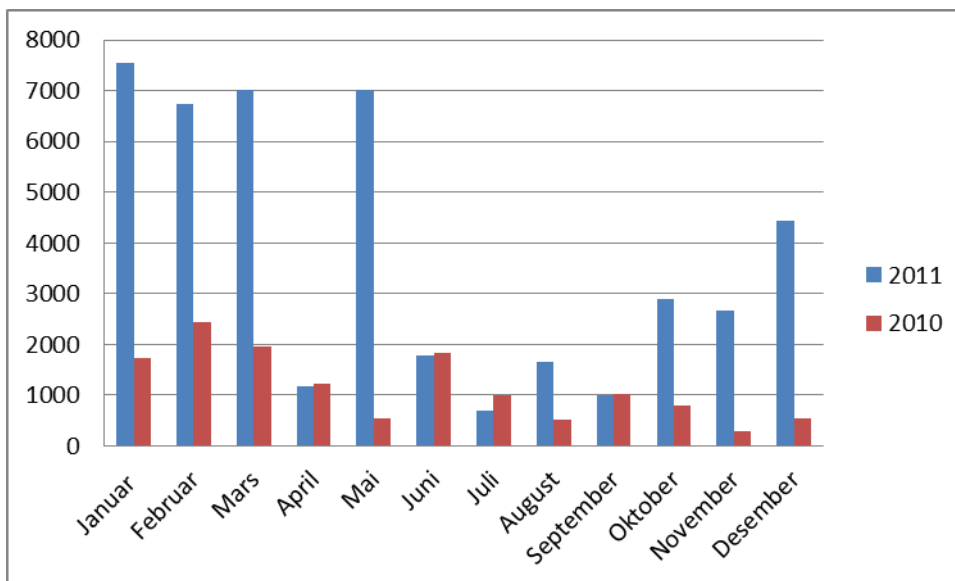


Figure 23: Tonnage per month 2010 and 2011

However, the point is that this historical data is often the only information available to GS-Hydro about future demand and thus GS-Hydro’s forecasts are wrong, resulting in GS-Hydro having excessive inventory in terms of too much volume, “wrong” components and out-dated components as described above. GS-Hydro can to some degree compensate for this demand uncertainty through their global consolidation of the procurement of their strategic components, which allow them to shift volumes between different warehouses in different countries. Nevertheless, the interviews revealed that the main challenge for GS-Hydro is to have the right inventory, both in volumes and types of components, due to lack of demand information.

A second and corresponding example of the lack of coordination in the supply chain is the distribution of tonnage supplied from the central warehouse and the regional warehouse. GS-Hydro’s warehouse and distribution strategy is designed to supply 90 % of the orders from the central warehouse and 10 % as urgent orders from the regional warehouses. In the current situation, however, this is not the case, because Ulstein often place orders in the morning for the components needed the same day, which are components that have to be supplied from Ålesund. Hence, there is currently a mismatch between the ordering routines of Ulstein and GS-Hydro’s (optimal) supplying

routines. The result is both excessive inventory at the regional warehouse, and excessive transportation and transportation costs.

This clearly indicates the lack of coordination and cooperation between GS-Hydro and Ulstein, and although the source of delays is mainly considered to be this lack of coordination, this also highlights the lack of planning at Ulstein and how this impacts the supply chain performance. As there is no formal planning concerning when components from GS-Hydro (B-components) are required in production, Ulstein often order on a daily basis what is required in production the same day. The reason for not including the B-components in the weekly production plans is to reduce the amount of details in the plans and the conditions that only “sound” activities should be included in the plans which again assume that the materials are available.

This can be considered one of the core issues concerning the lack of coordination between Ulstein and GS-Hydro. Traditionally, Ulstein has ordered on a daily basis from the regional warehouse at Ålesund. When GS-Hydro changed to having a central warehouse, this was mainly a strategic change, as the warehouse at Frogner in practice had been a central warehouse even before the change, to take advantage of the economies of scale of having a central warehouse and consolidate transportation to the regions, thus ideally reducing double handling and inventory holding at the regional warehouses. The downside is the increased distance to the customer, with longer lead times. For GS-Hydro to take fully advantage of the new system in terms of handling and distribution costs, the customers have to order before 15.00 for delivery the next day. However, Ulstein has continued to order in the morning and demanding delivery the same day, thus GS-Hydro have to supply the order from Ålesund to satisfy the customer.

The argument here is somewhat contradictory. On one hand, “the customer is always right”, and lean theory states that only what the customer, in this case Ulstein, perceives as value should be considered value adding. Therefore, one may argue that GS-Hydro should facilitate for this same day delivery to satisfy the customer (which they do in the current situation). On the other hand, from a value chain and lean SCM perspective, waste should be removed from the value stream through coordination and cooperation. This is an important point, because in the current situation, by demanding same day delivery, Ulstein does not consider the impact on downstream players in the supply chain and total supply chain costs, particularly as Ulstein have free shipping from GS-Hydro, thus not having the to consider the extra transportation costs related to this.

In addition, it seems oddly high that for 39% (percentage of annual orders supplied from Ålesund with courier in 2011) of the total orders in 2011, the demand occurred overnight at Ulstein, thus actually providing value to Ulstein to have the components delivered the same day. Based on the interviews, it seems clear that the majority (if not all) of the requirements for production is known at least one day before the components are required in production, and thus the information is available to order from GS-Hydro one day in advance. Therefore, this lack of planning combined with the traditional way of ordering from GS-Hydro is causing excessive inventory and transportation in the supply chain. Furthermore, this indicates that in the current situation the all-important value stream thinking in lean SCM is ignored, with each of the parties focusing mainly on own goals.

Further examples of the lack of coordination and collaboration were found in the communication between GS-Hydro and Ulstein. For instance, the interviews revealed that Ulstein believe that when they send an estimate of the demand for pipes for the upcoming projects the pipes are located in the regional warehouse in Ålesund. However, GS-Hydro allocates the components ordered from Ulstein in their central warehouse at Frogner, and normally stores the components there until they are requested by Ulstein. Similarly, it was reported that Ulstein in some cases order from GS-Hydro what they believe is an off-the shelf components in GS-Hydro's inventory, which is actually a component GS-Hydro have to order from a supplier, thus having a longer lead time. These two examples illustrate the often poor information flow in the supply chain, where the two parties clearly have divergent views on the reality, which is interrupting a streamlined flow of materials. It should be noted, however, that the interviews revealed that both parties consider the relationship with the other at the point of contact as good. Nevertheless, the point of contact between the two parties are limited to the sales personnel at GS-Hydro and a few employees at Ulstein, and thus that they consider the relationship as good, does not necessarily imply a high level of coordination and an efficient information flow between the two parties.

Correspondingly, the supply chain link between GS-Hydro and Ulstein is recognised by a high level of transactional or discrete contracting. For project specific B-components, the interviews revealed that Ulstein, as long as they have time for it (in the project), puts the order out for tendering to 2-3 suppliers. The supplier is selected primarily on price,

but delivery date and reliability also impact the decision. This high level of tendering is further showing the lack of cooperation and collaboration in the supply chain because it discourages value chain thinking in the supply chain, with each partner mainly focusing on own monetary short-term goals.

The lack of coordination is not only evident on the interface between the two parties, but also within the shipyard. This is particularly evident when considering the information available to the warehouse personnel. As discussed above, the warehouse personnel does not have information about when components are required in production, or about the upcoming demand for C-components, before they are required. Similarly, the deviation between confirmed delivery date and actual delivery date, which is believed to often be caused by the purchasing department not changing the confirmed delivery date, is another example of the lack of coordination between the departments.

This lack of information sharing between the departments at Ulstein also impacts the warehouse's ability to plan and the lack of planning is also considered a source of waste within the internal logistics. Particularly, the inability to plan incoming and outgoing materials due to lack of available and correct information results in peaks in the workload of the workers as well as making it difficult to determine the suitable storage location. This again leads to the wastes of excessive transportation and waiting discussed above as well as poor utilisation of the storage space within the shipyard.

In addition, the lack of control of the flow of materials within the shipyard can also be considered a source of waste, and this is mainly related to the lack of control of the inventory. For example, there is not control of or registration when B- and C-components are withdrawn from the inventory. As a result there is no information available concerning what is actually in stock, how long components are held in inventory, or whether the components are used for the right project. It was reported, for instance, that it is fairly common to "borrow" components from another project if the components were not in stock for the project it is required.

Subsequently, there is no accurate information available to decide whether an activity is "sound", other than that the components are received at the warehouse, and the assumption that the components have not been used for another purpose. The interviews

revealed that it does occur that components have to be ordered again, because the components cannot be found within the warehouse facilities, typically because they have been withdrawn for another purpose or project, or it is hidden behind other components. This illustrates how the lack of control can delay the flow of materials, and also emphasise the need for an improved information flow to improve cooperation and planning to reduce waste in the supply chain. This is further emphasised by considering the argument of Ala-Risku and Kärkkäinen (2006) that lack of information about materials availability often results in large inventory buffers on-site and excessive material handling.

Consequently, the main source of delays in the flow of materials from GS-Hydro to Ulstein is the lack of coordination. However, this lack of coordination is closely connected with the lack of planning and control. Particularly within the internal logistics, these can be considered sources of waste and delays. The cause and-effect diagram in figure 24 summarises the findings and discussion of how the sources of waste are related and results in the three types of waste identified in this value stream. The next section will discuss whether GS-Hydro's change to a central warehouse can be considered as a source of increased waste and delays in the flow of materials.

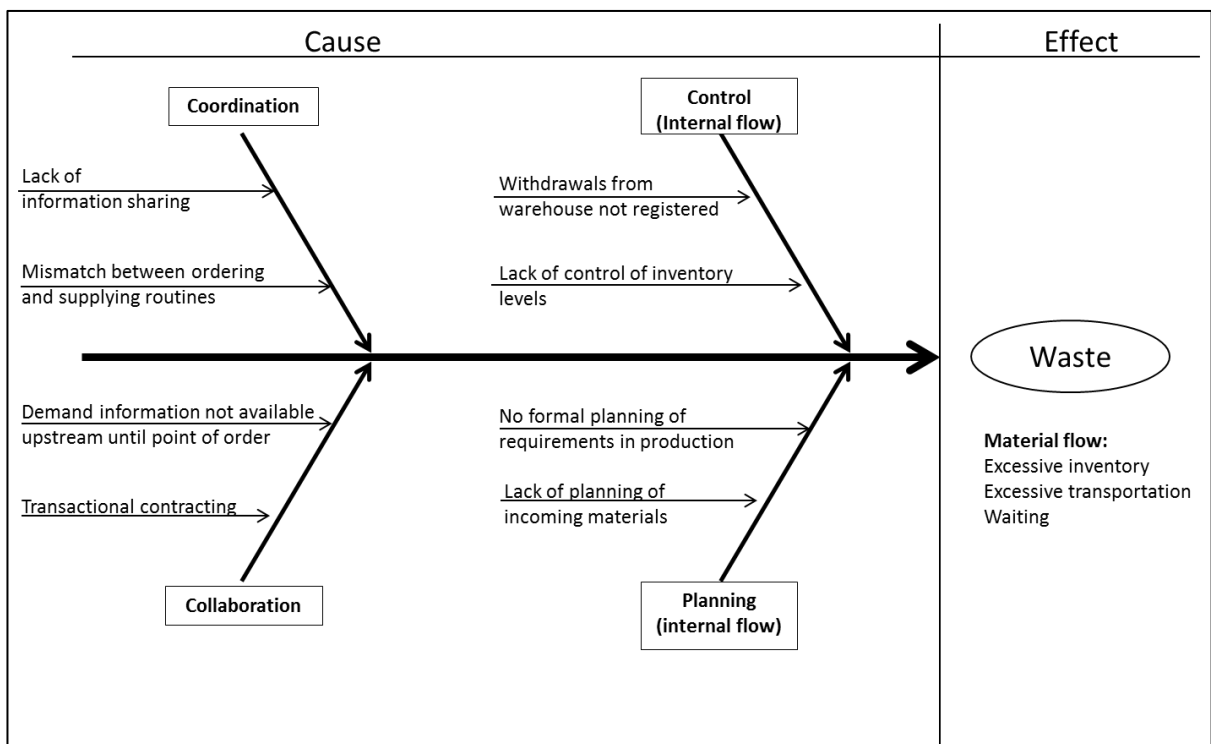


Figure 24: Cause and effect diagram, GS-Hydro- Ulstein

5.1.1.1. Central vs. regional warehouse

An important part of the background for this thesis, and the main reason for the involvement of GS-Hydro in this research, is the impact of GS-Hydro's change to a central warehouse at Frogner has had on the supply chain performance. For instance, Ulstein reported increased variability in the deliveries from GS-Hydro since the change, especially in the beginning after the change. One can argue that the role of GS-Hydro in this supply chain is to be a buffer between the manufacturers (second tier suppliers) and Ulstein, to deal with the long lead time from manufacturers, particularly pipe manufacturers, and the fluctuating demand pattern from Ulstein. The challenge is therefore to locate the warehouse(s) to minimise logistics costs (including inventory holding costs), while providing the required service to the customers.

From the findings there are no clear signs that GS-Hydro's change to a central warehouse has significantly increased waste and delays in the flow of materials, rather the opposite, that less material is shipped through Ålesund, thus reducing double handling and transportation. However, the interviews did reveal that there were some problems in the beginning including some deviations and delayed shipments.

Nevertheless, the change was mainly a strategic change as the warehouse at Frogner had been in a sense a central warehouse before the change, even though it was not used as one explicitly. The advantages of having a strategically central warehouse include economies of scale in procurement, transportation and handling and a larger assortment in the inventory.

The main disadvantage of having a central warehouse, on the other hand, is the increased distance and lead time to the customers, which can result in delays being longer if they occur and also require more planning, especially in the case of Ulstein, from the customer, as the order have to be sent the day before the components are required.

However, this is counteracted by GS-Hydro by having a regional warehouse, which should mainly service urgent, unexpected orders. The interviews revealed that the one of the main challenges for GS-Hydro was to change the mind-set of its own sales personnel who were used to having a regional warehouse. In addition, the use of

regional warehouses in the current situation is mainly due to the demands from the customers, were the sales personnel feel they have to accommodate this demand.

During the research, however, it became clear that a central warehouse appear as the logical logistical solution in this supply chain and that the waste in the flow of materials to Ulstein, from a value chain perspective, is mainly a result of the lack of coordination and collaboration on the interface between the firms, regardless of whether Ulstein is supplied from a regional warehouse in Ålesund or directly from a central warehouse at Frogner.

Particularly, considering this situation were some of the components in the supply chain have up to a year lead time from manufacturer, through GS-Hydro to Ulstein, one can argue that inventory is necessary in the supply chain, especially considering the unpredictable demand pattern from Ulstein. On the other hand, one wants the lowest costs possible in the supply chain. As a result, one may argue that a central warehouse, which can take advantage of economies of scale in the procurement and handling of the components, while having a larger product assortment than regional warehouse, is a suitable solution to balance the required service level while minimising costs in a complex supply chain.

The main challenge in the current situation is therefore to configure the supply chain to be able to integrate the unpredictable and variable, but permanent demand from Ulstein with the finished goods inventory at GS-Hydro while maintaining a required service level, at the same time as minimising the logistics costs in the supply chain.

5.1.2. Sources of waste Brunvoll- Ulstein

It has been suggested that waste in the information flow between a supplier delivering ETO-components and the customer's own ETO construction project is typically caused by the supply chain partners lack of a systems perspective and the lack of coordination between parties. In terms of the material flow on-site, it has been argued that waste is often caused by the lack of planning and coordination between the supplier and on-site activities causing inventories and unproductive workers on-site.

Clearly there are features in this supply chain that add to the lead time, without necessarily adding value to the end product. The findings suggest that there are particularly three sources of the waste in the information flow between Brunvoll and Ulstein; concurrent engineering, transactional contracting, and lack of coordination and cooperation. It is, however, difficult to determine the true value of these delays due to the complexity of the build no. 295, but this will be discussed further below. For the internal flow of materials, the findings suggest that the waste identified was mainly due to lack of planning and coordination.

In terms of the additional time identified due to the customisation, options and change orders, this seems to be a result of the concurrent engineering. Particularly as build no. 295, is a ship that is technological innovative, and thus some of the specifications were not fully established during the negotiation stage, which resulted in having the two options in the contract. Similarly, the additional lead time as a result of the change order can also be argued to be a result of the concurrent engineering. In addition, the delays identified waiting for decisions, can also be linked with the concurrent engineering, as this additional decision making time may have been necessary to have a better basis for making the decision.

Therefore, one can argue that the extra lead time caused by the change order and options are necessary to be able to provide the right product to the end product. On the other hand, when considering the impact the delays can have on the production plans (especially for the thruster delivered in June), one may question whether improvements can be made in the engineering or in the communication between the engineering and procurement departments, particularly with respect to the decision making time, in order to reduce the delays. However, it should be emphasised that the interviews

revealed that this ship (no. 295) is a particularly complex project, thus requiring more complex engineering where actual specifications are more uncertain than usual.

Furthermore, the interface between Brunvoll and Ulstein is recognised by a high level of transactional contracting, as the deliveries of thrusters to all of Ulstein's projects are put out for tendering to at least 2 suppliers. At the same time, the findings suggest that the relationship have some of the characteristics of a relational relationship including supplier flexibility and trust which have developed over time as Brunvoll is normally participating in the tenders for contracts with Ulstein.

Again, it is difficult to determine the true value of this competitive bidding process, due to, among others, the lack of information available concerning the actual cost savings obtained (if any) through the tendering and the cost in labour time of organising the tender. Nevertheless, some of the time of the competitive bidding process is used to define specifications, which would have to be done regardless of having a tendering or not, and thus the potential time saving of not having a tender is also difficult to determine. However, it seems obvious that the competitive bidding process increases the complexity and fragmentation of the information flow as for instance the specifications and potential change orders/options have to be discussed with all the suppliers participating in the tendering process.

Therefore, the most eminent source of delays is the lack of coordination on the interface between Brunvoll and Ulstein. The findings suggest that this is mainly related to the level of the relationship between the two parties, and as the relationship has developed over the years the method for working together has become a little bit loose. As a result, deadlines are not always complied with and assumptions are made in the communication between the two firms. It can be argued that this may be a consequence of the mixed relationship, with both transactional and relational characteristics.

One example from the interviews is that although Ulstein may have the right, according to the contract, to penalise Brunvoll for not complying with for instance the project schedule, this may be limited in practice. Particularly, if the delays have been caused by Ulstein not complying with the deadlines themselves, the means to penalise may be limited in practice.

In addition, as mentioned above, one of the main challenges for procurement at Ulstein is to obtain all the information and technical documentation. Although this was not specific to the relationship with Brunvoll, it further emphasises the lack of coordination between the two parties. This may not, however, directly increase the lead time for the components, but it was suggested that it can be very time consuming and be a factor for why Ulstein order earlier than the actual lead time should indicate, to ensure all the technical documentation is received on time.

This point also illustrates fragmented information flow between the different departments at Ulstein, with lack of coordination and adverse goals, which can be considered a source of non-value adding activities in the internal flow of components from Brunvoll. For instance, while the project coordinator/manager would like, at least traditionally, to have components delivered as early as possible to ensure on time delivery, the warehouse personnel would like to have the components delivered as close as possible to the installation date to avoid double handling and accumulation of components in the storage areas.

Correspondingly, the lack of coordination and information sharing also creates difficulties for the warehouse personnel to plan the receiving of components, storage location and transportation to the installation area, as this information is often not available other than on an immediate basis, which may cause delays and waste in terms of excessive transportation, double handling and waiting. The sources and corresponding waste in the value stream from Brunvoll to Ulstein is summarised in the cause and effect diagram in figure 25.

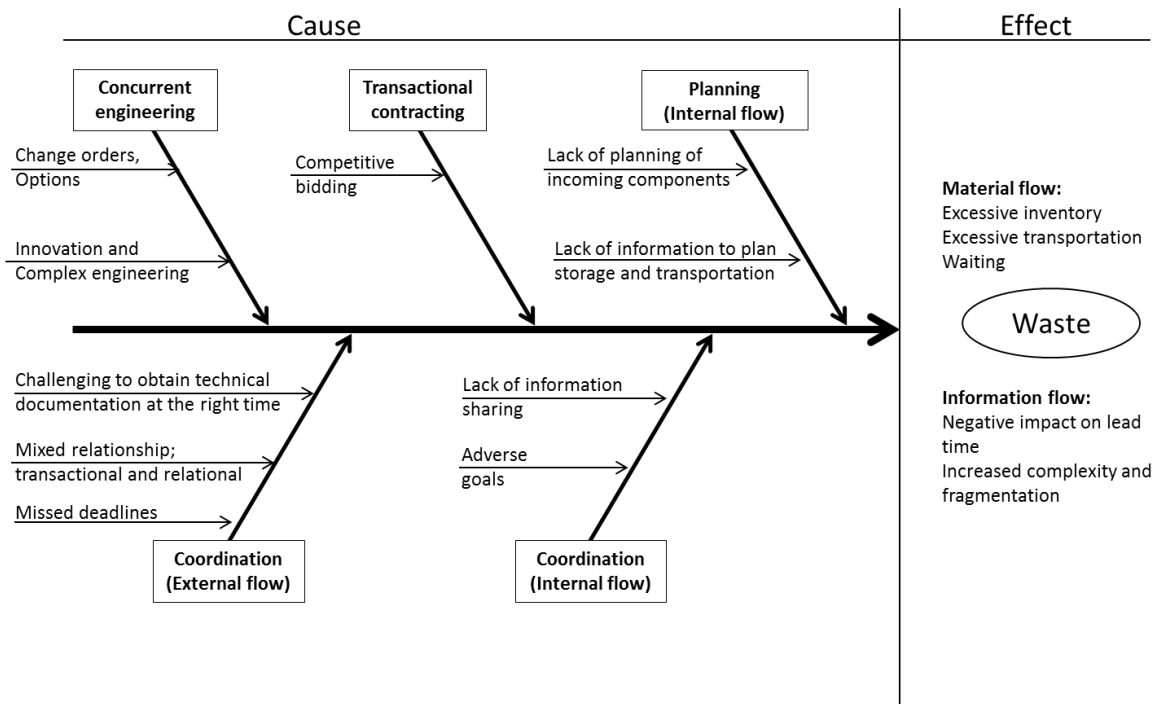


Figure 25: Cause and effect diagram, Brunvoll- Ulstein

5.1.3. Comparison

Based on the findings from the two supply chains discussed above, this section will compare the two supply chains with respect to what is impacting or delaying the flow of materials and discuss why sources of delays are similar or different for the two supply chains.

There is a clear difference with respect to the permanency and consistency of the two supply chains. While materials are flowing constantly, although volumes and types of components may vary depending on project, from GS-Hydro to Ulstein, the components from Brunvoll to Ulstein are flowing on a more irregular basis depending on the project. This was, at least to a degree, expected due to the nature of the usage of the components, where thrusters are strategic components low in number for each project and B- and C-components supplied by GS-Hydro are required in larger volumes.

Furthermore, the two supply chains differ in respect of the supply chain structure, where Brunvoll engineer-to-order, while GS-Hydro has a large finished goods inventory. This is the main reason why the lead time differs significantly. As a result, the findings suggest that for the components from GS-Hydro the delays and waste occur

mainly in the flow of materials, such as excessive transportation and double handling. In contrast, in the Brunvoll-Ulstein supply chain any delays in the flow of materials are mainly as a result of delays or waste in the information flow, such as waiting for decisions to be made or waiting for documentation, particularly as the production stage has not been evaluated.

However, when taking into account the long lead time (up to a year) GS-Hydro has from their pipe- suppliers (second tier supplier) who produce pipes to order for GS-Hydro, the importance of information sharing and cooperation as one of the main keys to reduce waste in both supply chains is clearly illustrated, even though Brunvoll engineer-to-order and GS-Hydro ship from inventory. For Brunvoll to have the right information to the right time is essential for the completion the engineering and have the components available in order to deliver the thruster(s) on time. Similarly, information is vital for GS-Hydro in order to have the right components, in the right volumes at the right time, to be able to offer a required service level, at the right price to the customer.

Subsequently, both supply chains share the lack of coordination and cooperation as a source of delays and interruptions in the supply chains. It can be argued that the lack of coordination in both the supply chains is a result of the high level of transactional discrete contracting between Ulstein and the suppliers in both cases. As discussed previously, this transactional contracting with a high focus on price tend to obscure the value stream thinking of collaboration and information sharing, with each of the involved parties mainly focusing on own short- term financial goals. However, the relationship between Ulstein and Brunvoll also has characteristics with relational contracting to a larger degree than the relationship between Ulstein and GS-Hydro. The findings suggest that this can be related to the long history between the two firms and the necessity to share drawings, specifications and similar between the two firms in order to be able to deliver the thrusters and complete the project.

Conversely, some of the delays can to a larger degree be associated with the concurrent engineering nature of the shipbuilding in the case of Brunvoll compared with the supply chain with GS-Hydro. Particularly, for project no. 295, which is highly innovative and thus the required specifications are not always available or calculated before the order is sent to Brunvoll, causing delays in terms of waiting for decisions and change orders. In contrast, the components shipped from GS-Hydro are typically relatively standard off-

the-shelf in their inventory, and with materials flowing consistently in the supply chain with a relatively short lead time, the delays cannot be associated with the concurrent engineering to the same degree.

In terms of the internal flow, there are some clear similarities in the both the waste occurring in the flow of materials and in the source of delays, particularly for A- and B-components. The main reasons for these similarities are that the components are handled by the same personnel, have no fixed storage location and there is a lack of information for the warehouse personnel regarding when components are coming in to the shipyard and when they are required in production. On the other hand, due to the small volumes and large sizes of the many A-components, for instance a thruster, the delays caused by incomplete deliveries and/or deviations in the documents and the shipments or having to search to find the components are typically avoided for A-components.

The internal flow of C-components differs somewhat from the two other types of components, mainly due to the fixed storage locations and the ordering procedures. However, any delays occurring in the flow of materials upon arrival at Ulstein seems to be a result of the lack of planning and coordination of incoming trucks, regardless of type of components.

In general, within the internal flow the wastes and sources of waste seem to be relatively similar for all three types of components. Although to what degree is varying between the types of components, within the internal flow the waste is mainly related to excessive inventory, excessive transportation and waiting in some form or another. Similarly, findings suggest that the sources are relatively similar for all the components, with the waste mainly being caused by lack of coordination and planning. It seems clear that these similarities seems to be a result of the same personnel handling all types (particularly A and B) of components and that the warehouse personnel lack accurate information to plan and coordinate the workload, receiving process, storage and internal distribution.

In addition, for B- and C- components lack of control was also found as a source of waste. This was different from A-components mainly due to the larger volumes and smaller sizes of the B- and C- components, which makes visual control, in lack of registering of withdrawn components from inventory, more difficult compared to the larger A-components. Table 5 shows an overview of the case study findings.

Table 5: Overview of findings

Supplier	Brunvoll	GS-Hydro
Type of components	A	B and C
Consistency of supply chain	Irregular	Permanent
Main flow(s) analysed	Information flow between Brunvoll and Ulstein Internal material flow at Ulstein	Material flow
Supply chain structure(mainly)	Supplier ETO Each component is an independent project at supplier	Supplier ship from inventory Inventory held at supplier's finished goods
Waste identified	Information flow: Waiting for information Internal material flow: Excessive inventory Excessive transportation Waiting (idle inventory, peaks in workload for workers)	Excessive inventory Excessive transportation Waiting (idle inventory, peaks in workload for workers)
Sources of waste (external)	Concurrent engineering Transactional contracting Lack of coordination	Lack of coordination Lack of collaboration
Sources of waste (internal material flow)	Lack of planning Lack of coordination	Lack of planning Lack of coordination Lack of control

5.2. Conclusion

The Norwegian shipbuilding industry is recognised by one-of-kind-production, a complex network of suppliers and being a cyclical industry, among others. In addition, increasing competition from low-cost countries has put pressure on the Norwegian shipyards to become more competitive.

To meet these challenges Ulstein has been engaged in two lean shipbuilding research programs, with the goal of tailoring lean thinking to the project-based production of the Norwegian shipbuilding, and developing lean tools and methods specific to the industry. While the first research program mainly focused on planning and control, including the implementation of the Last Planner system, the second, currently on-going program focuses on the project and social logistics.

As a part of the second research program, *Lean shipbuilding part II*, within the project logistics focus area, this study has focused on qualitatively exploring and highlighting where and why waste occurs in the external flow of materials and information from a first tier supplier to Ulstein, as well as within the internal flow of materials at Ulstein. The focus was selected because this is the first study on project logistics for the projects at Ulstein, and therefore a qualitative exploratory-explanatory case study was used to highlight issues in the current situation.

More specifically, this thesis has evaluated two different supply chains from a first tier supplier to Ulstein as the focal firm, with the aim of increasing the knowledge what type of waste and why it occurs in the supply chains. The first supply chain consists of Ulstein and GS-Hydro, a supplier delivering B- and C- components to the shipyard, while the second supply chain consists of Ulstein and Brunvoll, supplying thrusters, categorised as A-components to Ulstein.

Lean theory focuses on the identification and elimination of activities that is not adding-value to the end-product, i.e. waste. The aim is to develop a value stream where materials are flowing without obstacles or other delays, by pulling the product through the value stream based on downstream demand, through a process of continuous improvement focusing on maximising value to the customer while eliminating waste. Furthermore, lean philosophy focuses on improving the entire value stream, rather than individual processes and activities

Lean principles have been adopted by several industries outside the origin in the Toyota Production system, including lean construction, where the aim is to develop lean principles and methods to the peculiarities of construction. However, it is important to emphasise that application of lean to other industries than the car manufacturing industry from where it originates, is not about copying the tools and methods, but rather to develop own specific tools and methods to that industry, based on lean principles.

Similarly, supply chain management theory views supply chains as an integrated value-generating flow rather than a set of independent activities, and put emphasis on collaboration and coordination between stakeholders in the supply chain in order to satisfy the end- customers' needs.

Previous studies on construction supply chains suggest that waste in the value streams supplying A- components to a project is typically related to the information flow due to the long lead time, and particularly the time each party is waiting for information and documents. This is often caused by lack of standardisation and coordination on the interface between the supplier and the customer. For B- and C- components, on the other hand, waste is often related to the material flow, due to the shorter lead time. Excessive inventory and transportation are typical lean wastes in the value streams of these components, which is often caused by lack of demand information sharing and lack of collaboration between the parties. In addition, value streams supplying components to a construction project is often recognised by an unpredictable demand pattern, which adds to the uncertainty and complexity of construction (including shipbuilding) supply chains.

Important aspects of a lean supply chain management approach include pulling to site demand, information sharing, collaboration, planning of delivery and materials management.

The findings in this thesis suggest that waste in the supply chain link between Brunvoll and Ulstein is mainly related to the information flow, particularly as the manufacturing stage has not been evaluated due to lack of access to data. The waste identified was mainly related to waiting due to time buffers, which increased the complexity of the information flow and has a negative impact on the lead time. There is also a question of the true value of the time and resource consuming competitive bidding process.

For the supply chain link between GS-Hydro and Ulstein, waste was mainly related to the material flow. Lean wastes identified included excessive transportation, excessive inventory and waiting. Similarly, for the internal flow of materials within the shipyard for all types of components to some degree, waste was identified in terms of excessive transportation and inventory and waiting.

In terms of the external flow of materials and information, both the supply chain links share the lack of coordination and cooperation on the interface between the supplier and Ulstein as a source of waste. These are the main sources of waste in the external flow of materials from GS-Hydro to Ulstein, while concurrent engineering and transactional contracting are other sources of the added to lead time and information flow complexity in the flow of information between Brunvoll and Ulstein.

Sources of waste in the internal flow of materials for all three categories of components are considered to be lack of planning and coordination, while waste for B-and C-component also occur due to the lack of control in the value stream.

Therefore, based on the lean theory and the findings of this thesis, it seems clear that lean SCM principles are applicable to the Norwegian shipbuilding industry in the pursuit of a continuous, more reliable flow of materials to the shipbuilding projects. First of all, the general idea of maximising value and eliminating waste is applicable to any industry. Secondly, many of the features of the shipbuilding industry such as fixed-site of the shipyard and the permanent flow of B-and C- components from suppliers to the shipyard, points in favour of and facilitates for a lean SCM approach to the management of the flow of materials (and information).

Particularly, when considering the four roles of SCM in construction proposed by Vrijhoef and Koskela (2000), it seems clear that a lean SCM approach is applicable to the Norwegian shipbuilding industry. From the findings in this thesis, especially two roles are applicable to the supply chains considered here, namely the focus on the interface between the supply chain and construction site, and the focus on the supply chain. In addition, the role of focusing on the integrated management of the supply chain and the construction site, by replacing temporary supply chains with more permanent ones, appears logical for the supply chains supplying A-components to Ulstein. Lastly, the shipbuilding industry is already based on a pull methodology, as for instance A- and B- components are ordered from suppliers based on the specific requirements of a project.

Furthermore, this has been the first study of shipbuilding supply chains with a lean perspective with Ulstein, and has highlighted that there is a significant amount of waste and non-value adding activities and processes, as well as structural and relational arrangements that is currently hindering a continuous flow of materials from the (first tier) suppliers to Ulstein. However, one can argue that these wastes and non-value adding activities can be reduced or eliminated through an application of lean SCM principles.

Nevertheless, although lean SCM principles may be applicable to shipbuilding industry in Norway, it is again important to emphasise that this does not imply that tools and methods from other industries (including construction) should be directly copied and applied. Instead, the challenge for the Norwegian shipbuilding industry aiming to create lean supply chains is to take the lean SCM principles of continuous flow, pull, collaboration and value stream thinking, and develop an own set of tools and methods tailored specific to the individual needs of each specific shipyard and its suppliers.

5.2.1. Managerial implications

The purpose of this thesis has been to increase the understanding of what in the supply chains serving Ulstein shipyard that causes delays and/or interruptions in the flow of materials and why these delays occur. However, when comparing the case findings and discussion with the lean and SCM theory, some opportunities to improve the management of the supply chains and reduce waste in the flow of materials (and information) are apparent.

First, for the management of the external flow of B- and C-components from GS-Hydro to Ulstein particularly three, interrelated, points stand out:

- Increase demand (information) sharing between Ulstein and GS-Hydro
- Focus on the interface between the supply chain and the shipyard
- Focus on the supply chain

The lack of information about future demand is one of the main sources of waste in the flow of materials between GS-Hydro and Ulstein. Therefore, increasing the sharing of demand information seems crucial to reduce waste and to have smooth flow of information. On a short-term level, operational basis, this could include Ulstein ordering from GS-Hydro at least one day before the components are required in

production. This may require some extra planning from Ulstein, but should reduce the inventory and excessive transportation related to the regional warehouse in Ålesund.

On a more long- term, strategic level increased demand sharing may involve allowing GS-Hydro access to upcoming production schedules to forecast and plan their own inventory. Another option is to let GS-Hydro manage Ulstein's inventory, and thus components are supplied and refilled from GS-Hydro without Ulstein having to order, thus ensuring material availability. This could be a solution to reduce waste in terms of excessive inventory and excessive transportation.

However, it is important to emphasise that this would require both parties, and particularly Ulstein to have a more holistic value stream thinking approach, in contrast to the focus on own monetary goals in the current situation. For instance, Ulstein may not obtain reduced costs directly by reducing the excessive transportation and inventory holding in the external flow from GS-Hydro, because they currently have free shipping from GS-Hydro. However, Ulstein may obtain the gains indirectly to through lower prices and better supply conditions in general.

Correspondingly, it seems clear, by following the roles proposed by Vrijhoef and Koskela (2000) that the focus should be the interface between the two parties, and thereby reduce waste in the flow of materials to the shipyard through increased cooperation and collaboration with the suppliers (GS-Hydro in this case). Particularly, it is considered that engaging in long-term relationship with only a couple or few suppliers for delivery of each product group would facilitate for the removal of waste, compared to the current price-focused tendering where each party is mainly focusing on own financial gains. Reducing the competitive bidding and shopping would also facilitate for increased information sharing and vice versa between Ulstein and GS-Hydro.

Furthermore, still considering the four roles of Vrijhoef and Koskela (2000), Ulstein in cooperation with the selected suppliers (in this case GS-Hydro) should focus on the supply chain, by focusing on developing specific supply chains, which both accommodates for the requirements of Ulstein, as well as taking into consideration the transportation and inventory costs. This may, however, include more cooperation on a higher hierarchical level between Ulstein and GS-Hydro, compared to the current situation where most of the communication takes place on a shop-floor level with only a few employees.

It is difficult to make for clear suggestions for the management of the information flow between Brunvoll and Ulstein as a whole due to the limited data material available, and thus the information flow was only evaluated from Ulstein's point of view. However, for the management of the external flow of information, from Ulstein's perspective between Brunvoll and Ulstein, three points stand out:

- Standardise working and coordination procedure
- Improve document flow
- Standardise purchasing procedure

By having standardised working and coordination procedures between Ulstein and Brunvoll, less time should be spent searching for the right person to contact waiting for documents, drawings, specification or other types of information.

An important part of this is to improve the document flow, particularly to create working procedures between the firms that ensures for the right documents flowing at the right time to the right person.

Similarly, it seems clear that by standardising the purchasing procedure, the complexity of the purchasing procedure, and thus also in the information flow could be reduced, or at least controlled to a larger degree. Moreover, it is also considered that this would improve the follow up of document flow and project schedules.

In terms of the internal flow of materials within the shipyard for all types of components, the points below appear as improvement opportunities.

- Improve information sharing and coordination between departments
- Improve information accuracy
- Improve planning
- Improve inventory control

Improving the information sharing and coordination between departments at Ulstein is related to ensuring that each department, in this case particularly the warehouse function, have the right information at the right time.

Therefore, an important part of this is to improve the accuracy of the information available to the different departments, in this case particularly to the warehouse. This means that the information in the ERP system have to be up-to-date and reflecting the

reality, for instance for the expected delivery date, which is rarely accurate in the current situation. Similarly, the oral communication and procedures for withdrawal of materials from the warehouse, for instance by the foremen about upcoming requirements of C-components, should to a larger degree reflect the actual, concrete demand.

Correspondingly, by improving the planning of in- and out-going materials of the warehouse, warehouse personnel should be in a better position to decide where the components should be stored, as well as enabling the warehouse personnel to better plan the workload, thus reducing double handling and waiting. Improved planning and coordination could also facilitate for delivering of materials from the warehouse to the installation areas on a more just-in-time basis, or even in work packages towards the vision of Ulstein, with less waste in terms of excessive inventory and double handling.

Furthermore, the inventory control should be improved, particularly for B-components, as no information is currently available about inventory levels or materials availability, other than that the materials have been received and visual control. Therefore, improving the control is mainly related to registering withdrawals of materials (inventory tracking) from the warehouse, thus having information available about inventory levels and materials availability, which again should facilitate for improved planning and coordination.

Finally, it should be emphasised that it seems important, in order to be able to improve the project logistics through a lean methodology, to communicate this throughout the firm and to (at least) first tier suppliers, such that each party, department and employer understands the meaning of the changes and the importance of value stream thinking, compared to the currently widespread “silo” focus.

5.2.2. Further studies

This study has been the first study evaluating the project logistics for the shipbuilding projects at Ulstein. Naturally, as this study is part of the *Lean shipbuilding part II* research program, further studies should build on the findings of the current situation in this thesis, to further evaluate the applicability of lean principles and to develop tools to improve the project logistics at Ulstein.

More specifically, further studies of the supply chain, flow of materials and/or project logistics with Ulstein, may have a more quantitative focus on waste and non-value adding activities, and how to reduce waste and to better manage the project logistics, and thus improve the flow of information and materials between the parties involved.

Based on the findings in this thesis, particularly four research opportunities appear, mainly related to A- and B- components, as these have the main impact on project costs and schedule. First, how can waste in the external flow (in particular) of materials and information be reduced by Ulstein engaging in more relational contracting, with less use of tendering, with its suppliers. This is relevant mainly for A- and B- components. For A-components, this is related to whether less competitive bidding could make the information flow less complex and fragmented and more standardised. For B-components this is related to how minimise the waste in the flow of materials and this could include the ideal number of long-term suppliers, or the feasibility of vendor-managed inventory.

Subsequently, the second research opportunity is related to the actual impact of competitive bidding, in terms of labour costs, time used and the increased complexity of the information flow compared against the gains of the tendering process (mainly lower prices). This is again relevant for both A- and B- components.

The third research opportunity is to investigate the possibility of integrating the flow of materials in the Last Planner system to a larger degree. This could be a solution to improve the planning and coordination of incoming materials to the warehouse at Ulstein, and also the flow of materials from the warehouse to the installation areas.

Following in the same lines, the fourth possible research opportunity is to evaluate the prospect of closing the warehouse at Ulstein, thus registering withdrawals from the inventory with only the warehouse personnel accessing the inventory. The impact of closing the warehouse would be an interesting focus, as it should facilitate for tighter

control of the inventory, including inventory turnover and cycle time, and for improved coordination and planning between the departments at Ulstein, which again could result in improved flow of materials within the shipyard.

In addition, further study opportunities include quantifying the waste in the flow of materials identified in this thesis. This could include quantifying the time components are held in inventory (waiting), both at suppliers' and Ulstein's warehouse and measuring the double handling and excessive transportation in the flow of materials and the extra costs related to this.

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Appendices

Appendix I: Description of case study participants

Ulstein Verft AS¹

Ulstein Verft AS is located in Ulsteinvik, Møre and Romsdal, and is one of the main shipyards in Norway. It was established in 1917, as a family owned business engaged in ship repairs.

Over the years, Ulstein has developed the knowledge base and experience that guarantees the highest standards of quality, execution and on-time delivery, through the successful building of state-of-the-art vessels for demanding marine operations.

Today, Ulstein is building a wide range of highly-effective and sustainably efficient vessels. The company has unique expertise in engineering, installation, commissioning and upgrading, and places a strong focus on innovative technological solution and methods and on expertise within project management, effective logistics and pre-outfitting techniques.

Their work is based on a collaborative approach, with a continuous exchange of information between ship owners, designers, equipment manufacturers, engineers and shipbuilders, particularly within the maritime cluster in Møre and Romsdal in Norway. This, in combination with streamlined production processes results in a high level of flexibility and quality. One example of this is the development and innovation of the Ulstein X-BOW ® hull line design- a revolutionary hull design.

Currently, Ulstein is a leading supplier of complex vessels such as:

- Platform supply vessels (PSV)
- Specialised/Multifunctional vessels
 - Offshore construction vessels (OCV)
 - Pipe laying vessels
 - Seismic vessels
- Anchor handling tug supply vessels (AHTS)

GS-Hydro ²

The GS-Hydro Corporation is a world-leading supplier of innovative, non-welded piping solution, both low and high pressure, for hydraulics, with a focus is on quality, reliability and cleanliness. Its headquarters are located in Hämeenlinna, Finland, and the company is operating in more than 25 countries around the globe. The company is renowned for its design and engineering knowledge, comprehensive services and high quality products.

GS-Hydro's product range consists of complete piping systems, including design and engineering, materials and components, prefabrication and on-site services. Within this, they offer supervision, installation, flushing and testing, as well as documentation, customized prefabricated piping modules and separate piping components and materials. Their piping systems are used in a wide variety of industries, from offshore, marine and land based industries such as the automobile and aerospace industry.

GS-Hydro Norge AS is a wholly owned subsidiary of the corporation and is the largest of the corporations' 17 subsidiaries in the world. GS-Hydro Norge AS is responsible for the operations in Norway, and the national main office and central warehouse is located in Frogner, Akershus. In addition, GS-Hydro Norge AS has six national branch offices with regional warehouses in Bergen, Horten, Kristiansand, Stavanger, Trondheim and Ålesund. Furthermore, the warehouse located at Frogner is also the central warehouse for pipes in Europe.

Brunvoll AS ³

Brunvoll AS was established in 1912 by three brothers with family name Brunvoll. Today, Brunvoll AS is still a family owned business located in Molde, Møre og Romsdal and is a worldwide supplier of complete thruster packages, including the after sales service. The thruster systems can be tailored to the specific propulsion and manoeuvring requirements of the customers, with a focus on reducing installation time and life cycle costs.

Moreover, the company offers a complete technological environment with in-house expertise in hydraulics, hydrodynamics, electronics, mechanical and electrical engineering, and production. Within this technological environment, Brunvoll focuses on thruster production, including product development, engineering, propeller design, materials and components, machining, hydraulics, electronics and assembly. In

addition, the company places a strong focus on quality, to ensure a long- life time of the thrusters, with low life cycle costs and maintenance.

Currently, Brunvoll is a world leading supplier of thrusters, and the product range consists of:

- Tunnel thrusters
- Azimuth thrusters
- Low-noise thrusters
- Rim Driven Thrusters (RDT)
- Thruster control systems

¹ Source: www.ulstein.com

² Source: www.gshydro.no, www.gshydro.com

³ Source: www.brunvoll.no

Appendix II: Extracts from archival records

Log of commercial correspondence between Brunvoll and Ulstein for Ulstein build no. 295 (data obtained from Ulstein)

Dato	Aktør	Kommersielt	Teknisk	Tema
02.03.2011	U	x		Forespørsel
02.03.2011	B	x		Tilbud
02.03.2011	B	x		Forlenget gyldighet på tilbud
14.03.2011	B	x	x	Div teknisk informasjon oversendt etter forespørsel fra UVE
14.03.2011	B	x		Revidert tilbud pga telefonforhandling
24.03.2011	U	x	x	Ber om opsjon på å bytte ut en retractable, med en ytterligere tunnel.
25.03.2011	B	x	x	Etterspør teknisk info for å kunne tilby ytterligere tunnell
31.03.2011	U	x		Ber om opsjon på uttrekk av kontrollsystem for thrusterne, og opsjon for å bytte ut en retractable thruster med en kombinert tunnel/retractable thruster
05.04.2011	B	x		Tilbud på etterspurte opsjoner
08.04.2011	U & B	x		Møte ved Ulstein Verft. Gjennomgang av teknisk scope og forhandling.
26.04.2011	U	x		Sender bestilling basert på møtereferat/kontrakt utarbeidet 08.04.2011. Leveringstid; Retractable thrusters 13.04.2012, Tunnel Thrusters 30.03.2012
16.05.2011	info			Opsjonsfrist 1; Bytte en retractable mot en kombinert retractable/tunnel
16.05.2011	info			Opsjonsfrist 2; Uttrekk kontrollsystem for thrustere
18.05.2011	B	x		Etterspør Ulstein sin avgjørelse ift opsjoner (forståelse per telefon om at opsjonene i praksis fortsatt er gyldige)
18.05.2011	U	x		Etterspør forlenget opsjonsfrist til senest 29.05.2011
18.05.2011	B	x		Bekrefter forlenget opsjonsfrist
08.06.2011	U	x		Erklæring av opsjon 2 ifm uttrekk av kontrollsystem for thrustere fra Brunvoll sitt scope
09.06.2011	B	x		Bekrefter opsjon 2 implementert
14.06.2011	U	x		Sender revisjon1 av bestilling basert på opsjon 2
17.06.2011	U	x		Erklæring av opsjon 1 ifm bytte ut en retractable thruster med en kombinert retractable/tunnel thruster
17.06.2011	B	x		Bekrefter opsjon 1 implementert
23.06.2011	U	x		Sender revisjon 2 av bestilling basert på opsjon 1
14.09.2011	B	x		Informerer om forsinket leveringstid på Tunnel thruster til 20.04.2012. Dette pga forsinket levering av teknisk dokumentasjon fra Ulstein til Brunvoll
02.11.2011	U	x	x	Etterspør tilbud på å øke effekt på thrustere til bygg 295 med 200 kW per thruster
04.11.2011	B	x	x	Tilbud gitt, samt konsekvenser for leveringstid.
04.12.2011	U	x		Sender revisjon 3 av bestilling basert på økt effekt på thrustere. Ny leveringstid på kombithruster 01.06.2012
Månedlig	B	x	x	Oversender fremdriftsrapporter månedlig

Extracts from orders from Ulstein to GS-Hydro in 2011 (345 lines in total, data obtained from GS-Hydro)

Ordredato	Avg. Dato	År	Mnd	Uke	Fra Lagersted	Rute	Kunde nr	Kundenavn	Vekt	Antall Kolli
20.05.2011	23.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	47,50	3
23.05.2011	23.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	22,35	2
23.05.2011	23.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	2,90	1
24.05.2011	24.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	12,20	2
23.05.2011	24.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	75,20	2
25.05.2011	25.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	81,75	3
02.05.2011	25.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	0,40	1
26.05.2011	26.05.2011	2011	05	21	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	2,00	1
30.05.2011	30.05.2011	2011	05	22	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	98,30	4
31.05.2011	31.05.2011	2011	05	22	001 - FROGNER	Transferd Ålesund	30020	ULSTEIN VERFT AS	4,30	1
31.05.2011	31.05.2011	2011	05	22	002 - ÅLESUND	Lehman	30020	ULSTEIN VERFT AS	100,00	1
31.05.2011	01.06.2011	2011	06	22	002 - ÅLESUND	Lehman	30020	ULSTEIN VERFT AS	38,80	2
26.05.2011	01.06.2011	2011	06	22	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	9,00	1
06.06.2011	06.06.2011	2011	06	23	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	4,10	1
02.05.2011	06.06.2011	2011	06	23	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	30,00	3
07.06.2011	07.06.2011	2011	06	23	002 - ÅLESUND	Lehman	30020	ULSTEIN VERFT AS	40,70	2
08.06.2011	08.06.2011	2011	06	23	002 - ÅLESUND	Lehman	30020	ULSTEIN VERFT AS	80,50	1
09.06.2011	09.06.2011	2011	06	23	002 - ÅLESUND	Bruk kode MØRE	30020	ULSTEIN VERFT AS	33,00	1
10.06.2011	10.06.2011	2011	06	23	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	1,30	1
14.06.2011	14.06.2011	2011	06	24	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	4,30	1
14.06.2011	15.06.2011	2011	06	24	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	9,70	2
15.06.2011	15.06.2011	2011	06	24	002 - ÅLESUND	Bruk kode MØRE	30020	ULSTEIN VERFT AS	295,00	1
15.06.2011	15.06.2011	2011	06	24	002 - ÅLESUND	Kvikkas	30020	ULSTEIN VERFT AS	33,00	1
16.06.2011	16.06.2011	2011	06	24	002 - ÅLESUND	Lehman	30020	ULSTEIN VERFT AS	131,00	1

Extracts of orders supplied from GS-Hydro to Ulstein in March 2012 with net transportation cost (52 lines in total, data obtained from GS-Hydro)

Lagersted	Rute	Ordredato	Avg. dt	Kundenavn	Vekt	Antall Kolli	Pris netto
001 - FROGNER	Transferd Ålesund	20120202	20120305	ULSTEIN VERFT AS	308,9	5	398,48
001 - FROGNER	Transferd Ålesund	20120208	20120307	ULSTEIN VERFT AS	31,3	3	131
001 - FROGNER	Transferd Ålesund	20120213	20120302	ULSTEIN VERFT AS	60,2	2	131
001 - FROGNER	Transferd Ålesund	20120213	20120315	ULSTEIN VERFT AS	79,55	4	131
002 - ÅLESUND	Kvikkas	20120224	20120305	ULSTEIN VERFT AS	4,9	1	121
002 - ÅLESUND	Kvikkas	20120301	20120301	ULSTEIN VERFT AS	39,8	3	153
002 - ÅLESUND	Transferd Møre	20120301	20120301	ULSTEIN VERFT AS	295	1	200
001 - FROGNER	Transferd Ålesund	20120301	20120301	ULSTEIN VERFT AS	1494,7	4	777,24
002 - ÅLESUND	Kvikkas	20120302	20120302	ULSTEIN VERFT AS	57,9	3	158
002 - ÅLESUND	Kvikkas	20120302	20120305	ULSTEIN VERFT AS	2,2	1	121
001 - FROGNER	Transferd Ålesund	20120302	20120313	ULSTEIN VERFT AS	531,7	4	494,48
002 - ÅLESUND	Kvikkas	20120305	20120305	ULSTEIN VERFT AS	15,5	1	126
002 - ÅLESUND	Transferd Møre	20120305	20120305	ULSTEIN VERFT AS	154	1	150
002 - ÅLESUND	Kvikkas	20120305	20120306	ULSTEIN VERFT AS	2,8	1	121
001 - FROGNER	Transferd Ålesund	20120306	20120306	ULSTEIN VERFT AS	87,6	2	136
002 - ÅLESUND	Kvikkas	20120307	20120307	ULSTEIN VERFT AS	93	1	166
001 - FROGNER	Posten Distribusjon	20120309	20120309	ULSTEIN VERFT AS	1	1	118
002 - ÅLESUND	Kvikkas	20120309	20120309	ULSTEIN VERFT AS	55,6	3	158
002 - ÅLESUND	Kvikkas	20120312	20120312	ULSTEIN VERFT AS	57,5	4	158
002 - ÅLESUND	Kvikkas	20120313	20120313	ULSTEIN VERFT AS	43,7	2	153
002 - ÅLESUND	Transferd Møre	20120313	20120313	ULSTEIN VERFT AS	469	2	494

Extracts of orders supplied from GS-Hydro (hovedleverandør 8070 and 8746) to Ulstein, with expected delivery date in 2010 and 2011, (108 lines in total, data obtained from Ulstein)

HOVEDLEVERANDØR	LEVERINGSDATO	ORDREDATO	ORDRENUMMER	VARREFERANSE
8070	17.02.2010 00:00	17.02.2010 00:00	17949	DRIFT
8746	22.02.2010 00:00	17.02.2010 00:00	17950	DRIFT
8070	09.07.2010 00:00	04.06.2010 00:00	18171	DRIFT
8746	04.02.2011 00:00	31.01.2011 00:00	18634	DRIFT
8746	13.01.2012 00:00	06.12.2011 00:00	19211	DRIFT
8070	12.01.2010 00:00	12.01.2010 00:00	30029	10285
8070	14.01.2010 00:00	14.01.2010 00:00	30038	
8070	21.01.2010 00:00	21.01.2010 00:00	30051	10285
8070	22.01.2010 00:00	22.01.2010 00:00	30055	10285
8070	26.01.2010 00:00	26.01.2010 00:00	30065	10285
8070	27.01.2010 00:00	27.01.2010 00:00	30068	10285
8070	27.01.2010 00:00	27.01.2010 00:00	30072	REKVISITA
8070	28.01.2010 00:00	28.01.2010 00:00	30073	10285
8070	28.01.2010 00:00	28.01.2010 00:00	30080	10285
8070	03.02.2010 00:00	03.02.2010 00:00	30091	10290
8070	10.02.2010 00:00	10.02.2010 00:00	30103	10285
8070	10.02.2010 00:00	10.02.2010 00:00	30109	10290

Extracts of orders from Ulstein (to all suppliers), with confirmed (bekreftetlevdato) and wanted (onskettermin) delivery date in 2010, 2011 and 2012, (31563 lines in total, data obtained from Ulstein)

BEKREFTETLEVDATO	INDKOBSORDRE_ID	LINIESTATUS	ONSKETTERMIN	ORDRENUMMER	PROJEKTNUMMER
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056
04.10.2010 00:00	1479417600	SS	04.10.2010 00:00	18277	80073
05.10.2010 00:00	1970997152	SS	05.10.2010 00:00	18278	80073
15.03.2011 00:00	1821749831	SL	23.02.2011 00:00	85869	80736
31.08.2011 00:00	1248237979	SL	31.08.2011 00:00	19000	80056
19.01.2011 00:00	1318843382	SS	19.01.2011 00:00	18462	80056
22.11.2010 00:00	2065343872	SS	22.11.2010 00:00	18273	80073
12.05.2010 00:00	1390636565	SS	12.05.2010 00:00	18134	80910
12.05.2010 00:00	1390636565	SS	12.05.2010 00:00	18134	80910
12.05.2010 00:00	1390636565	SS	12.05.2010 00:00	18134	80910
12.05.2010 00:00	1390636565	SS	12.05.2010 00:00	18134	80910
15.03.2011 00:00	1821749831	SL	23.02.2011 00:00	85869	80736
15.03.2011 00:00	1821749831	SL	23.02.2011 00:00	85869	80736
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056
12.05.2010 00:00	1218725802	SS	12.05.2010 00:00	18142	80910
20.12.2010 00:00	1440469455	SS	20.12.2010 00:00	18461	80056
20.12.2010 00:00	1440469455	SS	20.12.2010 00:00	18461	80056
20.12.2010 00:00	1440469455	SS	20.12.2010 00:00	18461	80056
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056
12.02.2011 00:00	1878881084	SS	12.02.2011 00:00	18619	80056

Appendix III: Interview guides

Here, two of the interview guides used for the open ended-interviews is presented, one for the second round interview of the internal flow at Ulstein and one for the interviews with GS-Hydro. The guides were used as an outline of what aspects it was expected to investigate, but due to the open-ended nature of the interviews, other aspects came up as well.

Interview guide for internal flow/warehouse at Ulstein

General:

What do you consider as the most common challenges/bottlenecks concerning the internal flow of materials? Does this differ depending on type of materials (ABC)?

How would you describe the information flow between the departments internally at the shipyard?

Inbound logistics:

Is there any scheduling with respect to arriving trucks, and does the level of scheduling differ depending on type of product (ABC)?

Is there any information available concerning when and what will be delivered, does this differ depending on type of component?

Receiving:

How is the receiving procedure and who conducts the receiving (dedicated personnel)?

How and where are the incoming components registered?

Does the receiving procedure differ depending on type and size of component (ABC)?

Are the components received/registered immediately after arrival at the shipyard?
If not, why? How long before they are registered?

Does this differ depending on type of component?

Storage:

To what degree is the storage location fixed for different components and how is the storage location determined?

Who is responsible for deciding the storage location, and where is the storage location recorded?

How long are different components (ABC) typically stored?

Picking

How is material requirements communicated from the production function to the warehouse for the different types of components (ABC)?

Is withdrawal from storage registered of any kind?

Who conducts the picking of production orders, does this depend on type of component? (dedicated personnel, warehouse personnel, production workers)

Internal distribution:

Is there any formal planning/scheduling for when components are needed in production?

How are the components distributed from storage to production, and does this differ depending on type of component?

To what degree and for what type of components are staging areas used?

Who distributes the components from the storage location to production/staging area (dedicated personnel, warehouse personnel, production workers)?

Interview guide for interviews with GS-Hydro

General

In general, how would you describe the current situation for GS-Hydro?

How would you describe the current situation for GS-Hydro with Ulstein?

Outbound logistics

Can you describe the processes from the order is received to the goods are shipped?

Approximately, how much is MTO to Ulstein and how much is shipped directly from inventory?

What is normally the reason(s) if deliveries are delayed from GS-Hydro?

Coordination in the supply chain

How would you describe the buyer-supplier relationship with Ulstein?

How is the contact with the customer(s) organised?

Control in the supply chain

Can you describe the processes from when the goods are sent from GS-Hydro (Frogner or Ålesund) to they are received at Ulstein?

How are the goods/ transportation progress monitored/controlled until confirmed received at Ulstein?

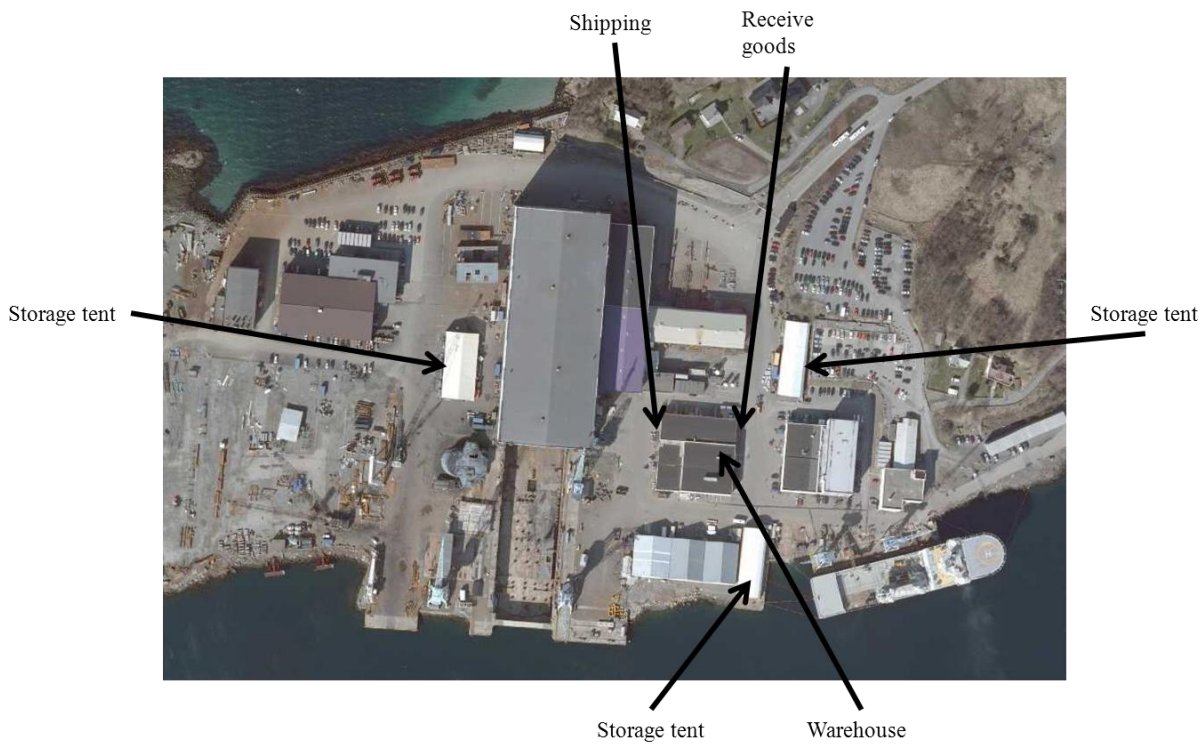
How do you monitor the inventory at the regional warehouses?

Change to central warehouse

Can you please describe the process and challenges of changing to a central warehouse?

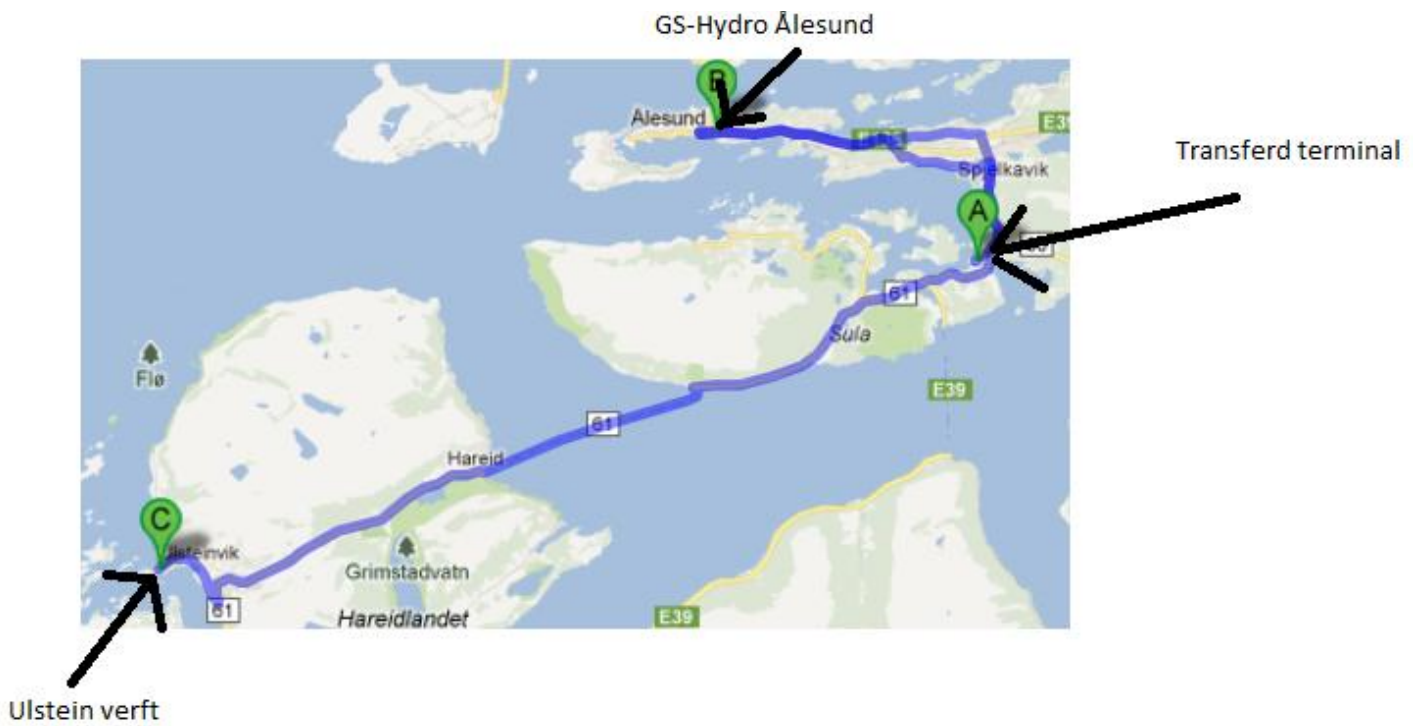
How did Ulstein (and other customers) respond to the change?

Appendix IV: Map of Ulstein Verft



Source: sunnmorskart.no

Appendix V: Map of location of GS-H Ålesund, Transferd and Ulstein Verft



Source: Google maps