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Warehouse Management in a
Lean Shipbuilding Perspective
- An Exploratory Case Study
of Ulstein Verft AS

Kjersti Kjos Longva

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Author(s): Kjersti Kjos Longva

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PREFACE

This master’s degree thesis has been written during the spring of 2009, and is the final stage of the degree Master of Science in Logistics at Molde University College. The thesis has been executed in collaboration with Ulstein Verft AS and Møreforskning Molde AS, and was arranged through the Lean Shipbuilding program.

The thesis process has been completed under the guidance of supervisor Arild Hervik, and I would like to start with sincerely thanking him for providing professional guidance and valuable critique, comments and advices during the course of the thesis.

My profound gratitude also goes to Research Assistant Karolis Dugnas at Møreforskning Molde AS, who has been an important contributor of remarks, discussions and suggestions throughout the research process, and has also served as a link to the Lean Shipbuilding program and the case company.

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Trondheim, 23.05.09

Kjersti Kjos Longva

ABSTRACT

The purpose of this thesis has been to explore how theoretical concepts from Lean Shipbuilding and Warehouse Management could be applied to identify improvement opportunities for the warehouse function at Ulstein Verft AS. The theoretical streams of Lean Production and Lean Construction are also outlined in the theory review since Lean Shipbuilding is considered to be a notion between these; as is Lean Warehousing, a hybrid concept that introduces lean to the warehouse setting. Additionally, examples from project-based warehouse practices attempt to link the elaborated theories to practical cases.

The chosen explorative case study approach combines both theoretical and empirical findings. Empirical evidence has been collected through interviews, observations and seminar participation at the shipyard, and has served as a basis for understanding challenges faced by the warehouse function.

The theoretical framework and empirical findings suggest that the material flow at a shipyard is influenced by industry specific characteristics as one-of-a-kind production, fixed position manufacturing, consistent production facilities, temporary organizations and a current capacity shortage in terms of supply and labour. The warehouse at Ulstein Verft AS needs to operate within these conditions, but empirical findings indicate that the focal point for material flow faces challenges with respect to handling the substantial amount of outfitting components flowing through the warehouse.

The thesis concludes that concepts from both lean methodology and warehouse theory can be utilized as a basis for formulating managerial implications for Ulstein Verft AS. Waste elimination, standardization, visibility, levelled work flow, inventory tracking, material handling steps and JIT deliveries are keywords in the suggested implications, and can hopefully address and solve current capacity shortage in terms of storage space, material handling equipment and personnel at the warehouse.

1. INTRODUCTION

1.1 Background

The maritime cluster in Møre and Romsdal has its origin in the strong maritime traditions of the region. A rich coastline and an economy that relied heavily on fishery, gave ship owners and shipbuilders vital experience in operating and building vessels. When opportunities within oil and gas activities emerged some decades ago, they were ready to employ their competence and take part in the new industry. As a result, construction and operation of highly advanced and customized offshore service vessels currently takes place in Møre and Romsdal.

The main participants in the maritime cluster – shipyards, ship consultants, equipment suppliers and ship owners – participate in an industry with significant cyclical turnarounds. Sensitivity towards variations in oil prices and currency, in addition to the considerable time lag between demand and supply due to long construction lead time, has presented the industry with its ups and downs (Stopford 1997, Oterhals et al. 2008).

The maritime cluster is currently facing substantial challenges due to the recent economic development and the global financial crisis, and ship owners are struggling to charter vessels and acquire financing of newbuildings. However, ship consultants, shipyards and equipment suppliers are still experiencing high activity due to the time lag in shipbuilding. Vessels contracted years ago, when a critical period with low activity from 2001 to 2004 was relieved by the building boom, are now being constructed at shipyards. Expectations of high oil prices and high profitability in 2004 set off oil searching activities, development of new oil fields and tail production at already existing fields. Accordingly, the demand for offshore service vessels increased as well, and the shipyards' order books were filled up until 2011 (Hervik et al. 2005, Hervik et al. 2007).

The opposite situation can be observed today, as oil prices have been low (around $50) over longer time and there are limited expectations of rapid increase in prices within the nearest future[1]. Participants in the maritime cluster consequently have to prepare for tougher times,

[1] Article from E24: http://e24.no/olje/article3024138.ece (15.05..09)

and history indicates that such recessions have a tendency to reduce the number of cluster participants. Regrettably, the period with high activity and full order books has not produced the desired results for all of the cluster participants. While ship owners and ship consultants have performed exceptionally, with profit margins of respectively 36% and 35% in 2007, the shipyards have been struggling (Oterhals et al. 2008).

Shipyards in the maritime cluster had a profit margin of 4,7% in 2007, and the margin is expected to decrease in 2008. The poor results can be traced back to capacity difficulties in terms of labour and supply due to a tight program of delivery (Oterhals et al. 2008, Dugnas & Oterhals 2008). The sizeable amount of vessels to be delivered during the building boom implied an effective construction period and reliable deliveries. However, several vessel have been significantly delayed in the recent years, which threatens one of the major competitive advantages for the shipyards; namely punctual deliveries (Hervik et al. 2007).

The recent poor financial results[2], cost competition from low cost countries and the threatening recession, are all factors that reinforce the importance of maintaining competitive advantages as punctual delivery, quality, functionality and customization. Recent FAFO-studies (Hervik et al. 2005, Aslesen 2005; 2008) emphasize the necessity of investigating alternative approaches towards the organization of vessel construction in order to achieve innovative and effective shipbuilding.

The Norwegian Lean Shipbuilding program was established in 2006, as a mean to achieve this. It is part of an innovation program for maritime and offshore installations, and three of the major shipbuilders in Norway – Ulstein Verft AS, Kleven Maritime AS and STX Norway Offshore AS – participate in the program. The main objective of the group is to enhance shipbuilding in Norway by contributing to process innovation, with a particular focus on project accomplishment and logistics.

1.2 Research Problem

Ulstein Verft AS (hereafter referred to as Ulstein) is an active participant in the Lean Shipbuilding program. The shipyard is currently developing its own production system based on lean methodology called the Ulstein Production System. Although the Ulstein Production

[2] Article from E24: http://e24.no/spesial/article2894485.ece (15.05.09)

System to a great extent is inspired by recent developments in Lean Construction, the company emphasize the importance of adjusting the concept to the culture and facilities at Ulstein (Toftesund 2008).

In the first phase of the development of Ulstein Production System, the main focus was on planning methodology. In November 2006, Ulstein implemented the Last Planner System (LPS) as a new method for planning and management of production. Through implementing of the LPS, vessel construction projects shifted focus from top-down detail planning to increased participation from foremen and operators, primarily in relation to short term planning with a time horizon of 1-2 weeks. Suppliers were also encouraged to participate in the preparation of the shipyards weekly plans. The project management is thereby less involved in the weekly plans, and is able to primarily concentrate on process and period plans, which have a longer time horizon.

In the present phase, a key focus area at Ulstein is the warehouse function and the flow of materials within the shipyard. An efficient vessel construction project requires a well-organized flow of material and information in order to ensure that the right components are delivered to the right place at the right time. The warehouse function consequently holds a key position as a focal point of the material flow within the shipyard, since it is responsible for receiving deliveries from suppliers, storing the material until requested, and finally, delivering it to the appropriate place in production. Since materials received are input for vessel construction projects, the warehouse needs to be managed in a manner that takes the particular characteristics of project-based shipbuilding into consideration.

This master's degree thesis aims to explore how the warehouse function and the material flow best could be managed at Ulstein. After obtaining an understanding of the current situation at the warehouse, both operations and utilization of the facilities will be addressed. The objective is to identify areas that are not optimally managed in the present state, and to provide constructive recommendations concerning warehouse management at Ulstein based on the theoretical framework and examples from other warehouse practices.

The thesis will aim to explore theoretical aspects within Lean Shipbuilding and Warehouse Management, along with examples from warehouse practices in project-based industry, in order to provide a theoretical basis for suggesting managerial implications adjusted to the empirical findings from the case study at the shipyard. A key motivation for the study of lean methodology and warehouse theory is to explore how differing concepts within these literature fields can be applied, either alone or combined, to the warehouse function in a Norwegian shipyard.

1.2.1 Limitations

The thesis will have a rather theoretical angle as this was an appeal from Ulstein. The shipyard currently has a work group consisting of warehouse employees who are investigating concrete practical moves for improvement. They are therefore interested in acquiring a theoretical view point founded on contemporary logistics literature that addresses the same issues, but in a more general and theoretical manner, i.e. not detailing concrete procurement and implementation, but rather outlining potential ideas and concepts for improvement.

Considerable emphasis is therefore given to contemporary theory that could provide suitable solutions for the warehouse at Ulstein. However, empirical findings from the case study are also an essential element of the thesis, since such findings provide an empirical basis for understanding the key challenges at the warehouse and for evaluating whether potential managerial implications based on the theoretical framework are suitable or not.

It is also essential to emphasize that this thesis will address mainly the outfitting items at the shipyard warehouse, as these make up the major fraction of the warehouse, both in terms of space and cost. The warehouse also has items that are grouped into tools and accessories, but since Ulstein preferred that the main focus was kept on the outfitting warehouse, these item groups will not receive the same amount of attention as outfitting components in the thesis.

Finally, the main focus in the thesis will be on the warehouse function itself, as apposed to the surrounding functions of engineering, procurement and production. Although these are obviously closely interrelated, the core purpose is to look at how the warehouse function could be better organized internally. Nevertheless, as the warehouse functions is a focal point in the material flow at the shipyard, some attention will be showed towards the collaboration both between functions and also within the supply chain.

1.3 Thesis Outline

The thesis can roughly be divided into three main parts: the methodology, the theoretical review and the case study. The methodology is outlined in the subsequent chapter and describes how the research problem will be attempted solved through an exploratory case study.

The theoretical review is divided into two sections: one addressing lean theory where the concepts of Lean Production, Lean Construction and Lean Shipbuilding are discussed, and one describing theory on Warehouse Management. The reviews will provide the theoretical basis for the content in the final part of the thesis.

The case study commence with a description of the current state at Ulstein’s warehouse, and is followed by a discussion connecting concepts outlined in the theoretical framework and the best-practice examples with potential improvement opportunities at the warehouse. Ultimately, the concluding part will suggest managerial implications that summarize the findings from this discussion.

2. METHODOLOGICAL FRAMEWORK

2.1 Research Design

Research is conducted in order to provide information and solutions in relation to a research question, and the chosen research methodology should be closely connected to the type of research problem that a study is based on. The purpose of a research can either be explorative, explanatory, causal, or of a descriptive character (Yin 2003, Cooper & Schindler 2008) depending on the objective of the research. Explorative research is used when the objective is to gain ideas and insight about the research topic and in order to break vague problems into more precise sub-problems.

The objective of my thesis is to explore the existing theoretical framework within lean theory and warehouse management, and subsequently how theoretical findings from the literature and practical examples from warehouses in similar settings can be applicable to shipyard warehouses. Hence, the research question mainly concentrates on exploring the unit of analysis through "how/"why-questions, and an exploratory case study approach should be chosen according to the framework of Ellram (1996).

2.2 Case Study Research

Yin (2003) has developed a framework for conducting case studies, and defines the concept 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 evident" (page 13)*

The definition implies that the case study approach is an appropriate method for this particular manner of conducting research, as variables tend to be wage, the researcher has little control over events, and relevant research questions and answers to these might occur during the actual case study. Yin (2003) also defines six key sources of evidence that can be applied, namely: documentation, archival records, interviews, direct observations, participant observations and physical artefacts. As the research problem stated in this thesis concentrates on studying an actual warehouse by applying multiple sources of evidence, and research questions will be shaped during the study, the case study approach appears appropriate and relevant for the thesis.

The case study will have a deductive character, which means that theory is confronted with real-world data, and the existing literature is applied to draw conclusion about the collected empirical findings (Golicic et al. 2005), as apposed to an inductive study where theory is built through data collection.

However, the purpose of the thesis is not to conduct an in-depth and detailed empirical analysis of the warehouse at Ulstein, but to conduct a case study to achieve a thorough understanding of the situation at the warehouse, and thereby ensure that suggested recommendations fit the reality at the shipyard.

2.2.1 Data Collection

The term "data" refers to the empirical evidence or information gathered through one or more data collection techniques, and serves as the basis for analysis in a research (Cooper & Schindler 2008). Data can be collected through either *quantitative* (precise measurement and mathematical analysis) or *qualitative* (interpretive research on descriptive data) techniques, through for example questionnaires, interviews, observations, experiments etc. Additionally, the data can be of *primary* character, i.e. first hand data from the source itself, or be *secondary data* that is existing data gathered for other purposes.

In this study, qualitative techniques of data collection are applied. The data consists of both primary data collected from interviews and observations, as well as secondary data from archival records and other research projects.

The main source of information is primary data collected through interviews with warehouse employees and other key personnel. The first data collection through interviews took place in December 2008 before I got involved in the project through the thesis. 12 persons were interviewed by researchers from FAFO and Møreforskning, and I received the summary of these interviews when I became involved in the project. The interview guide for these interviews can be found in appendix I. The interview summary provided a useful insight regarding the current state of the warehouse with respect to warehouse structure and management of warehouse operations. Additionally, some key challenges at the warehouse were identified. Obviously, the problematic areas pinpointed were based on the subjective opinion of interviewed warehouse personnel, and should consequently not be treated as objective information. Nevertheless, the interview summary provided an initial understanding of the warehouse situation and was – when supplemented with other sources of information – a valuable foundation for the case findings part of the thesis.

Furthermore, I had the pleasure of participating in a seminar arranged by FAFO and Møreforskning at Ulstein. The seminar lasted for six hours, and warehouse personnel, other personnel involved in warehouse decisions at Ulstein, and researchers involved in the Lean Shipbuilding program, took part. The results from the interviews were presented and discussed at the beginning of the seminar, and there were numerous interesting dialogues about challenges faced by the warehouse. The seminar provided a great deal of information and inspiration, and enabled a better insight into the situation at the warehouse.

After I started the work with the thesis, I have visited the warehouse at Ulstein three times in order to speak with key personnel. Most of the dialogues have been of informal character, but I also developed an interview guide for one of the visits (see appendix II). The visits took place within a time frame of two months, which was quite useful as I got to see the warehouse and other shipyard facilities in different production phases. At all three visits I had the opportunity to walk through all warehouse locations and make observations. I was accompanied by the manager of the warehouse at all three occasions, which provided the chance to clarify and ask questions about observations instantly. Some of these observations were documented by taking pictures for the report.

Additionally, I have received secondary data from Ulstein in the form of archival records from yard no. 279 and 280 (see appendix III – extract of archival records). The data from Ulstein’s ERP system Multiplus provides an overview of all outfitting items used for these newbuildings. Although the data could not be utilized for quantitative analysis, they provided a helpful outline of which items that are encompassed in the outfitting warehouse.

2.2.2 Validity

Qualitative research often faces challenges in terms of validity and reliability, which are measures that indicate the quality of the research. Validity makes a point of ensuring that the correct operational measures for the concept studied are utilized, and aims to ensure cohesion between conceptual frameworks, research methods and findings in the study. Three different concepts address validity in research (Yin 2003): *construct validity* (establishing the correct operational measures for studied concepts); *internal validity* (testing causal relationships between variables) and *external validity* (applicability and generalization of findings).

In this thesis, it has been attempted to construct validity by applying the concept of triangulation. In triangulation, multiple sources of evidence are used, since findings and conclusions generally are more convincing and accurate when based on several sources of information. Additionally, the information obtained from the primary interviews was written down, presented and discussed by warehouse personnel and researchers from FAFO and Møreforskning at the seminar in order to avoid misunderstandings.

2.2.3 Reliability

Reliability is concerned with the replication of the study, and whether the same results would be achieved if the study was repeated. This is critical for the quality of the research, since research results should not vary depending on how and by whom a study has been conducted. In order to strengthen the reliability, it is crucial to thoroughly describe and document the research procedure, which is the objective of this chapter and the information in the appendices.

2.2.4 Statistical Generalization

Case studies as a method has been criticized for not providing the opportunity for statistical generalization, where an inference can be made about a larger population based on empirical findings from a sample. Though according to Yin (2003), the objective of a case study should be to expand and generalize theories through analytical generalization, not to enumerate frequencies with statistical generalization. The aim of the thesis is therefore to offer a deeper insight into the case, as the case study method only can seek to expand and generalize theories.

3. THEORY REVIEW: LEAN SHIPBUILDING

3.1 Background

In the subsequent chapter, the concept of Lean Shipbuilding will be examined, with particular focus on the concept of inventory and material flow within various lean research streams. Seeing as the concept is relatively young as a field of research, the available literature addressing it, is accordingly limited. In this theory review, two differing research fields will be explored: the Lean Shipbuilding Model (Liker & Lamb 2000/2002, Lamb 2001) developed by studying shipyards in the US and Japan, and the Lean Shipbuilding concept in Norway (Dugnas 2007, Uthaug & Dugnas 2007, Dugnas & Oterhals 2008, Aslesen & Bertelsen 2008) inspired by the features of Norwegian Shipbuilding. As the Norwegian concept of Lean Shipbuilding can be perceived as a notion between Lean Manufacturing and Lean Construction (Bertelsen 2007), it is essential to understand the underlying theory extended from Toyota Production System, Lean Production and Lean Construction, before entering into a further discussion of the existing Lean Shipbuilding theory.

3.1.1 Lean Thinking

Lean Thinking is viewed as a production philosophy with a set of tools for eliminating and reducing non-value adding time. Its origins can be found in the factories of Toyota, which caught the world's attention when western manufacturers became aware of the performance gap between Toyota and other car manufacturers (Holweg 2006, Liker 2004). A considerable amount of research has been conducted in order to capture the essence of the successful production philosophy which challenged the accepted mass production practices, and the ideas of lean thinking has subsequently spread throughout the world and gained ground in numerous companies across diverse industries.

3.1.1.1 Toyota Production System

Toyota's foundation dates back to 1918 when it was a spinning and weaving business, based on an advanced automatic weaving loom which automatically stopped whenever a thread broke. After selling patent rights of the loom, the capital was used to establish Toyota Motor Company in 1937 and start production of trucks and cars. While Ford and GM in the US were experiencing boom times and introducing mass production techniques, Toyota faced challenging business conditions. A small market with diverse products did not justify large batch sizes, while low productivity, poor quality and capital constraints amplified the need for finding a system for simultaneously achieving high quality, low cost, short lead time and flexibility. Consequently, engineer Taiichi Ohno at Toyota began developing the Toyota Production System (TPS). He extended the concept of small lot production throughout the company and to suppliers, while constantly attempting to reduce costs and shorten the production flow by eliminating waste. This enabled production of a variety of cars in comparatively low volumes at a competitive cost (Liker & Lamb 2002, Liker 2004, Holweg 2006).

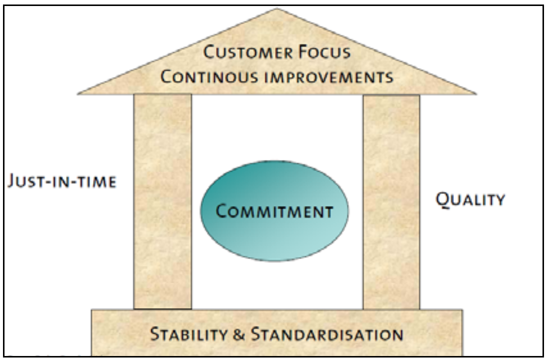

Figure 1: The Toyota Production System House (Friblick 2007)

The fundamentals of the TPS are frequently described as a house (see figure 1 above), where the roof represents the primary goal of providing customer value in terms of quality, low cost, short lead time, while the foundational elements provide stability through *Heijunka* (levelled production schedule) and standardized and reliable processes. The two outer pillars embody Just-in-Time (JIT), which removes inventory used to buffer against production problems, and Quality (*Jidoka* – built-in-quality), a pillar preventing defects from passing through the production by applying automation with a human touch. In the centre of the house we find the workforce, as TPS requires a high degree of involvement from trained and committed employees. The house structure emphasizes the structural system of TPS, where each element is critical, whereas they also reinforce each other (Liker 2004).

3.1.1.2 Lean Production

Lean Production directly descends from TPS, and was first coined in publications from The International Motor Vehicle Program at MIT, where it describes a manufacturing system that uses less of everything compared to mass production; less human effort in the factory, less manufacturing space, fewer investments in equipment, fewer engineering hours and less inventory kept in warehouses (Womack et al. 1991). While early publications focused on Lean Production in the automotive industry, Womack & Jones (2003) argued that the lean concept could be extended into other sectors through their concept of Lean Thinking. It was also considered a key development since value was linked to customer requirements, instead of only being defined through its opposite (waste), and since it – apposed to earlier contributions – described lean at a system level rather than focusing on single tools and aspects (such as JIT, Kanban, SMED) (Holweg 2006, Hines et al. 2004). Lean Thinking suggests a cyclical route to seeking perfection, revolved around four key principles seeking a fifth:

1) Specify value

Value should be defined by the customer and expressed in terms of a specific product with specific capabilities meeting the customer's needs at a specific price and time.

2) Identify the value stream

Identify all activities necessary to bring a specific product through the supply chain, while eliminating all non-value adding activities in the process.

3) Make value flow

Allow for the remaining value-adding activities to create a continuous smooth flow towards the customer by reducing obstacles (for example batch and queue production).

4) Let the customer pull value

Reduced lead time achieved from the three first principles should enable short-term response to customer's pull signals (demand, specifications etc.).

5) Pursue perfection

The prior principles should facilitate a continuous improvement process aiming to produce maximum value for the customer while eliminating waste.

Although the five principles of Lean Thinking and the concept of Lean Production have gained ground throughout industries and countries, there has also been criticism towards the claimed universal applicability. Cooney (2002) argues that the production system is suitable for the automotive industry, but in industries with differing business conditions, buyer-supplier relationships or labour conditions it might not be appropriate. While suitable for standardized volume production, it might be less applicable in customized low volume production as for example construction and shipbuilding.

Hines et al. (2004) recognize this critique along with criticism towards contingency, human exploitation and ability to cope with variability, but suggests that the raised points regarding shortcomings of Lean Production has developed the concept further while allowing for adaptation to specific industries and circumstances. Liker & Lamb (2002) also emphasize the importance of adapting lean theory to fit the circumstances in other industries. While the principles and philosophy might be applicable across sectors, the techniques and tools for implementation need to be adapted and adjusted to the characteristics of industries.

Presently, Lean Production is commonly regarded as a system which is more than the sum of its components, as opposed to just a set of individual tools (Liker 2004, Bicheno 2004). However, there still exists a semantic confusion surrounding Lean Production as there is no agreed upon common definition (Shah & Ward 2007, Pettersen 2009). Accordingly, concepts as Lean Thinking, Lean Production, Lean Manufacturing and sometimes even TPS and JIT are used interchangeable to address the system. The inconsistency in conceptual clarity can be traced back to the lack of distinction between tool and system in early research. Whereas conceptually multi-faced, different contributors all recognize TPS as the starting point of Lean Production and several common core concepts persist. Some of these are detailed below.

Waste Elimination

A fundamental concept in TPS and Lean Production is identification, elimination and prevention of waste. Waste is anything that adds to the time and cost of making a product, but does not add value from the customer's (internal or external) point of view, and should consequently be reduced or eliminated. Toyota defined seven main wastes, while an eight was added later (Bicheno 2004, Liker 2004, Harrison & van Hoek 2002):

1) The waste of overproduction

Producing too much, too early or "just in case".

2) The waste of waiting

Occurs when time is used ineffectively, and materials are not moving.

3) The waste of unnecessary transport

By definition all transport is waste and should be kept at a minimum.

4) The waste of inappropriate processing

Solving simple procedures by unnecessary steps or by too complex equipment.

5) The waste of excess inventory

Although zero inventory is unlikely, reducing excess inventory is critical.

6) The waste of unnecessary movement

Bending, reaching or moving excessively during work.

7) The waste of defects

Producing defect parts which requires correction.

8) The waste of unused employee creativity

Losing time, ideas, skills, improvements and learning.

Waste elimination is a mean for achieving Lean Production, but is however not an end in itself. The objective should be to let waste elimination work interchangeable between the different wastes, as well as with pull systems, smooth flow and continuous improvement. For example, the waste of overproduction generates other wastes through longer lead times, inventory buffers, overstaffing etc. and accordingly discourages a smooth flow. This can however be prevented by making use of pull systems that only allows for work to move forward when the next work area is ready to receive it. It is also essential to distinguish between non-value adding activities and activities that are non-value adding but required. Hence, some non-value adding activities are necessary or cannot be avoided, i.e. holding some inventory buffers or transporting equipment between storage and point-of-use, but should however be reduced as much as possible (Liker 2004, Womack & Jones 2003).

The concept of waste elimination as a measure to reduce lead time and cost is one of the major differences between traditional manufacturing and lean manufacturing. Figure 2 below portrays how traditional manufacturing frequently focuses on improving value-adding activities, and thereby only achieve marginal lead time improvements. Lean, on the other hand, aims to reduce lead time by elimination non value-adding time, which has a greater effect on the flow and thereby allows for a higher amount of time to be eliminated.

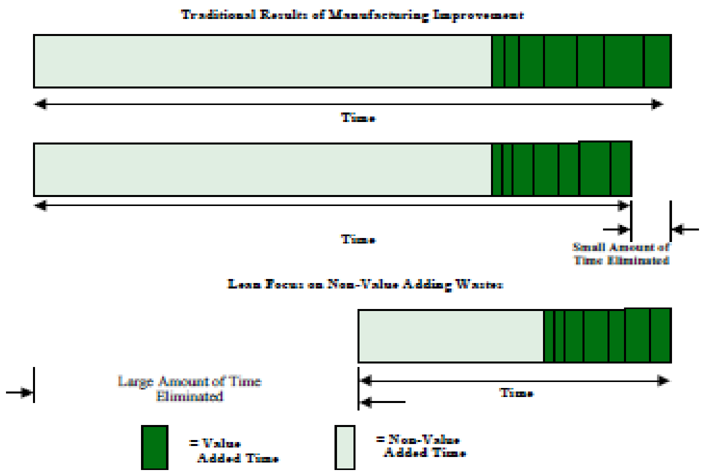

Figure 2: Improving lead time by eliminating waste (Liker & Lamb 2002)

Continuous Flow

Another core concept in Lean Production is creating a smooth continuous flow that enables work within each process to flow smoothly from one step to another without interruptions. As apposed to traditional mass production and its batch and queue operations, the ideal is to have a single piece flow, where one unit is made at a time according to the rate of the customer demand (takt time). If single piece flow is not feasible, small batches should be pursued, and the thought is that smaller batches will shorten the lead time from raw material to finished goods and thereby also improve response time to customers order, quality, productivity, flexibility, cost and space requirements (Bicheno 2004, Liker 2004).

A smooth continuous flow also affects the level of inventory, as there is less need for buffering at each stage of the production process. With less inventory it concurrently becomes immediately apparent were bottleneck operations are located, since inventory is not able to conceal them. Additionally, a continuous flow rate facilitates material planning and in that way enables raw materials to be delivered shortly before or just-in-time for the production processes.

Pull System

A pull system initiates production at each stage only when it is requested, contrasting push systems found in traditional manufacturing where production planning for all levels is done in advance based on forecasts. Consequently, all production is linked to and driven by real demand, and is a response to fulfil actual orders. Pull systems should start with the customers, who will signal an order. The customer order is a signal that triggers initiation of production in the upstream process. Subsequently, each upstream process should receive a signal from the downstream process all the way back to the supplier of raw material (Bicheno 2004, Nahmias 2005, Harrison & van Hoek 2002).

Kanban (Japanese for cards) can be an enabler for the pull system by providing information on replenishment signals upstream and is a central tool for systematic operation of JIT. Applying pull systems supported by Kanban and JIT ought to have major implications for the inventory level, seeing as ideal pull systems should not produce any inventory. Since all production is based on actual demand, materials are delivered upstream according to replenishment signals just in time.

Continuous Improvement

Continuous improvement (*kaizen* in Japanese) is another cornerstone in Lean Production and is an enabler for creating learning within organization. Through recognizing problem areas, identifying root causes of problems, providing countermeasures and finally, having committed and empowered employees to implement measures, an organization can constantly aim to reduce waste, create a smoother flow and improve pull systems throughout the supply chain. Standardization is essential for pursuing perfection as improving frequently shifting processes only will add one more variation. Consequently, processes need to be standardized and stabilized before implementing improvements. Finally, knowledge of improvements and new standards needs to be transferred throughout the work force to ensure that processes stay standardized and stable (Liker 2004, Womack & Jones 2003).

Inventory Reduction

Lean Production and inventory reduction are concepts that are obviously connected; however, lean is not defined by the process of eliminating inventory (Sheldon 2008). Even TPS incorporated inventory buffers as they considered them to be strategic weapon with respect to providing customer service or enabling flow buffers between operations. It is however necessary to have an understanding of the root cause of holding inventories as it tends to hide problems, increase lead times, space requirements and storage cost. Figure 3 below shows how inventory can be perceived as a sea that hinders problems for reaching the surface and being addressed since high levels will generate less visibility.

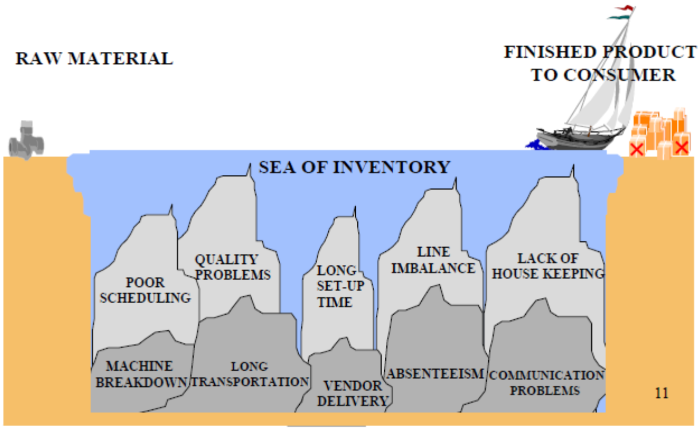

Figure 3: Sea of inventory (Liker & Lamb 2000)

High inventory levels can indicate that the flow is disrupted, and although zero inventory is an unlikely scenario, reducing excess inventory should be pursued. By applying pull system and having a smooth flow, inventory levels can be reduced. Additionally, variability in supply could be reduced by creating a dependable and involved supplier base consisting of a few key suppliers with long term contracts that allow for frequent orders and deliveries (Liker 2004, Shah & Ward 2007).

3.1.2 Lean Construction

Lean Construction is an adaptation and implementation of Japanese manufacturing principles within construction processes. In recent decades, the concept has achieved much attention within construction industry throughout the world, and institutions as the Lean Construction Institute, the International Group of Lean Construction, as well as regional and national Lean Construction forums have been founded. This chapter aims to give account for core developments and key principles within Lean Construction, in addition to discussing the applicability of Lean Thinking within the construction industry.

3.1.2.1 Background

Compared to productivity growth observed in manufacturing industry in recent years, the productivity growth in construction industry has historically been much lower (Bertelsen 2004, Veiset et al. 2004). Consequently, the construction industry has looked to production systems in manufacturing for inspiration. As Lean Production with its concepts of JIT, pull systems, value maximization, waste elimination etc., has been identified as a probable cause for productivity gains in manufacturing, attempts to adapt a lean approach to construction have been made, resulting in the expansion of Lean Production to Lean Construction.

The development of Lean Construction principles and practice has taken place within two interacting research streams. A theoretical stream has focused on application of lean production philosophy to construction, based on the Transformation-Flow-Value theory and the understanding of construction as a kind of production (Koskela 1992; 2000), while a practical stream has attempted to provide new methods for production system design and production control (Howell 1999, Ballard 2000a/b).

The research field has developed through interpretation and adaptation from TPS in post-war Japan, to Lean Production in the US in the 1980s, and thereafter expansion to other countries and other sectors, including the construction industry (Jørgensen & Emmit 2008). Figure 4 below portrays this sequential diffusion, as well as the further diffusion into local variants of the concept.

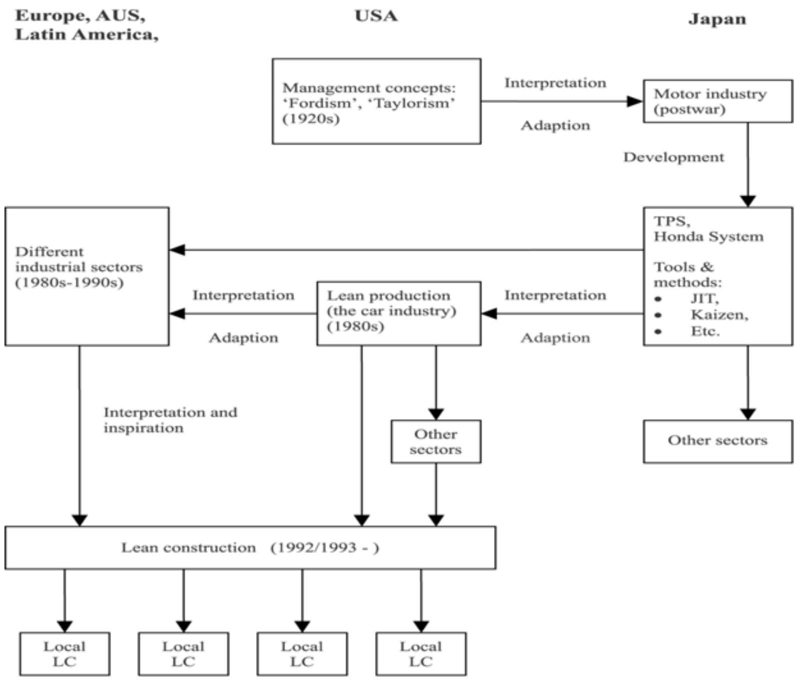

Figure 4: Sequential overview of the diffusion of Lean Production (Jørgensen & Emmit 2008)

3.1.2.2 Characteristics of Construction

Lean Construction has rejected many ideas from Lean Production due to a conviction that construction is fundamentally different from manufacturing (Daeyoung 2002). Construction is considered a special kind of production with certain peculiarities influencing the product level, production level and the industry level, and consequently the implementation of lean principles within construction process needs to be adapted to its particular characteristics (Bertelsen 2004, Ballard & Howell 1998, Howell 1999). Although the below characteristics can be found in other industries as well, it is the combination of the characteristics together that defines the uniqueness of construction (Bertelsen & Koskela 2004, Koskela 1992; 2000, Vrijhoef & Koskela 2005, Salem et al. 2006):

- *Site production:* Production within construction projects takes place at the final site of the constructed product, and occurs as fixed-position manufacturing, a characteristic shared by ship and airplane production. Often production even takes place within the constructed product. Site production generates high demands on planning and coordination as the site is a necessary input resource for production and a production infrastructure needs to be created. Additionally, workstations move through the emerging wholes of the product instead of having material move through workstations as in a factory, and the products eventually become rooted in place.

- *One-of-a-Kind Production:* Although materials, components and skills required in project-based construction are usually similar or the same, the one-of-a-kind nature of construction projects arise due to the engineer-to-order nature of projects. Different clients have differing needs and priorities, while designers will prefer varying solutions for customization and innovation. Because construction is typically site production, site facilities and the surroundings will also change. Consequently, the prototype nature of construction integrates design and production activities, and generates uncertainty relating to customer acceptance.

- *Temporary Organization:* Construction is usually organized in temporary project organizations formed for a particular construction project. This reflects the one-of-a-kind nature of construction, and different companies and workers join the project depending on contractual arrangements and the particular expertise needed. This short-term, multi-organization characteristic of construction projects complicates systematic and long-term approaches to productivity improvement.

- *Complex Production:* Construction can be understood as a complex and dynamic system that takes place in a complex and non-linear setting with overlapping activities of different contractors. Moreover, workstation moving through the building can cause congestion since numerous workers operate within a small space. In the building design process, preconditions are often defined in parallel with the solutions, and design and production takes place simultaneously. Furthermore, many projects may take place simultaneously and require the same resources; thereby, disturbances are transmitted between projects. The highly parallel and non-sequential nature in construction processes requires bottom-up management based on cooperation and learning.

3.1.2.3 Applicability of Lean Philosophy

The characteristics and the potential uniqueness of construction as a form of production have received great attention in discussions concerning the applicability of lean principles in construction. Seeing as the combined effect of site production, one-of-a-kind production, temporary organization and complex production is uncertainty, the applicability of Lean Production principles derived from an ordered situation with well known products and customers, precisely defined production processes and established supply chains, have been questioned by contributors (Howell 1999, Bertelsen & Koskela 2004, Bertelsen 2004). Additionally, Lean Production has tended to focus more on reducing cost than on generating value. Bertelsen (2002) claims that Lean Construction needs a more value centred focus than mass producing industry, since value specified by the customer is quite different in project-based one-of-a-kind production with a high degree of customization.

Consequently, it is argued that construction could attempt to become lean by reducing the degree of complexity to a level where principles from Lean Production are applicable. This might be an appropriate strategy for smaller construction projects, but thoroughly complex construction projects will never completely resemble manufacturing due to the characteristics that create uncertainty, thus adaptation appears to be a more appropriate strategy (Ballard & Howell 1998, Bertelsen 2004). The research on Lean Construction has therefore been extensive in the last decade, and LCI has developed production systems and implementation tools in order to facilitate adaptation of Lean Production to the construction industry. The result is a project delivery system that emphasizes reliable and speedy delivery of projects while providing maximized value and minimized waste (Bertelsen 2002, Daeyoung 2002).

Lean Construction has received criticism for leaving the critical literature on Lean Production behind when extending the theory to construction, and additionally for developing Lean Construction theory within annual IGLC-conferences where there is little critical debate regarding the concept (Jørgensen & Emmit 2008, Green 1999). This can possibly be traced back to the maturity of the concept. Literature on Lean Construction is rather young compared to Lean Production, which is considerably more developed. Consequently, there is still a need for a coherent theory, and as in Lean Production, there is also semantic confusion that needs to be addressed. Nevertheless, although there are shortcomings with respect to theory development, Lean Construction is increasingly being implemented across the construction industry, and reports indicated a positive effect in productivity and overall results (Salem et al. 2008, Bertelsen 2004).

Compared to traditional construction, the major difference within Lean Construction is that it applies pull systems in scheduling. Traditionally, push systems has been prominent in construction, with top-down planning and release of material, information and directives according to plans. Pull systems on the other hand, emphasize the readiness of the process, which is what initiates delivery of input. Another significant difference is the focus on flow optimization in Lean Construction. While traditional construction aims to be productive by optimizing specific activities, the optimization focus in Lean Construction is on the entire project, and on achieving higher productivity in the entire construction process by improving the flow between activities (Skinnarland & Andersen 2008, Daeyoung 2002).

3.1.2.4 Last Planner System

The Last Planner System (LPS) has become the most popular measure of applied initiatives within Lean Construction, and addresses the issue of coordinating human resources and material. It is a production control system that facilitates collaborative management in networks and the communication required for production planning, coordination and delivery of a project. The main objective is to obtain an even workflow, carry out weekly work planning and to carefully monitor the performance according to plan (Ballard 2000a, Bertelsen 2002).

LPS is structured through a plan hierarchy with four levels (Ballard 2000a): *The master schedule* (overall project schedule), *the phase schedule* (finer detailed schedule for more than six weeks), *the lookahead plan* (workable backlog for 3-12 weeks) and *the weekly work plan* (WWP) (make ready actions with a timeframe of 1-2 weeks).

The overall plans are administrated by the project management, while WWP introduces the term "Last Planner", which refers to the workers that are accountable for the completion of individual assignment at the operational level, as these are the ones that are responsible for controlling that "healthy" activities can take place. Healthy activities have seven premises which need to be fulfilled (see figure 5) (Skinnarland & Andersen 2008, Daeyoung 2002).

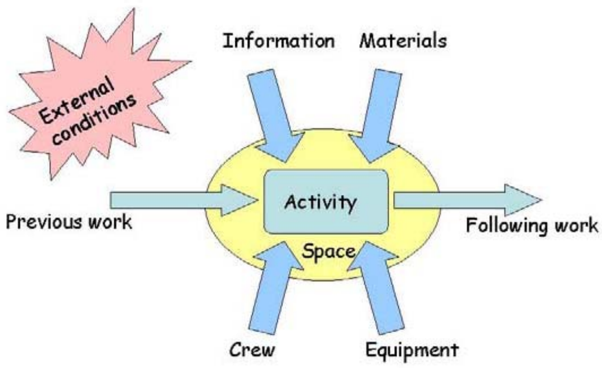

Figure 5: Premises for healthy activities (Bertelsen 2008)

Planning according to this method enables project management to be proactive towards production obstacles and flow variability, instead of dealing with uncertainty in retrospect. Another important aspect of LPS is the Percent Planned Completed (PPC), which is a tool to monitor the number of completed tasks and a measure for plan reliability (Bertelsen 2002, Daeyoung 2002). PPC thereby enables root cause analysis of incomplete tasks and provides a technique for continuous improvement. Although LPS was originally developed for the construction industry, it is argued that is can also be applied for production planning in other project delivery processes, as for example the shipbuilding industry (Ballard et al. 2001, Aslesen & Bertelsen 2008).

3.1.2.5 Material Flow

An efficient construction process greatly depends on having the right material available at the construction site at the right time. In view of the fact that construction is site production, several logistics challenges arise (Bertelsen 1997). For example, there is little space available for storing materials at the site, so frequent deliveries of exact amounts are essential. While material supply in construction creates no value per se, it is critical for a smooth flow that again will facilitate improved labour productivity.

Nevertheless, lack of materials is one of the most frequent causes for delay in construction processes and several strategies have been investigated to identify opportunities for improvement. Commonly, the root cause can often be chaotic processes and lack of production planning, which needs to be addressed to solve underlying problems (for example by applying LPS). However, there are also logistics strategies that can be applied. Kitting, i.e. consolidation of products to assembly packages in logistics centres off-site, is one potential strategy, while a closer connection to LPS is outlined as another. As LPS serves as a vital link between production and planning, lead times, procurement and delivery dates could be closer incorporated through meetings, and enable materials to be pulled from suppliers on a JIT basis (Mossman 2008, Zimmer 2008).

3.2 Lean Methodology in Shipbuilding

Throughout the recent decade lean methodology has also been applied in a shipbuilding context. Compared to the available literature in the previously elaborated research fields of Lean Production and Lean Construction, the worldwide research is limited, which is quite natural since Lean Shipbuilding is a much narrower field of research and an extension of the above. When searching for literature within Lean Shipbuilding, it becomes apparent that there are two major research groups dominating contributions. One is the Lean Shipbuilding program in Norway, which has been developed in close cooperation with Lean Construction researchers and Norwegian shipyards, and the other is the National Shipbuilding Research Program (NSRP) in the US that developed the Lean Shipbuilding Model for adaptation of Lean Production principles. Before discussing these concepts further, it is necessary to understand the characteristics of shipbuilding, and how it differs from manufacturing and construction.

3.2.1 Characteristics of Shipbuilding

Although there is considerable variance in shipbuilding features across countries and sectors – commonly due to the level of customization and complexity of the vessel built – there are still some basic characteristics that are typical for the industry of shipbuilding (Liker & Lamb 2002, Dugnas & Oterhals 2008):

- *One-of-a-kind production:* Even though series of vessel occur, the final product is typically unique due to the fact that design frequently changes during the lengthy production process. Vessels are engineer-to-order products, that become unique through the communicated requirements and specifications from the customers (ship owners). Thus, shipbuilding shares the element of product uniqueness with construction, but also has features similar with mass production, as there for example are production lines for pipe fabrication.

- *Consistent production facilities:* While construction is characterized by site production, shipbuilding takes place within the same production facilities at the shipyard. Thereby, vessel construction has the advantage of having an established production infrastructure, and the site is not considered an input resource as it is in construction.

- *Fixed position layout:* Shipbuilding does not encompass the feature of becoming rooted in place as construction, since vessels can be moved during the construction period. However, fixed position manufacturing occurs, as vessels commonly remain stationary during the majority of time because they are too big to be moved around. As a result, staff, materials and equipment needs to be brought to the work areas, and workstations move through the product, as apposed to traditional material flow through workstations in production facilities known from mass production. However, prefabrication and pre-outfitting off-site frequently takes place in order to simplify the construction process.

- *Temporary organizations:* Since shipbuilding is a project driven industry, temporary organizations are created to manage specific project. Although participants vary between projects, the randomness in organization is minor to that found in construction project organizations, since the production facilities, the shipyard employees and regular subcontractors commonly are the same through several projects.

3.2.2 Applicability of Lean Philosophy

As outlined above, shipbuilding encompasses both similar and differing characteristics to production found in mass production and construction. Consequently, neither the theory of Lean Production and Lean Construction can be transferred to a shipbuilding context without adjustments. However, the basic principles within TPS, as added customer value, shorter lead times and elimination of waste, applies to any process whether it is high or low volume, customized or standardized (Liker & Lamb 2002). A key objective should therefore be to avoid copying solutions from TPS, Lean Production or Lean Construction, but instead adapting lean approaches to fit the specific circumstances found in a shipbuilding environment, as well as specific features of each shipyard and even each shop in the shipyard.

3.3 The Lean Shipbuilding Model

Liker & Lamb (2000) developed the below model of Lean Shipbuilding (see figure 6) after studying shipbuilding practice at US shipyards in addition to three Japanese shipyards. The model is based on the TPS house (Liker 2004), but is portrayed within a shipyard with a ship in the dry-dock as the centrepiece.

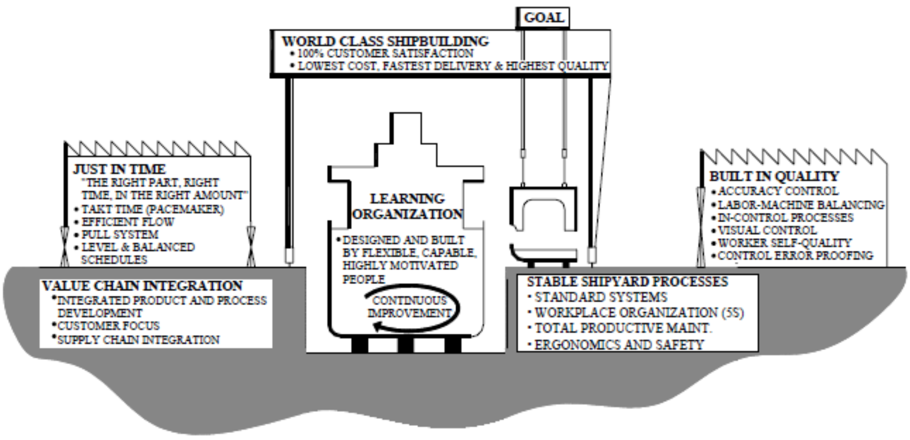

Figure 6: The Lean Shipbuilding Model (Liker & Lamb 2000)

The model introduces a framework for design of a lean shipbuilding process and includes familiar concepts from TPS and Lean Production, as for example JIT deliveries, continuous flow, built-in-quality, process standardization, customer value, waste elimination, visual control, and continuous improvement through a high degree of involvement by flexible, motivated employees (Liker & Lamb 2000; 2002), and is greatly inspired by contemporary practices at Japanese shipyards.

The model emphasizes the importance of having stable and reliable shipyard processes, and encourages use of standardized work processes for manual operations, as well as efficient workplace design and layout through for example focus on the 5S tool and ergonomics. Built-in-quality through visual control, error-proofing, employee empowerment is also an important feature, since it will enhance the likelihood of only passing on good parts to the next process. Furthermore, integration with suppliers and frequent deliveries of material and equipment just-in-time, is another essential aspect of the model.

The ideal for JIT is a one-piece flow, which according to the authors can be achieved by identifying families of parts that go through the same set of processes and dedicating a production line to that product family. The objective is to have all productions that are assigned to a family go through operations one piece at a time, or alternatively in small batches. Takt time (the customer demand rate) can be utilized as a pacing mechanism, to which the overall shipyard schedule can be balanced.

Although the model provides helpful insight when it comes to introducing concepts from TPS and Lean Production, it assumes that ships are designed to be manufacturable and are based on standard modular design (Liker & Lamb 2000; 2002). Accordingly, vessels are of low complexity with little customization, and are built on moving lines. Consequently, the model is not entirely applicable to Norwegian shipbuilding, as the maritime cluster produces advanced, highly customized vessels, and the products complexity is considered a competitive advantage (Hervik et al. 2005b, Dugnas & Oterhals 2008).

Nevertheless, although vessels might not be designed to support this kind of standardized, modular construction, the fundamental principles and philosophy will still apply, but the specific details of the lean implementation will be different. Accordingly, it is valuable to understand how lean is implemented throughout shipyards across the world, in order to understand how it should best be implemented in ones own shipbuilding environment.

3.3.1 Lean Shipbuilding in Japan

Japanese shipyards were facing many of the same challenging conditions as Toyota after World War II, and had a reputation of low productivity, poor quality and low degree of innovation (Liker & Lamb 2000, Lamb 2001, Koenig et al. 2002). From 1960-65 however, there was a productivity improvement of 100%, followed by a productivity improvement of 150% from 1965-1990. Liker & Lamb (2002) argues that much of the substantial productivity gain can be attributed to impact of lean principles such as employee involvement, process standardization, one-piece flow and focus on continuously eliminating waste.

Japanese shipyards can be characterized as ship factories where standardized, modular designs are applied to create a constant flow of basic and intermediate products. As opposed to fixed position manufacturing, the production takes place with moving lines, where materials (blocks) move through the yards in a carefully sequenced manner. The smooth and sequenced flow enables delivery of materials and equipment on a JIT basis. Through focused selection and development of suppliers, and a high degree of trust and mutual learning, some of the best Japanese shipbuilders are able to demand for example steel deliveries multiples times a day according to schedules.

3.3.2 Lean Shipbuilding in the US

Shipbuilders in the US have been struggling with competitiveness in the world market, as they have been serving a highly protected US defence and commercial market. In 2002, the productivity was half of that in Europe and only one third compared to shipbuilding in Japan (Lamb 2001). For that reason, NSRP initiated a study on applying TPS-principles to shipbuilding and Liker & Lamb (2000; 2002) detailed the framework for design of lean shipbuilding processes, and several shipyards are currently applying lean principles in their production.

Todd’s Pacific Shipyard, a NSRP-member, has integrated the 5S approach with ship repair operations. The tool is a method for organizing the workplace and will be discussed in detail in the next chapter of the thesis. According to DiBarra (2002) 5S has been quite successful, for example with respect to block building materials which were previously stored in piles, but are now sorted by size, shape and stored on separate pallets that enables visible assessment of inventory. In addition, scaffolding storage was reduced by 33,5 tons of scrap metals when it was sorted and stored appropriately closer to the point of use.

3.4 Lean Shipbuilding in Norway

Compared to the previously described shipbuilding industry in Japan and the US, which are building more standardized vessels, Norwegian shipbuilders are orientated towards the oil and gas activities, and produces complex and highly customized offshore service vessels (mainly PSV, AHTS, MPSV and seismic vessels). Due to long experience with shipbuilding and the positive effect of being part of a strong maritime cluster, Norwegian shipbuilding has developed competitive advantages as punctual delivery, quality and functionality (Hervik et al. 2007, Oterhals et al. 2008), and it will be critical to maintain these order winning advantages in order to stay competitive.

3.4.1 Shipbuilding Process

Norwegian construction of offshore service vessels is considered a highly complex project production comprising of planning, design of basic, detailed and shop drawings, material specification, procurement, production and hand over. In general, these activities take place in a parallel and overlapping manner in order to reduce the overall production time, and there is a high level of customization and innovation during the construction period, due to frequent change orders from ship owners and development of design and ship drawings simultaneously as the vessel is being built (Aslesen & Bertelsen 2008, Dugnas & Oterhals 2008). Furthermore, there is a complex network of both equipment suppliers and trade contractors; hence Norwegian shipbuilding is a highly complex, multi-actor process.

The production process of a vessel delivered from a Norwegian shipyard can be divided into four key production phases (Dugnas & Oterhals 2008):

- *Hull fabrication:* In the first production phase prefabrication, assembly and formation of the steel structure of a ship takes place through hull block construction. During the last decades, this labour intensive process has increasingly been outsourced to low cost countries.

- *Primary outfitting:* Outfitting refers to the installation of systems, equipment and fitting to the ship. Because outfitting cost increases significantly as the process proceeds, shipbuilders gradually seek to finish as much of the outfitting as early as possible and a significant share of outfitting therefore takes place during hull construction in low cost countries before the hull is towed to Norway.
- *Final outfitting:* Due to simultaneous design and production activities and frequent change orders, a remaining part of outfitting will need to be postponed to a later phase of the production.
- *Testing:* Testing is a quality assurance phase that takes place when the vessel draws near completion and hand over.

Another essential contemporary feature of Norwegian shipbuilding is the capacity shortage the industry is experiencing due to the building boom (Oterhals et al. 2008). The capacity shortage in terms of labour and supply has made it difficult to maintain a sufficient and qualified workforce, and delayed deliveries of equipment have caused major problems with respect to the critical lead times in the industry.

3.4.2 Development of Lean Shipbuilding

Because of the complex and project-driven production of one-of-a-kind products in Norwegian shipbuilding, lean techniques from Lean Production or from Liker & Lamb's (2000; 2002) lean shipbuilding model can not be uncritically transferred to shipbuilding in Norway. While a mass production inspired implementation of lean principles in Japanese and US shipyards might be an appropriate strategy for standardized, modular production in so-called ship factories, it appears less applicable for Norwegian shipyards. The construction process in Norwegian shipbuilding bears more resemblance to complex and dynamic projects found in the world of construction (Bertelsen 2008, Dugnas 2007), and the lean approach in Lean Construction theory is therefore more suitable for implementation of lean methodology in such a shipbuilding context.

Shipbuilding and construction are both project-driven industries that deliver one-of-a-kind products of advanced and complex character. Lean Construction theory has therefore been applied as a theoretical base and Lean Shipbuilding in Norway has been developed in cooperation with Lean Construction forums. However, while the concept of Lean Construction is a more appropriate foundation than merely Lean Production, the differing features also need to be considered. As previously mentioned, the production facilities will for example remain the same from project to project in shipbuilding, and there is also commonly less randomness in terms of project organization compared to construction.

Dugnas & Uthaug (2007) have developed a framework (see figure 7) for adaptation of eleven lean principles formulated by Koskela (1992). Koskela argued that his principles were applicable for the construction industry, and Dugnas & Uthaug (2007) suggest that most of them are applicable for Norwegian Shipbuilding as well. However, some of the principles need to be adapted to better fit the features of a shipbuilding environment (Dugnas & Oterhals 2008). The value concept is for example perhaps even more challenging in shipbuilding than construction, since there is a continuous customization and innovation, with a high amount of change orders during the construction period. This demand structure has led to current discussion of whether Agile or Leagile Shipbuilding is a more appropriate term (Dugnas & Oterhals 2008).

The term "agile" is defined as using market knowledge and a responsive supply chain network to exploit profitable opportunities in a volatile marketplace (Christopher & Towill 2000, Harrison & van Hoek 2002). Whilst being distinct concepts, the lean and agile can also coexist and be mutually supportive; hence, the "leagile" concept has been developed. A leagile strategy is recommended when agility – i.e. flexibility and responsiveness in the supply chain – is a market winner, while being lean through cost efficiency is a market qualifier (Mason-Jones et al. 2000, Goldsby 2006). The Norwegian shipbuilding industry faces such conditions with requirements of being lean in a volatile market, thus leagile might be a suitable strategy for addressing these challenges.

The creation of value for ship owners through customization and innovation is a critical competitive advantage, and lean strategies for standardization and simplification of products most therefore be carefully managed in order to avoid reducing the gained benefit. Furthermore, long term co-operation with suppliers are complicated by the fact that deliveries commonly are chosen by ship owners.

LEAN CONSTRUCTION	LEAN SHIPBUILDING IN NORWAY
Reduce the share of non value-adding activities (waste).	Reduce the share of non value-adding activities (waste).
Increase output value through systematic consideration of customer requirements.	Increase output value through systematic **and continuous** consideration of customer requirements (**Awareness of 'change orders', Agile production**[1]).
Reduce process variability. Consider process interdependency and isolate supply-related variation.	Reduce process variability. Consider process interdependency and isolate supply-related variation.
Reduce cycle times. Eliminate inventory stock and decentralize the organizational hierarchy.	Reduce cycle times. Eliminate inventory stock and decentralize the organizational hierarchy.
Simplify by minimizing the number of steps, parts and linkages **in a product** and the number of steps in a material or information flow.	Simplify by minimizing the number of steps, parts and linkages in a material or information flow. **The product's complexity is a competitive advantage in Norway: gain more control in this area.**
Increase output flexibility. Use modularized product designs, reduce the difficulty of setups and changeovers and train a multi-skilled workforce.	Increase output flexibility. Use modularized product designs, reduce the difficulty of setups and changeovers and train a multi-skilled workforce.
Increase process transparency.	Increase process transparency.
Focus control on the complete process. Allow autonomous teams to exercise control over the process and build long term co-operation with suppliers.	Focus control on the complete process. Allow autonomous teams to exercise control over the process and **gain more involvement in often temporary** co-operation with suppliers **chosen by the end-customers.**
Incorporate the best practices into the organization and combine existing strengths with the best external practices.	Incorporate the best practices into the organization and combine existing strengths with the best external practices.
Build continuous improvement into the process.	Build continuous improvement into the process.
Balance flow improvement with conversion improvement.	Balance flow improvement with conversion improvement.
By improving performance at the planning level increase performance at the project level. The Last Planner method is an appropriate alternative.	By improving performance at the planning level increase performance at the project level. The Last Planner method is an appropriate alternative.
Shift the design work along the supply chain to reduce the variation and match the work content.	Shift the design work along the supply chain to reduce the variation and match the work content.
Benchmark.	Benchmark. **Take advantage of knowledge-transfer within the Norwegian Maritime Cluster and beyond.**

Figure 7: Adaptation of Koskela's 11 LC principles to Lean Shipbuilding in Norway (Dugnas & Oterhals 2008)

The above principles outline a framework for ideal shipbuilding, but since every shipyard to some extent is unique in terms of strategy, organisation, facility layout and capabilities; implementation needs to be adjusted to fit specific circumstances. Additionally, instead of implementing all principles simultaneously, it can be sensible to choose a focus area as a starting point and thereby let the first implemented principles serve as enablers for others (Dugnas 2007, Quarterman 2007).

The Lean Shipbuilding program has for example initially focused much on implementation of production planning through the Last Planner System (Dugnas & Uthaug 2007) and phase-based project management (Ciobanu & Neupane 2008), which address some of the principles and enables implementation of other lean tools that can address remaining principles. In the later and current phase, the research program has increased the focus on material planning, flow and management within shipyards.

3.5 Material Flow at Shipyards

The material flow at a shipyard is characterized by the specific features encompassed in such project-based production. Since shipbuilding resembles construction in terms of site production, there is for example limited space available for storing materials at the work site, as production often takes place within the product being made. However, shipbuilding differs from construction in terms of production facilities, which will remain the same throughout different projects, and infrastructure for material handling can therefore be utilized for all projects. A warehouse in a shipyard accordingly becomes the focal point of material flow, and enables support of efficient production processes by frequent and timely deliveries of materials at the production site.

The one-of-a-kind character and the use of temporary organizations in shipbuilding imply that materials, equipment and suppliers differ between projects. Although a shipyard can propose preferred product solutions and suppliers, the final decision is made by the ship owner. This leads to differing solutions depending on the project specifics, and reduced possibilities of standardization of materials and closer co-operation with suppliers.

The current capacity shortage in supply also produces challenges for the material flow within shipyards. Since late deliveries of crucial components can cause critical delays with respect to timely delivery of vessels, there is a significant use of time buffers when setting delivery dates, which obviously increases the storage space requirements.

3.6 Summary of Lean Shipbuilding Theory

Lean Shipbuilding is a research field with relatively limited research, which is quite natural since it is considered an extension of TPS, Lean Production and Lean Construction (see figure 8). The existing research is greatly adjusted to the context for which the theory is developed. Hence, Lean Shipbuilding developed for standardized and modular US shipbuilding applies

Lean Production principles, while Lean Shipbuilding developed in Norway has adopted several principles from Lean Construction due to its complex, customized and innovative character. These characteristics have also contributed to recent discussion regarding the applicability of agile and leagile concepts.

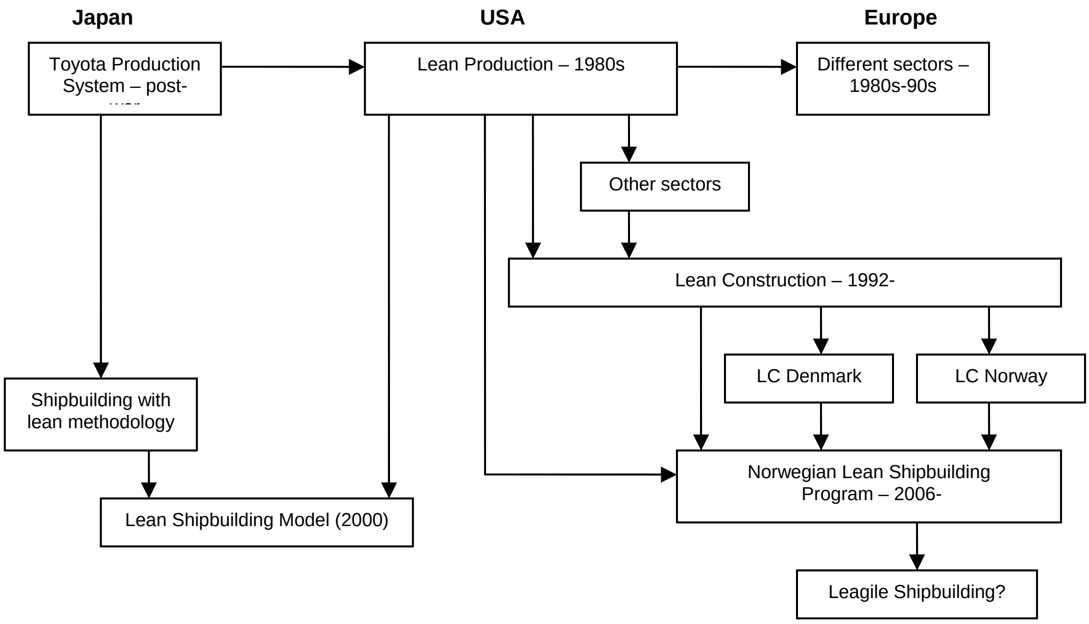

Figure 8: Sequential overview of expansion of lean methodology in shipbuilding

The characteristics of Norwegian shipbuilding also have significant implications for the material flow at the shipyard. As in construction, fixed production manufacturing places restrictions on the utilization of the limited space available on site. Though shipyards have the advantage of consistent production facilities, and consequently have the opportunity to build material flow infrastructures as for example warehouses. The prospect of standardization in terms of equipment is however limited due to the one-of-a-kind nature of projects and the employment of temporary organizations. Along with the considerable use of delivery time buffers due to current capacity shortage in supply, these features indicate that a shipyard's material flow needs to be managed somewhat differently than a traditional manufacturing flow.

4. THEORY REVIEW: WAREHOUSE MANAGEMENT

4.1 Introduction

Warehouses hold a key role in a firm's supply chain and logistics system, as they provide storage of inventories (raw material, components, work-in-process or finished goods) between point of origin and point of consumption, while simultaneously providing information to management on the status, condition and disposition of the items being stored. Thus, the three basic functions of warehousing can be defined as movement, storage, and information transfer (Grant et al. 2006, Frazelle 2002a).

Although several recent initiatives – such as for example Lean Production which considers inventory to be one of the eight wastes – have aspired to minimize and eliminate inventory, the flow of materials between point of origin and point of consumption will never achieve the coordination required to completely eliminate warehouses. Storage of inventory in warehouses is necessary when incoming and outgoing flow patterns differ in speed and frequency due to for example fluctuations in demand, unreliability of supply, bulk purchasing or batching in transportation and production. Holding inventory in order to buffer for this variability along the supply chain is expensive, but might still contribute to a reduced total cost of logistics activities due to trade-offs against transportation time and cost, production progress, customer service etc. (Gu et al. 2007, Grant et al. 2006).

The subsequent chapter aims to introduce prevailing theory and practices within warehouse management, the applicability of lean philosophy in warehousing, as well as examples of warehouse practices within shipbuilding and other project-based industries. The established theory on the topic of warehouse management is to a great extent focused on the analysis of specific aspects of warehousing, such as layout, storage allocation or order picking. This type of isolated sub-analysis assumes well-defined problems where all necessary factors are known, which is seldom the case in real life. As this thesis has a exploratory character where the problems encountered can not be reduced to multiple isolated sub-problems, the theory presented will maintain focus on general warehouse operations and how they are interrelated both with other warehouse processes, as well as with the overall warehouse design and layout

4.2 Warehouse Operations

The fundamental process in a warehouse can be described relatively simply; a stock keeping unit (SKU, also called item) arrives at the warehouse, is – if not directly needed – stored until required either by a customer or by production, and is thereafter retrieved and assembled for shipment. Consequently, the basic operations at a warehouse can be described as receiving, storing, picking and shipping (Gu et al. 2007, Rouwenhorst et al. 2000). The purpose of these operations is to ensure fast and efficient movement of items through the warehouse, coupled with timely and accurate information about the storage and movement. The operations appear straightforward in theory, though in practice, when influenced by factors as time, quality, cost and external conditions (Grant et al. 2006), warehousing is quickly turned into a complex process with high management and optimization requirements.

The figure below portrays common warehouse activities where receiving and shipping is perceived as the interface for incoming and outgoing material flow (Gu et al. 2007). In a warehouse that applies cross-docking, received items are sent directly from the receiving dock to the shipping docks, possibly with a few hours waiting time. Thereby, products are not stored for longer periods and inventory levels are reduced. However, cross-docking presuppose reliable supply with short lead times, available information about arrival times, departure times and destinations through the entire supply chain, dependable transport scheduling and predictable demand (Vis & Roodbergen 2008), and the need for holding inventory come about when cross-docking is not feasible. Thus, the receiving and shipping operations become more complex to manage as they are coupled with storage and order picking operations.

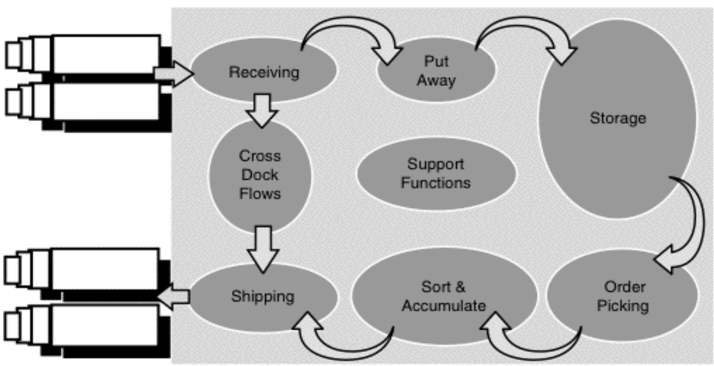

Figure 9: Common warehouse activities (Frazelle 2002a)

4.2.1 Receiving

Receiving is the first process encountered by an arriving SKU, and the process is the setup for all other warehousing activities since proper receiving is a prerequisite for high performance in storage, picking and shipping. SKUs arrive at the warehouse from outside transportation or an attached factory, and the warehouse accepts responsibility for the item after unloading the products, identifying the products, checking the quantity and quality against orders and shipping records, and updating the warehouse inventory records. Thereafter, the SKUs may be repacked into different storage modules and are staged while waiting for transportation to the next process.

4.2.1.1 Scheduled Receiving Docks

In an ideal scenario, receiving should only be allowed on a scheduled basis. When every incoming load is assigned an unloading time, the allocation of receiving resources (dock doors, personnel, staging space, material handling equipment etc.) can be more properly managed and it will facilitate creation of timetables for warehouse operations. In doing so, time consuming receipts can be shifted to off-peak hours and waiting time for incoming trucks can be minimized. The availability of advanced information technologies such as radio-frequency identification (RFID), GPS and advanced shipping notices (ANS) has made scheduled receiving dock increasingly common (Gu et al. 2007), as it can be used to proactively schedule receipts. These electronic capabilities also present the opportunity for obtaining shipment information before the load actually arrives, which is advantageous with respect to time spent on product identification, storage allocation etc. (Frazelle 2002b).

4.2.1.2 Checking Method

A crucial activity in the receiving operation is the verification of quantity and quality of the items received. If quantity and quality errors are not discovered at the receiving stage, the errors are transferred onto the subsequent operations at the warehouse, and the detection of errors will occur at a later point in time. Hence, early detection of errors is critical and should receive great attention during receiving operations. Profoundly checking of all deliveries will be time consuming, so deciding upon check frequency with respect to a supplier's past delivery performances might be useful. Mulcahy (1994) defines three methods for verification of items: *the 100% accept method*, where a supplier's excellent past performance places him on an approved list which indicate that no quantity or quality check is necessary; *the 100% verification method*, where the entire inbound delivery is checked due to previously poor delivery performance; and ultimately, *the random sample method*, where 7-10% of the delivery is checked before the rest of the delivery is accepted.

4.2.1.3 Alternative Receiving Practices

Frazelle (2002b) argues that there are "world-class receiving principles" that can streamline receiving operations by simplifying the material flow. By reducing handling steps a minimization of work content, mistakes, time and accidents can be accomplished. The touch analysis (see figure 10) outline how a reduction in handling steps can be achieved by applying differing receiving practises.

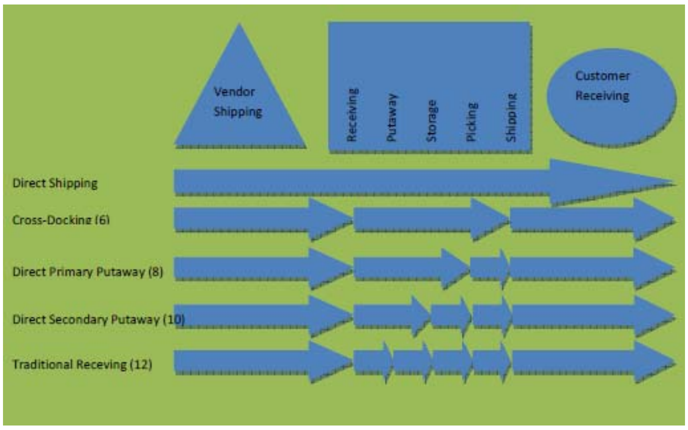

Figure 10: Touch analysis for alternative receiving practices (Frazelle 2002b)

Direct shipping occurs when an item bypasses the warehouse and is shipped directly to the customer, and consequently operations as unloading, receiving, staging, internal transport, storage, picking, packing and shipping can be avoided. If materials cannot be shipped directly, cross-docking is a potential solution, as it eliminates storage and order picking operations since items are routed to their end destination as soon as they are received. Direct primary putaway refers to putting items directly into the picking area after receiving, while direct secondary putaway takes place when items first leave for storage before being assigned to the picking area. Traditional receiving adds yet another process; staging before the items are transferred to primary or secondary storing. Given the positive effect of reducing material handling steps, the top receiving practices in figure 10 should be aggressively pursued, though while simultaneously considering trade-offs with respect to predictability and reliability in the incoming and outgoing material flow.

4.2.2 Storage

In theory, storage functions should not need to take place if all items arrived in time and was directly shipped to the assembly function. Though, the zero inventory idea from JIT is not necessarily feasible in real life. Most manufacturing companies need to hold inventory to buffer against variability in the supply chain, and even TPS incorporated “buffer zones” that linked process steps to the temporary storage of inventory (Liker 2004). Accordingly, the costly storage function prevails as a part of warehouse operation, but needs to be organized the best way possible in order to achieve high space utilization and facilitate efficient material handling in putaway and picking activities which greatly depends on the selected storage mode.

The storage function is shaped by three fundamental decisions, i.e. how much inventory should be kept in the warehouse for each SKU; how frequently it should be replenished; and where the SKUs should be located in the warehouse (Gu et al. 2007). The first two decisions can be categorized as inventory management decisions and will not be discussed in-depth here as they are less appropriate for the thesis’ topic. However, it should be mentioned that research indicates that when a warehouses reaches 85-90 % occupancy, the productivity and safety diminish dramatically (Baudin 2004, Frazelle 2002b). The decision regarding the physical storage and storage location assignment is more relevant, and will therefore be further elaborated below.

4.2.2.1 Pallet Storage System

The storage system needs to be adjusted to the physical characteristics of the items (pallet storage or case storage), and the selected system has considerable implications for the putaway and picking operations. The most common pallet storage systems found in warehouses are floor storage, block stacking, stacking frames, single-deep pallet racks, double-deep pallet racks, drive-in racks and drive-thru rack (Frazelle 2002b).

Block stacking refers to unit loads stacked on top of each other and stored on the floor in storage lanes and retrieved under a last-in-first-out (LIFO) discipline. The storage system is particularly effective when there are multiple pallets per SKU that are withdrawn in large increments. The investment in a block stacking system is low since pallets are placed directly on to the floor surface; however, the potential space-loss needs to be taken into consideration, as empty pallet spaces cannot be utilized effectively until an entire lane is emptied.

Picture: Block stacking

Single-deep pallet racking is a construction of metal uprights and cross-members, and the major advantage of this pallet storage system is the full accessibility to all pallets. Additionally, as apposed to block stacking, there is an immediate opening when a pallet is removed and there racks enable the full utilization of height available in the warehouse. The major disadvantage is the amount of space devoted to aisles.

Picture: Single-deep pallet rack

Baudin (2004) argue that it is decisive to avoid the one-size fits all approach when deciding upon storage devices for the warehouse. When one type of storage is applied for all items, it will be suitable for some items but inappropriate for other. Hence, it is necessary to take the items characteristics, volume or frequency of use into consideration in order to achieve the best possible utilization of storage space.

4.2.2.2 Storage Locator Systems

There are three basic systems for assigning SKUs to specific storage locations, which can be divided into the following categories: random, dedicated and zone storage (Muller 2003, Arnold et al. 2008, Sheldon 2008).

Dedicated storage

The dedicated storage system – also referred to as the fixed location system – basically represent a system where every item has a dedicated permanent space and nothing else can be stored at that particular location. The system is common in manual labour situations, and has the major disadvantages of being inflexible (for example when storage space requirements change) and requiring large amounts of space since space planning must allow for the total cubic volume of all products likely to be in a facility within a defined period of time. The major advantages are apparently the immediate knowledge of where items are located and the possibility of storing and retrieving items with a minimum of record keeping.

Random storage

In a random storage system – also called floating-location system – items are putaway in the first available slot when they arrive, and the same item may be stored in several locations at the same time and different locations at different times. By applying such a system in warehouses, one achieves flexibility and maximization of space utilization as empty locations are always made use of. However, at the same time one faces more resource demanding picking with longer travel times. Additionally, the system requires a well functioning locator system which provides accurate and up-to-date information on location as well as on availability of empty storage space.

Zone storage

Zoning refers to a location system where items with certain characteristics are located in a particular area. It is a combination of the random and dedicated storage system, as items are randomly stored within dedicated zones. Zone storage can have a positive effect on the picking efficiency, as parts common to one assembly can be in the same area and allows for flexibility as items can easily be added or moved in and between zones. As with random storage, this system requires a high-quality information system.

4.2.2.3 Item Placement

While locator systems provide a broad view of where SKUs can be found within a facility, item placement is concerned with the stock location of individual SKUs within any particular locator system. The most common manners of locating items are (Grant et al. 2006, Arnold et al. 2008): compatibility, complementarity and popularity.

Compatibility refers to grouping products that can be stored harmoniously together, for example with respect to chemical reactions, safety or temperature of storage, since physically similar items often require specialized storing facilities and handling equipment. Complementarity is concerned with the co-location of items which are similar in their use or is often ordered together, as this facilitates more efficient order picking. Popularity considers the inventory turnover and the demand rates of items, and fast moving items are preferably placed close to the receiving and shipping area in order to minimize lengthy moves of material handling equipment and personnel. Which items that should be located near receiving and shipping can for example be decided with an ABC-analysis. The placement analysis is based on Pareto's Law and his "80-20 rule" (within any given population, 20% have 80% of the value), and separates items into A-B-C-categories, where A-items represent the fastest moving items which should be placed closest to the point-of-use.

4.2.2.4 Inventory Tracking

An essential element of warehouse management is providing accurate and reliable information about inventory held in the warehouse. The information transfer should occur simultaneously with the movement and storage function, and the three most critical pieces of information are part description, quantity and location (Grant et al. 2006, Arnold et al. 2008). If this is not accurately recorded in the inventory records, it will not be possible to analyze inventory, as for example with respect to ABC-analysis, order picking routing etc.

One method of tracking inventory is the memory systems, which solely depends on human recollection. Although, it might be appropriate in small areas with only a limited amount of SKUs due to its simplicity, its limitations quickly become apparent in more complex setting as its ability to function rely heavily on human memory, health, availability and attitude of individuals (Muller 2003).

While manual files of inventory control have been common in the past, most of larger facilities presently rely on computer-based control of inventory. Additionally, the introduction of bar coding or RFID will obviously improve the speed and accuracy of information gathering, as systems are updated automatically when the items pass a scanner/reader.

4.2.3 Picking

Order picking refers to the retrieval of SKUs from storage location in order to satisfy a customer order or requests from production, and can be performed manually or automatically. The process is generally perceived as the most expensive process in a warehouse (Petersen & Aase 2004, Gu et al. 2007), due to its labour-intensive operation, and as a result there is also a large amount of literature written on the topic.

Theory distinguished between two main groups of picking systems, namely picker-to-parts and parts-to-picker system (Ghiani et al. 2004, de Koster et al. 2007). The first refers to human labour, where the order picker travels to the storage locations to manually pick items, while the latter deals with automated devices, where items are delivered automatically to stationary order pickers. While automated order picking can provide advantages in terms of labour cost reduction, improved service level and increased control through better information accuracy, they require a high initial capital cost and might reduce flexibility once implemented. Frazelle (2002b) argues that automation should accordingly be the last resort, and that it is critical to simplify and streamline process first before implementing such expensive systems.

The most appropriate system depends greatly on the storage allocation system in the warehouse, as well as the structure of customer orders. There are several organizational variant of order picking range from *batch picking* (picking by article), *discrete picking* (picking by order), *zone picking* (logical storage areas are split into multiple parts with different order pickers) and *wave picking* (picking orders for common destinations simultaneously (Petersen & Aase 2004, de Koster et al. 2007).

4.2.4 Shipping

Shipping can be perceived as the receiving process in reverse. Orders are picked and brought to the shipping area, where they are checked for completeness, packed in appropriate containers, shipping documents are prepared and finally, the shipment is loaded in external carriers or are brought to production by internal transport equipment (Frazelle 2002b, Gu et al. 2007). In order to ensure accuracy in inventory holding records, it is essential to transfer information about the shipment as soon as possible after delivery. As with the receiving process, truck scheduling will facilitate allocation of shipping resources and creation of shipment timetables.

4.3 Warehouse Design

Design of warehouse systems consists of a large number of interrelated decisions which aims to minimize throughput time of orders, while maximizing the utilization of space, labour and equipment (de Koster et al. 2007). While there is a wealth of research written on particular aspects of warehouse design, there appears to be a lack of a common systematic approach to warehouse design (Rouwenhorst et al. 2000, Baker & Canessa 2009).

Decisions concerning warehouse design can however be divided into three hierarchical levels (Rouwenhorst et al. 2000): *the strategic level* which is long term decisions (5 years) concerning for example size, number and location of warehouses, design of process flow or selection of technical systems; *the tactical level* which are medium term decisions (2 years) regarding layout, selection of equipment and storage system.; and finally, decisions at *the operational level* dealing with short term issues (1 year) as for example replenishment, allocation of products, assignment of order picking etc. The warehouse design decisions considered in this thesis are mainly on the tactical level, and are previously addressed in connection with description of warehouse operations.

4.3.1 Material Flow

The determination of the overall flow pattern in a warehouse is however a tactical decision that it is necessary to mention. Material flow can take place through several set-ups; among other the U-shaped flow and the flow-through pattern (Frazelle 2002b, Barker & Canessa 2009). In a U-shaped warehouse both receiving and shipping is located in front of the warehouse, while storage takes place in the back of the facility. The U-flow has advantages in terms of dock utilization, opportunities for cross-docking and potential expansion opportunities in three directions. The flow-through would require placing receiving and shipping docks at opposite sides of the warehouse, and one avoids that the processes interfere with each other, but at the same time decreases storage capacity and makes it difficult to take advantage of for example ABC-analysis.

4.4 Lean Warehousing

In view of the fact that holding inventory by definition is a non-value adding activity, there initially appears to be a contradiction between Lean Production and Warehousing. However, as previously mentioned, even TPS incorporated buffer zones linking process steps with temporary storage of inventory (Liker 2004). After all, TPS states that only *excess* inventory is considered a waste that should be eliminated. TPS’ motivation was to draw attention to the tendency of always storing more than needed, not to eliminate inventory completely (Baudin 2004).

While Lean Production is engaged in reducing inventory by applying JIT deliveries, lead time reduction through improved flow and waste elimination, the concept does not address how the remaining inventory should be managed in warehouses. Though while TPS and Lean Production both have spread throughout industries worldwide, it has also spread internally within companies from the shop-floor to service organizations, administrative environments, offices etc. Warehouses have also become subject for lean implementation, and although research is still rather limited, various concepts have been developed through relatively practical research. Some of the concepts and tools suggested to Lean Warehousing are more appropriate for distribution warehouses or warehouses of mass production industries, however, some general concepts relevant for this thesis are presented below.

4.4.1 Waste

The concept of waste elimination can also be applicable in warehouses, as activities that absorb resources without adding value decrease flexibility and speed of material flow (Ackerman 2005, Davies 2007, Sheldon 2008). A major warehouse waste can for example be waiting for parts, material handling equipment, manpower or information. This type of waiting could be pursued eliminated by encouraging better planning of the work day. Another waste is transport, referring to unnecessary movement of material. Obviously some movement is necessary in a warehouse, but material movement due to for example blocked aisles or inventory accessibility, should be kept at a minimum.

Unnecessary movement is a critical waste that occurs when workers need to search for tools that cannot be located or walk long distances to pick items, and can be eliminated by optimizing facility layout through for example zoning. Excess inventory is obviously another essential waste, as it requires additional space and reduces warehouse efficiency. Finally, unnecessary processing occurs when non-value activities are preformed needlessly. Cross-docking can be a mean for eliminating such steps, as items will move straight from receiving to shipping without being putaway, stored or picked. If items are meant for production a comparable manner can be applied by creating temporary buffer storage at the receiving dock where inventory is briefly held before going to the production area.

4.4.2 Standardization

An essential foundation for establishing lean warehouses is standardization of the workplace in order to make it well organized. As stated by Liker (2004), standardization is a prerequisite for implementing improvement, and a well organized workplace can thereby serve as an enabler of implementation of other lean concepts. Standardization can take place through establishment of processes where all employees perform work in the same way. The reduction of variation in the process provides operational stability and work can be evenly distributed based on priority creating a smooth levelled workflow (Davies 2007, Baudin 2004).

4.4.3 Visibility

A key to efficient warehouse operations is having visibility throughout the organization. It is critical to have visibility of what is stored where in the warehouse, as it facilitates operations as order picking. Warehouse visibility can be improved by applying coordinates (preferably three: aisle, column within aisle and level within column) for rack identification that are adequately displayed, by utilizing zone identification for block stacking both by triangular signs above the storage area and properly labelled lines on the floor of staging areas, and by enabling inventory tracking to a well-functioning computer system (Baudin 2004, Sheldon 2008).

4.4.4 The 5S Tool

The most applied concept in Lean Warehousing appears to be the lean tool of 5S. The 5S approach originated in TPS, and is a systematic approach providing a cyclical methodology for achieving the above mentioned concepts of waste elimination, standardization and increased visibility (see figure 11).

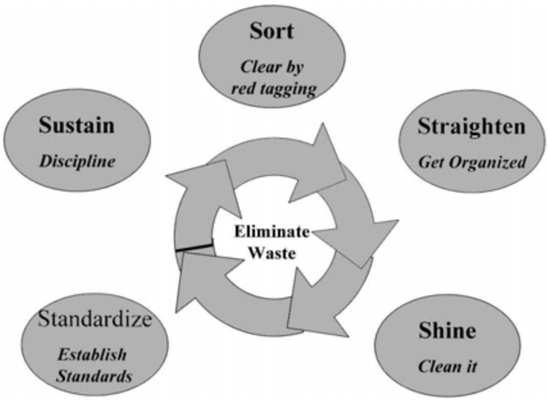

Figure 11: The 5 S's (Liker & Lamb 2002)

A major strength of the tool is the simplicity of the concept and the commonsense approach. It is therefore typically the first lean methodology that an organization puts into effect. The tool promotes employee driven changes and provides a structure for standardization, stability and continuous improvement (DiBarra 2002, Bicheno 2004). 5S encompasses five key words, which all can be adapted to a warehouse setting (Ackerman 2005, Davies 2007, Bartholomew 2008):

- *Sort (Seri):* The initial phase of the 5S approach refers to the process of separating items that are needed from those that are not being used. Unnecessary and obsolete items thereafter need to be removed from the warehouse. The red tag approach can be used as a method for identifying items that are not being utilized. The criteria can vary, but a common rule is to red-tag items not used in the last 6 months. Thereafter the items are moved into an area for disposition where the management has a certain amount of time to evaluate what should be done, before the items are thrown out, sold or donated.

- *Straighten (Seiton):* After removing unnecessary items, the remaining should receive proper locations within the warehouse. A common phrase in this phase is "a place for everything and everything in its place". This does not mean that all items should have dedicated storage location, but that items should be stored according to the most appropriate method for each item. Racking can achieve improved cube utilization, while block stacking can be more appropriate for other items. Additionally, items can be stored according to frequency of use, volume, destination or source, handling characteristics or zones.

- *Shine (Seiketzu):* The third "S" focuses on cleanliness, and ensures that everything stays neat, clean and ready for inspection. In a warehouse, all racking should be fixed to the floor to avoid clutter, locations should be properly labelled to ensure quick and effective orientation and no products should be allowed in the aisles.

- *Standardize (Seiso):* The first three "S"s should enable standardization of best practice in the warehouse. Systems and procedures must be developed in order to maintain and monitor the achievements obtained by the previous steps.

- *Sustain (Shitsuke):* The final and most difficult process is to maintain the new standards and a stabilized workplace. It is a human tendency to return to status quo and old comfort zones, so the definition of a new status quo of warehouse standards and establishment of management system is essential. The objective is to maintain the gains, while simultaneously ensuring a process of continuously improvement.

The first three steps can be carried out at the beginning of a warehouse project in order to fully understand the character and level of inventory, while the last two should occur after the improvement strategy is devised.

4.5 Examples from Best-Practice Warehouses

While gaining insight in own warehouse processes and layout is essential for understanding how the warehouse function can be improved, it can also be useful to benchmark against best-practices. A benchmark is typically a quantitative assessment of some aspect of performance of an enterprise, and benchmarking is the process of gathering and sharing those assessments and developing an improvement plan based on the assessment (Frazelle 2002b).

There are three perspectives of benchmarking: *internal benchmarking*, which focuses on operations within a single company; *external benchmarking*, which looks at firms outside the firms industry; and *competitive benchmarking*, referring to firms conducting business in the same industry. Competitive benchmarking has the advantage of being directly transferable to ones own company, but can obviously be difficult to perform, since competitors in the same industry may not be willing to share sensitive information. External benchmarking across industries can therefore be a helpful strategy.

External benchmarking is particularly valuable when it comes to transferring breakthroughs across industries. Essentially, one might be the leader in ones own industry, but only mediocre in general. This can be illustrated by the previously discussed adaptation of lean methodology in construction and shipbuilding, where these industries became aware of the achievement in manufacturing through Lean Production, studied the gains, and transferred the concept of lean to own industries.

The remaining part of this chapter will be used for description of other warehousing practices both within shipbuilding and other project-based industries. Although the descriptions are not thorough enough to be characterized as benchmarking, the objective is to provide insight into how warehousing is managed in other logistically similar companies, and possibly inspire for more thorough benchmarking at a later point of time.

4.5.1 Shipbuilding Industry: Inventory tracking at STX Norway Offshore Langsten AS

STX Norway Offshore Langsten AS (hereafter referred to as STX) is one of five shipyards in the shipbuilder group STX Norway Offshore ASA (previously Aker Yards ASA), which operates in the same offshore service vessel segment as Ulstein. The shipyard has made use of a logistics system called TagManager for several years, and due to its success the system has recently also been transferred to other Norwegian shipyards within the STX shipbuilding group. This sub-chapter will provide a short description of how the system improves inventory tracking in the shipyard, and the information is taken from Jansen (2007) as well as system brochures from Wise AS, the administrator of the system.

Previously, the SFI system was attempted applied in order to achieve an overview of the component flow, but the system had shortcomings in terms of tracking since different components could have the same SFI-number in differing projects, or within project if one component was replaced by another. TagManager and the web based "tag"-generator TagIt, replaces this system by generating unique "tag"-numbers for each component that enters the shipyard. The tag-number is created for a specific component, and is not used again even if the component is removed from drawings.

The receiving area is situated in a large hall in close proximity to the main entrance. The hall is divided into two parts, with the receiving area in the front, and storage for components that cannot be kept outside in the back. The majority of the deliveries arrive by truck and are unloaded by fork lifts into a marked dedicated part of the receiving area. Warehouse personnel thereafter check the components against the delivery document and approve it. The components are marked with stickers with tag-numbers by the supplier, as these have been communicated along with the purchase order.

Upon arrival, the warehouse personnel enters the tag-number into the TagManager system, the component description and drawing number appear, and the component is registered as arrived. The storage location of the component is thereafter entered. Tools and accessories have fixed storage locations, but storage location of outfitting components is random. These are either stored in the large hall, in one of several smaller indoor storage areas, or in outside areas. Only components that are too large for indoor storage and can handle rough weather conditions are stored outside (about 5%).

The system is closely linked to drawings and enables access to TagManager for all project participators. Thereby, employees in purchasing, engineering, production etc. can choose drawings in TagManager, get the complete component list, and immediately see the inventory status for the component with respect to expected arrival date, when it arrived, where they are located in the warehouse and when and by whom it was withdrawn from the warehouse.

Commonly, the foreman is responsible for communicating withdrawal towards the warehouse, as he has the overview of which components that are going be used in the near future. He generates an order picking list through selecting components in the TagManager, and in addition to technical information about the component, the order outlines which components that are needed, their current storage location, as well as when and to which location it needs to be delivered. The order is sent automatically to the warehouse personnel, which are able to plan withdrawal according to the required date.

When withdrawal approaches, the order picking list is printed and presented for the warehouse employee who is registered as responsible for the particular order in the system. He picks components according to tag-numbers and storage locations, delivers it to the stated location on the order, and he leaves a copy of the order picking list so that workers in production can see which components that are part of the order. Immediately after delivery to the production site, the order is registered as completed and components are automatically marked as withdrawn in TagManager.

The TagManager system enables the shipyard to have a remarkable control of inventory without applying article numbers. The components can be tracked from purchase order, to actual delivery date, receiving at the warehouse, storage location, withdrawal and delivery. The control achieved through the system has also made the implementation of an advanced automated storage system possible, where components can be putaway and retrieved automatically. The shipyard was one of few that were doing well during the crisis in 2003[3]. Although, that may be attributed to several factors, STX claim that the outstanding inventory control most likely is a contributing cause.

4.5.2 Shipbuilding Industry: Inventory tracking at Kleven Verft AS

Kleven Maritime AS (hereafter called Kleven) is another shipbuilder in the maritime cluster, with its two shipyards located in respectively Ulsteinvik and Gursken. As Ulstein and STX, the shipyards mainly produce offshore service vessels. The hulls are subcontracted from low cost countries and delivered to the yards either complete or in blocks, and are thereafter assembled and outfitted.

In order to achieve an improved material flow within the shipyard, Kleven has rearranged the layout and operations in the shipyard warehouse[4]. The warehouse was relocated to a larger hall where all warehouse activities were co-located, and tall lengthy pallet racks were

[3] Article from Teknisk Ukeblad: http://www.tu.no/nyheter/produksjon/article36912.ece (02.05.09)
[4] Article from Kompass: www.klevenmaritime.no/site/img/231/Kompass2007.pdf (20.05.09)

mounted to exploit cubic volume (see picture below). Emphasis was given to proper labelling of aisles and bar code identification of locations in the ERP-system Multiplus.

Picture: Central warehouse with pallet racks

Multiplus allows for computer controlled registration of the material flow within the shipyard from receiving and storage to withdrawal. Thereby, the ERP-system always has information of whether a component has arrived, at which exact locations it is stored, and when it was retrieved from storage[5]. The ERP-control is aided by bar code scanners, and the shipyard has also begun marking expensive and critical components with RFID-chips to improve inventory tracking and location control[6].

The system also enables foremen to generate order picking lists in the ERP-system without difficulty. At retrieval the SFI-number, component number and the quantity withdrawn are automatically registered in the ERP-system either through bar code scanning or RFID-chips, and inventory levels are automatically updated.

4.5.3 Aircraft Industry: Boeing & New Breed Logistics

After facing challenges of parts-supply problems and shortage of workers in 1997, Boeing recognized the need for changing its manufacturing practices. An adaptation of lean principles to the aircraft industry was made through for example utilizing standard parts that could be quickly assembled, developing a new factory layout that mimics moving lines in automotive plant, and by offering fewer customer options (Lunsford 2001).

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[5] Information from Kleven Verft AS: http://www.klevenmaritime.no/site/img/1165/06_-_Sommarinnsyn_04_jul_2008.pdf (20.05.09)
[6] Article from Logistikk & Ledelse: http://www.logistikk-ledelse.no/2007/it/it12-02.htm (02.05.09)

A substantial focus on supplier development supported the lean implementation which developed into the Boeing Production System[7]. The company focuses on long-term strategic relationships with a core supply base of high-performing suppliers, and reduced the number of suppliers with 79% in eight years. The remaining suppliers experienced a shift from strictly being suppliers of raw materials and components for aircraft assembly to assuming greater responsibility. Boeing now outsources whole sub-systems, and it is in the hand of suppliers to improve design[8].

Furthermore, Boeing pushes inventory back onto suppliers, and demands that suppliers produce and deliver components using just-in-time techniques. They have developed an online supply-chain tool called consumption-based ordering, that allows Boeing to share inventory levels with suppliers, and thereby enables establishment of vendor managed inventories where suppliers can assess inventory and ship replenishment when the inventory levels fall below a specified threshold.

Boeing has also decided to make use of a 3PL provider of logistics services supporting the final assembly. Boeing's philosophy is that they will focus on the core skills within the company, i.e. final assembly, integration and testing of airplanes, while other areas are outsourced to experts. Their long-term vision is that the first Boeing employee to be in physical contact with a part should be the mechanic who installs it on the aircraft.

Consequently, traditional warehousing function has been outsourced to New Breed Logistics to eliminate non-manufacturing related storage and labour in Boeing plants[9]. The 3PL company has built facilities in close proximity to the Boeing 787 production site, and provides logistics support to the final assembly through offsite warehousing. New Breed Logistics has applied lean methodology when designing this warehouse in order to support the lean manufacturing strategy at Boeing[10]. The 5S tool has among other been applied in order to improve workplace organization, and has served as a baseline for subsequent improvement processes.

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[7] Article from Boeing: http://www.boeing.com/news/frontiers/archive/2005/march/mainfeature1.html (13.05.09)
[8] Article from Supply Chain Digest: http://www.scdigest.com/assets/newsviews/05-04-21-1.cfm (13.05.09)
[9] Information from New Breed: http://www.newbreed.com/nb_document.jsp?DocumentID=83 (13.05.09)
[10] ASQ publication: http://www.asq.org/2009/02/lean/improving-productivity-lean-six-sigma-warehouse-design.pdf (16.05.09)

New Breed Logistics' warehouse handles operations as receiving, storage and distribution for Boeing's production facilities. Additionally, the warehouse management system provides accurate inventory control and visibility as all products are RFID-based. The improved inventory control and material handling has made the introduction of work package kitting possible at Boeing. The 3PL provider assembles tools and parts for production process into ergonomically designed kits and delivers them to specified locations on a JIT basis.

4.5.4 Construction Industry: London Construction Consolidation Centre

As previously mentioned, construction faces the peculiarity of site production, and limited storage space is available at the work site. Thus, numerous separate and un-scheduled deliveries, along with high inventory levels on site, pose the risk of congestion, which tend to hinder productivity, increase damages to material, in addition to posing a safety threat. When construction projects take place in an urban and densely populated area, there is even less space available in the surroundings and managing material flow becomes a major challenge.

Consolidation centres introduce the use of warehousing in construction in order to manage inventory and provide an efficient flow of materials between the suppliers and the project. A consolidation centre can be viewed as a focal point for material flow which receives materials from suppliers, stores them in a central location, and delivers them to construction sites in required quantities (Mossman 2007). Such a centre can serve several construction projects at the same time, and can also offer additional services as assembly, kitting, consolidation, cross-docking etc.[11]

The London Construction Consolidation Centre (LCCC) is one such facility that serves construction projects in London[12]. Suppliers to construction projects deliver materials to LCCC instead of distributing it directly to the construction site. The quality and condition of materials are inspected thoroughly on arrival in order to detect damages and defects at an early stage. If defects are first discovered at a later stage, they might cause delays in the construction process. Thereafter, the material is logged into the warehouse management

[11] WRAP report: http://www.wrap.org.uk/downloads/MLP_Guidance_Document_v5_Final_Draft_Jacobs_20Dec07.19fb1c1b.4956.pdf (10.05.09)
[12] TFL report: http://www.tfl.gov.uk/assets/downloads/businessandpartners/LCCC-interim-report-may-07.pdf (10.05.09)

system and stored properly until required. Even though the warehousing activities are handled by the centre, the contractors still require just-in-time deliveries from suppliers, and the maximum storage time at LCCC is ten days.

Contractors place daily delivery orders with LCCC based on the production plan for the subsequent day, stating exactly which material is needed, when it is required and where it should be delivered[13]. The materials requested is thereafter assembled into work packages for each task, and are delivered from LCCC to the construction site in consolidated loads within a timeframe of 24 hours. Deliveries take place daily at designated logistics points located as close to the workface as practicable possible, and only according to schedule. Additionally, the operation of so-called "milk rounds" from LCCC facilitates the removal of waste (return, damaged materials, packaging etc.); since it can be transported back on the vehicles return journeys.

Consequently, LCCC is able to function as a buffer for the variable process steps as it enables materials to be delivered to the construction site on a JIT basis. By unloading inbound deliveries and consolidating them into appropriate outbound loads to be delivered upon request, LCCC allow for a reduction of materials stored on site and thereby additionally reduces congestion both at work site and at the gates, and provides a better organized and safer construction site. Furthermore, the overall transport decreases, while certainty of supply, inventory control and visibility increases, and contractors can concentrate on construction tasks instead of being away from their work stations to assist with material handling.

4.6 Summary of Warehouse Management Theory

Whether controlled internally or externally, it is critical to manage the warehouses properly in order to avoid interruptions in production or poor customer service. A substantial amount of contemporary warehouse management theory focuses on analysing isolated well-defined problems. This is however less appropriate for this thesis, and the theory discussed has therefore been centred on basic warehouse operations and the interrelation between these, warehouse design and layout. Since no single warehouse solution fits all, operations, layout and design have to be adjusted to the context surrounding the warehouse, i.e. industry characteristics, production facilities, customer demand, supplier profile etc. Nevertheless, key

[13] FQP Resource Sheet:http://www.tgfqp.co.uk/Images/FQP%20Resource%20Sheet%205.pdf (10.05.09)

initiatives as minimizing inventory levels, reducing handling steps, utilizing floor space and cubic volume, standardizing procedures, ensuring inventory accuracy, storing items according to product characteristics, volume and frequency etc., are applicable in most scenarios.

For a shipyard employing Lean Shipbuilding, it could be interesting to consider the applicability of lean methodology with respect to material flow and warehousing. The lean 5S tool has for example been applied successfully both in warehouses and shipbuilding settings. It could also be constructive to look to other companies for inspiration. Other shipyards in the maritime cluster are a natural source of inspiration as they operate under the same conditions. The measures implemented to improve inventory tracking at STX and Kleven clearly indicates that this is a critical aspect of a high-quality material flow within shipyards. But looking to logistical similar partner in other industries might also be beneficial since valuable ideas can be discovered and adjusted to a shipyard’s specific circumstances. External 3PL warehouses at Boeing and consolidation centres in the construction industry might not be suitable for a shipyard setting. However, the concepts utilized, as for example kitting, JIT deliveries and levelled order picking, might be transferable.

5. CASE FINDINGS

5.1 Shipbuilding at Ulstein Verft

After repairing and rebuilding vessels since the foundation in 1917, Ulstein produced its first newbuilding, a car ferry with yard no. 11, in 1957. Presently, yard no. 284 is being constructed, and the shipyard has an order book that is filled-up until 2011 with three newbuildings in 2009, three newbuildings in 2010 and two scheduled deliveries in 2011 (see appendix IV – order book). The shipyard primarily constructs anchor handling tug supply vessels (AHTS), platform supply vessels (PSV) and specialized and multifunctional vessels.

Following the key trend of outsourcing hull production and primary outfitting to low-cost countries, the steel intensive components of Ulstein's hulls are manufactured primarily in Poland and Ukraine. Thereafter, hulls are towed to the shipyard in Ulsteinvik, where they are placed in the dry dock for further outfitting. When a vessel draws near completion, it is moved to a dock at the seaside, where final outfitting and testing takes place. The shipbuilding at Ulstein involves disciplines as design, engineering, planning, procurement, warehouse and production, and on-going customization and innovation during the construction phase is not uncommon. Additionally, several functional trades (carpentry, piping, electrical installation etc.) participate in the construction process and a wide range of suppliers are involved.

The equipment suppliers are chosen in cooperation between the shipbuilder and the ship owner. When a contract is drawn up, they agree upon a specification of the ship and a maker's list where potential suppliers are listed. Commonly, suppliers of strategic components are determined by the ship owner, while possible suppliers of other components are identified through the maker's list. Thus, although the shipbuilder might communicate preferences in terms of price, relations etc., suppliers will vary between newbuildings according to the ship owner's selection.

The complex process with multiple agent process at Ulstein, require a high level of coordination, and Last Planner System was implemented for yard no. 277 in order to improve production planning and thereby workflow reliability at the shipyard. At Ulstein, Last Planner has four planning levels; *process plan* (a superior plan with milestones for the whole project), *discipline plan* (a more detailed project plan for each discipline), *period plan* (a detailed discipline plan with a time frame of 4-8 weeks, that ensures the preparation of healthy activities) and finally, *weekly plan* (an agreement of which assignments will be finished within the next 1-2 weeks). While project management focuses on process and period plan, a change from top-down to bottom-up decision-making takes place through the weekly plan. The foremen attend Weekly Work Plan (WWP) meetings where they report on deviation from the WWP (PPC in Last Planner), and plan next weeks WWP according to prerequisites for starting work of healthy activities: drawings, material, tools, space, resources and external conditions.

As previously mentioned, shipbuilders have been struggling to achieve the desired results during the building boom due to capacity constraints in terms of supply and labour. Ulstein however, delivered their best year ever with an operating profit of 240,8 million NOK (almost 10%) in 2007 and an estimated profit of 431,1 million NOK in 2008[14], which by far exceeds the financial results of competing shipbuilder. Additionally, all vessels were timely handed over to ship owners. According to Aslesen & Bertelsen (2008), Ulstein can not state explicitly that the Lean Shipbuilding initiative and LPS implementation were main reasons for these results, as other factors can not be excluded from the equation. Nevertheless, indicators such as speed of throughput, signal that LPS might have been a key factor.

With the current turbulent business conditions due to the financial crisis, it becomes even more critical for Ulstein to maintain its strong position in terms of profit and delivery punctuality. Earnings are expected to be reduced in periods of recession; however, a better organization of the logistics system might contribute to less decrease in profit. Moreover, while a crisis definitely creates challenging conditions, it can at the same time provide opportunities for example in terms of better access to qualified labour, more reliable deliveries, increased authority towards suppliers and a workforce motivated to make improvements.

5.2 The Warehouse Function at Ulstein Verft

The warehouse function at Ulstein has a vital role in the shipyard's logistics system. Since advanced offshore service vessels are being built at the shipyard, a large amount of materials,

[14] Article from Skipsrevyen: http://www.skipsrevyen.no/nyheter/28920.html (03.05.09)

components and complex systems needs to be ordered, received, stored and distributed to production. It is crucial for the construction and outfitting progress that the right components are delivered in proper condition at the right place at the right time. Especially in the current demanding times with high activity and pressure on time, cost and resources, it is critical that the warehouse is run efficiently in order to support the production function.

Aslesen (2009) has outlined the flow of material at Ulstein in the figure below. The figure illustrates how engineering specifies components to be purchased, while the purchasing department formally places orders with the suppliers. Items are delivered at the shipyard warehouse when they arrive, are received and registered, and thereafter either sent directly to production or stored in outfitting/tool/accessory warehouse until requested by either the shipyard production department, at outsourced production locations, or by sales to after market.

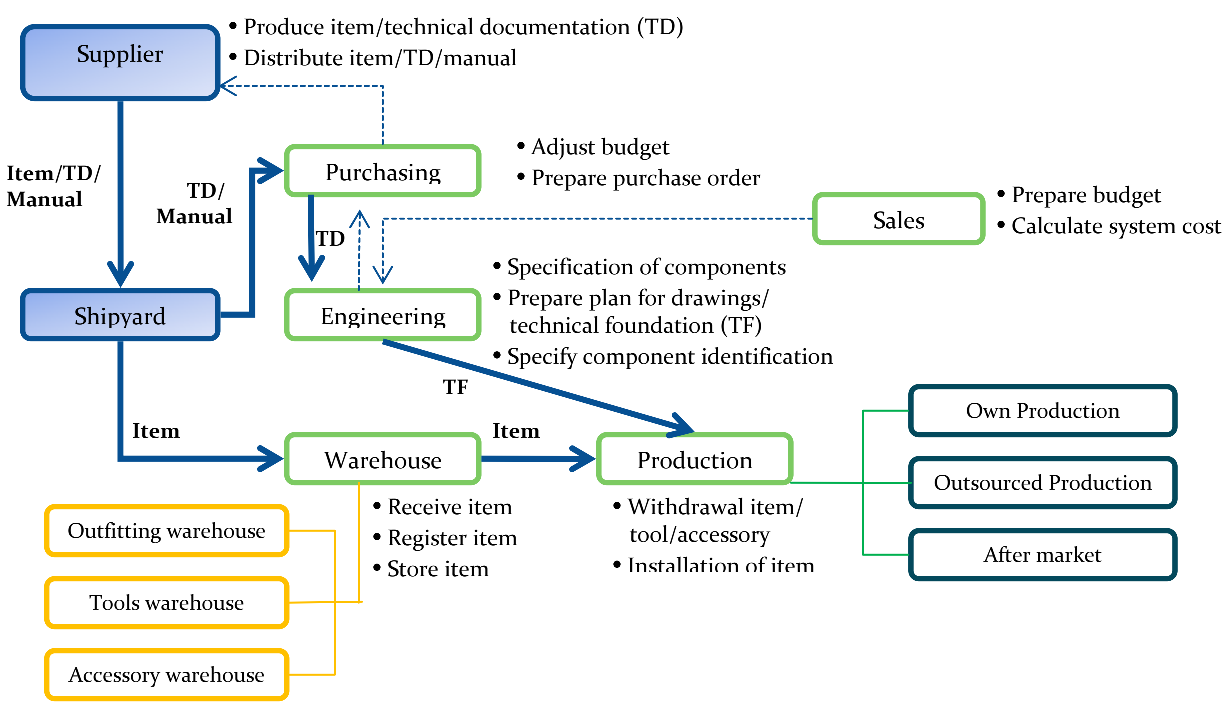

Figure 12: Material Flow at Ulstein Verft (After Aslesen 2009)

The fixed position manufacturing that takes place at the shipyard has major consequences for the warehouse function, since there is only a limited amount of space available within the vessel. Consequently, the warehouse serves as a buffer between suppliers and production since deliveries and production planning are not sufficiently coordinated to adapt JIT-deliveries.

It is essential that production employees can use time efficiently in production instead of picking up, looking for or waiting for equipment. The warehouse thereby serves as a focal point for material flow and should contribute to maintaining an efficient production function. Ulstein’s ultimate vision for the material flow within the shipyard is that required material should be delivered to production workers just-in-time and possibly in the shape of work packages which contains drawings, tools and components for whole work operations.

5.2.1 Warehouse Design and Layout

The warehouse at Ulstein is divided into three departments according to product characteristics: *tools*, which are used in varying production phases and thereafter delivered back to the warehouse; *accessories*, comprising of for example bolts, nuts and smaller standard components; and finally *outfitting components*, which refers to larger project specific and engineer-to-order components.

All storage facilities are situated at the shipyard, and consist of several buildings (see appendix V – map of Ulstein Verft). The central warehouse is situated in the middle of the shipyard between the dry dock and seaside dock, and stores outfitting components, accessories and tools. This is also where receiving and shipping takes place. The central warehouse is designed for a U-flow, where goods both arrive and are shipped from the same area. Tools and accessories are also stored in smaller locations in the dry dock, while outfitting components either are stored in a large hall near the entrance, in a smaller hall on the opposite side of the dry dock, in two seaside warehouse halls or outside.

5.2.2 Warehouse Management System

Along with several other shipbuilders in Norway (Kleven Maritime, Bergen Yards, Fiskarstrand Verft, Fosen Yards), Ulstein employs Multiplus Solutions for management of the shipbuilding process, as well as for the warehouse and logistics. The system is used as a basis for ordering components based on drawings with component lists, and the warehouse complete purchase orders when the items are registered as received.

Opposed to other ERP-systems for inventory management in traditional manufacturing, where all components are coupled with a company's ordinary warehouse, Multiplus is developed to handle project-based production and therefore distinguish ordinary warehouses and project warehouses. According to Multiplus (see appendix VI – Multiplus Warehouse Solution), items are separated into stock goods (items that are bought for/registered in the ordinary warehouse solution, and are transferred and charged to a project upon reservation) and project specific components, which are bought for specific yard no, charged to a project at the purchasing stage, and are registered in the project warehouse solutions. Multiplus offers solutions concerning reservation and withdrawal of warehouse stock, article numbers, and recently also RFID technology, but Ulstein does not make use of these options.

Like most other Norwegian shipbuilders, Ulstein utilizes the SFI group system for newbuildings, a Norwegian system tool for technical and financial information on vessel projects. The system is applied to categorize vessel parts and components according to vessel and system, and is built up as a three digit decimal classification system where sub-groups can be broken further down by digit codes. The SFI system divides the vessel into eight main groups (see appendix VII – SFI group system), and indicates where the component are to be placed within it.

5.2.3 Receiving

As opposed to tools and accessories, outfitting components are already reserved for projects when they arrive at the shipyard, and the cost is charged to the project when the purchase order is sent. Accordingly, there is no stock of outfitting components, and the main task for the warehouse is to store the components until they are required in production. Outfitting components commonly arrive by trucks to the warehouse entrance, which is the receiving area. There is usually no prior information about the arrival of such deliveries, and sometimes they even occur outside warehouse opening hours.

The warehouse is experiencing problems with so-called unofficial receiving outside opening hours. If there is no one present at the warehouse, others might sign for the goods and bring them to a storage area or to production without notifying the warehouse. However, if receiving process proceeds in a sought-after manner, the goods should be unloaded by warehouse personnel, checked according to packing list (100% verification method), approved, received in Multiplus, and thereafter putaway for storage. Ideally, all received items should be thoroughly checked before they are received. That however, sometimes requires technical competence that it cannot be expected that warehouse personnel have. Thus, if such items are not inspected by technical personnel, defects might pass through warehouse processes into production.

The registration of incoming items appears to be a problematic and time-consuming area for the warehouse. Receiving is supposed to take place within two days after arrival, but often takes longer time. Additionally, some items are not properly registered or not registered at all, due to for example unofficial receiving by others than warehouse personnel, the level of technical knowledge required or simply registration mistakes. The interviews reveal that in some occasions items are first received in the ERP-system after departure of the vessel. If posts in the purchase orders are open at departure, warehouse personnel have to assume that the item has been installed in the vessel without passing through the warehouse. The problem with insufficient registration is that it can have serious consequences for the rest of the warehouse process as well as for purchasing, invoicing and production.

As previously mentioned, there are no article numbers in the shipyard system, and outfitting components are marked with yard no., SFI-number, a description of the system that it is part of and the supplier. Some suppliers mark components with information as in the picture below, but there are also several unmarked components which the warehouse labels with handwritten information. Thereby, one has to know the supplier, the SFI-number or the purchase order number to retrieve information from the ERP-system concerning a component.

Picture: Item labelling

5.2.4 Storage

After receiving, outfitting components are putaway in storage in one of six storage locations: central warehouse, hall 1, 2, 3 or 4 or outside. These are also the storage locations registered in Multiplus, and the locations are entered after the items have been received. However, according to warehouse personnel, the locations are often not updated when items are moved. As shown in the pictures below, aisles in the central warehouse are marked with letters for identification, but these locations are however not utilized. If an item is located in the central warehouse, that is the only information obtainable in the ERP-system, and it is not possible to identify aisle, column or column level without either remembering where it is located or spend time looking for it.

Pictures: Central warehouse

The main inventory tracking method is thereby human memory, which puts a lot of responsibility on warehouse personnel when it comes to recalling material movement in order to locate items. This is further complicated by the fact that items often are moved between storage locations several times during storage. Since remembering all storage locations of such a large number of components is impossible, a lot of time is spent searching for items.

The interviews and seminar discussions reveal that there is a considerable focus on the lack of storage space by warehouse personnel. Especially the central warehouse is considered to be too small, due to low ceilings. Components stored in the central warehouse are shown in the below pictures. They are stored in four storage high single-deep pallet racks, and pallets are marked with handwritten technical product information, yard no., SFI-group and sometimes also supplier.

Pictures: Single-deep pallet racks in central warehouse

Storage location is mainly random, where pallets are placed in the nearest available place. Though, it is a formulated strategy to store components that are needed in near future close to the entrance, while components with a longer time frame are stored in the back and moved forward in the warehouse as they are needed in production. However, this strategy is not applied consequently. In fact, in the left picture above, the two pallets to the left at the third level (closest to the receiving area), are items for yard no. 287 which will first arrive at the shipyard next summer.

Storage of outfitting components in the halls primarily takes place through block stacking or floor storage, but there are also a small number of single-deep pallet racks at some of the walls (see pictures below). Components stored in halls, are generally larger than components stored in the central warehouse. There is no labelling of storage space in the halls, and components are simply placed on an available space on the floor.

Components are often placed in front of other components, which create a time consuming situation when several components have to be moved in order to reach the ones standing in the back. Components are also placed in front of the few single-deep pallet racks, which obviously reduce their accessibility significantly. Moreover, the storing facilities are frequently shared with other departments as for example carpentry or maintenance, and the warehouse thereby lacks control of the space at is disposal as other departments also utilize it.

Pictures: Block-stacking in warehouse halls

Presently, there is a quite high level of inventories at the warehouse, which can be traced back to capacity shortage in supply due to high activity. Consequently, purchasers add a significant buffer in terms of delivery time in order to avoid delays in production, and components often arrive long before they are needed. The building boom has made it difficult to make use of JIT-deliveries, and the warehouse is therefore filled up with items that are stored for shorter or longer periods.

While holding inventory buffers in order to protect production from delays seem reasonable in current times, some extreme cases can be found in storage areas. The pallet in the picture below is – as the two pallets in the central warehouse – also for yard no. 287, a hull that arrives next summer. But although the pallet will not be required for a year, it is nevertheless placed right in from of a pallet rack and several components in floor storage, and is consequently blocking accessibility to these.

Pictures: Component for yard no. 287

Another storage space consuming issue in the warehouse is the amount of obsolete material stored. The picture below shows how excess equipment from years ago (yard no. 271 & 277) is kept in storage areas "just-in-case" they can be utilized in future projects. One other example that were both mentioned in the interviews and observed at warehouse visits, is a bathroom interior unit that was supposed to be fitted into a vessel seven years ago. It was however not utilized and is consequently still stored in the warehouse.

Pictures: Pallet with obsolete components

5.2.5 Picking

At the present time, everyone has access to the outfitting warehouse and can withdraw components, but in general, withdrawal is handled by warehouse personnel. However, some level of self-service is unavoidable at the present state, since production employees naturally encompass a technical knowledge about items that warehouse personnel cannot be expected to have.

Withdrawal of tools is registered in the computer system, but withdrawn accessories are always charged to the vessel temporarily situated in the dry dock, even if withdrawn materials are used for the vessel at the seaside dock. Thereby, even if the total amount of withdrawn accessories is correct in the long run, there is no method for obtaining information about what is actually consumed by each vessel.

Outfitting components are charged to the projects at the time of order placement and registered in Multiplus at arrival, but there is no record keeping on withdrawal. Consequently, it is not possible to know whether the component is in storage or has been utilized in production without relying on human memory or manual locating the component. Additionally, interviews indicate that outfitting components are sometimes borrowed from other projects, if there for example is damage to a product or a delayed delivery. As this is not registered in the ERP-system in any manner, problems will occur of the borrowed component is not replace.

There is no steered formal information transfer about forthcoming component requests in production. The warehouse personnel are well informed about production progress due to good informal knowledge obtained through daily interaction at the shipyard. Nevertheless, it is obviously not possible to have detail knowledge of all needed components or the exact time they are required. When a component is needed, production workers address warehouse personnel and enquire it. There is no formal notice in advance and components are usually needed immediately, which apparently has implication for the ability to plan order picking and the work tasks to be completed within the day.

5.2.6 Shipping

Shipping takes place from the same area as receiving operations, and the same dock is utilized for both. The majority of items received at the warehouse are for production purposes. These are distributed to production upon request, but since there also is a substantial amount of self-service, some items are brought to production by production workers. The transport by warehouse personnel mainly occurs by trucks.

There is also a transport department at the shipyards, which have two large vehicles (multi-wheelers) for transporting heavy equipment. Since items can be located at various storage locations, there is a substantial amount of transport between warehouses and production facilities during order picking and delivery of components. As portrayed in the picture below, there are no market transport routes in the shipyard and there are often obstacles hindering transportation.

Picture: Truck obstacles at the shipyard

The warehouse also handles some shipping to external locations. The majority of these shipments concern components to the hull manufacturers in Poland and Ukraine where primary outfitting takes place, but there is also some shipping due to after market sales and guarantees. When sufficient load to the destination in Zaliv (Ukraine) is obtained, whole truckloads can be sent from the warehouse by a fixed carrier. Otherwise components are sent as part loads with various transport companies. Goods for Zaliv are sometimes shipped directly from the supplier, but most deliveries are received at the warehouse before they are shipped to external locations.

Warehouse personnel express concern about the increasing amount of external shipments due to increased focus on after market sales and outsourcing. Some feel that they lack competence to conduct such shipments for example with respect to shipment and customs documents and delivery terms. Additionally, the process of informing the warehouse about such shipments (mainly a task conducted by sales or purchasers) is characterized as disordered.

5.3 Summary of Case Findings

The warehouse at Ulstein is currently serving a shipyard experiencing high activity, and accordingly has to handle large amounts of materials flowing through the shipyard. The high activity level of the building boom has brought along capacity constraints in terms of supply. This has resulted in a considerable use of time buffers with respect to delivery dates, and consequently the necessity for keeping a substantial fraction of arriving items in storage for a longer period of time has also increases. The inventory occupancy is further increased by the high quantity of obsolete items kept in the warehouse.

Although warehouse personnel seem to perform excellent service towards production and are held in high esteem by other departments, findings in the case indicate that they are not able to perform at their utmost under the present warehouse conditions. It appears to be a consistent lack of standardization of procedures and operations, which seem to lead to a somewhat unorganized workplace. Accordingly, there is also little opportunity for planning the work day, as most tasks commonly has high priority and needs to be dealt with straight away, which again causes an unlevelled work flow and poor utilization of warehouse resources.

While the chosen storage system in the warehouse facilities – single-deep pallet racks, block stacking and floor storage – appears to be proper storage methods in a shipyard, they are however not exploited in a manner that achieves maximum utilization of floor space and cubic volume or maximum access to stored items. Furthermore, the random storage system utilized is not matched with the necessary record keeping system required for rapid location and order picking of items. In fact, warehouse performance is generally greatly dependent on the presence and recollection of warehouse personnel, and employees are occupied with matters that an improved warehouse management system could perform, enabling warehouse personnel to use time and resources for other demanding tasks.

Due to the lack of such a suitable warehouse management system, combined with the fact that there are no registered information of withdrawals in the ERP-system, it becomes apparent that there is little accurate information about inventory levels and the tracking history of items. Such information is essential for understanding warehouse processes, maintaining superior inventory control and for being capable of identifying improvement opportunities based on quantitative analysis.

6. CONCLUSION

6.1 Discussion

In this final chapter, the theoretical framework and concepts from warehouse practices in project-based industries will be applied to discuss case findings and possible managerial implications for Ulstein. Warehouse management theory will be adjusted to both the characteristics of Lean Shipbuilding as well as the particular circumstances at the shipyard. Insight into these circumstances was obtained by collecting empirical evidence through interviews, seminar discussions and observations at the shipyard.

Ulstein currently has a warehouse work group that is looking into concrete practical moves that can improve the warehouse function. Thus, recommendations formulated in this chapter will not aim to propose detailed solutions for acquisition and implementation of improvement measures, but will instead seek to provide recommendations of a more general character. The recommendations will be rooted in the theoretical framework and adjusted to empirical findings, and will seek to propose ideas and concepts that Ulstein can prepare further within the frames of the warehouse work group.

As mentioned before, shipbuilding faces the same peculiarity as construction in terms of fixed position layout, but at the same time has the opportunity to build and maintain material flow infrastructure and a warehouse function. The subsequent discussion aims to provide suggestions to how such a warehouse at Ulstein best could be handled. It appears to be a widespread perception by the warehouse personnel that there is too little space available at the warehouse, too few trucks and a workload that exceeds the workforce. It is indeed true that there is little space available in warehouse facilities, that the central warehouse has a quite low ceiling height and that the workload is considerable in building boom times.

However, the following discussion aims to outline how these challenges can be met without investing in larger warehouse facilities, more trucks and additional employees. The chapter proposes that measures to achieve an organized work site, stable and standardized work processes, scheduling of work tasks, improved inventory tracking, fewer handling steps and JIT deliveries, will create a levelled work flow and lower inventory levels. Thereby, the strain on warehouse storage space, material handling equipment and warehouse personnel should also be reduced. If investments in facilities, equipment of personnel are still needed after implementing such improvement measures, it will however be easier to justify investments. In a well-organized warehouse it will be easier to actually trace problems back to capacity constraints, instead on blaming warehouse clutter and poor organization.

6.1.1 Workplace Standardization

According to lean methodology, a well-organized and standardized workplace is a prerequisite for enabling stability and sustainable continuous improvement. A workplace characterized by randomness, variability and untidiness will only hide waste and deteriorate improvements made, since they just create one more variation. Standardization and tidiness can on the other hand provide the foundation and stability needed for identifying, carrying out and sustaining improvements.

At Ulstein there are several indicators of improvement opportunities with respect to organizing the workplace and creating standardized processes. Visibility is for example an important concept in Lean Warehousing, and an area where Ulstein has a great potential for improvement. Satisfactory physical visibility is for example hindered by overfilled warehouses, unstructured placement of components, large amounts of obsolete items, and insufficient labelling of zones, aisles, columns and levels. The visibility in terms of record keeping could also be improved, as there is only information about the arrival of items and less about the further processes, the exact location of the item, or the overall inventory level.

The amount of waste – another core concept in Lean Warehousing – in the warehouse is also sizeable. There is for example a substantial amount of unnecessary worker movement, as warehouse personnel spend a lot of time physically searching for items due to poor location records. The excess inventory due to obsolete materials and too early arrivals is another critical waste. Additionally, since warehouse personnel are occupied with managing the material flow in a challenging warehouse setting, the waste of unused employee creativity occurs. This waste could be hindered by allowing employees to work in a standardized and stable work site where they are able to use their capabilities in continuous improvement processes, as apposed to having to use all resources to deal with so-called fire fighting tasks.

Consequently, improved organization and increased standardization will be essential for enabling improvements at Ulstein's warehouse. The 5S tool has been applied in several warehouse settings, and could also be helpful for enabling improvements at Ulstein. The tool provides a foundation for standardization and enables continuous improvement through creating a well-organized workplace where improvement opportunities become more visible. Furthermore, there could also be a potential for applying 5S outside the warehouse if successful, as good results have been reported from Lean Shipbuilding in US and Japanese shipyards.

Sort

As there are several obsolete items in the warehouse which occupy valuable storage space, a primary 5S initiative could be to separate items for future projects from the remaining items of past projects (for example by a red tagging technique). Items that probably will not be utilized should be removed, either by disposal, sale or donation. If there are remaining items that might be used in future projects, the availability of these needs to be communicated throughout the organization (through for example the ERP-system), and it would be beneficial to place them in a dedicated area for left over material, which does not interrupt with the material flow of non-obsolete items.

Straighten

After an extensive clearing process at the shipyard, where unnecessary items are removed, the remaining items need to be stored in the most appropriate manner. In order to maximize utilization of floor and cubic volume, it is generally recommended to run storage racking parallel to the long axis of the building, along all interior walls and also make use of over-aisle storage. Ulstein has single-deep pallet racks in the central warehouse, and at some of the interior walls in the halls, but there is a great potential for improved cube utilization by adding such racks at all warehouse interior walls.

Furthermore, block stacking and floor storage is currently utilized for some components, but in a rather chaotic manner since components are placed at the first available floor space. Consequently, a large amount of unnecessary material movement takes place in order to collect inaccessible items. Marking block stacking and floor storage areas, either by floor labelling or physical dividers, could enable improved storage organization. It will then be essential to position such areas in a manner that allows for space between pallet racks and components stored on the floor, and also between different components on the floor, in order to maximize accessibility for order pickers and trucks. Such solutions will need to be flexible, since the amount and characteristics of outfitting components in storage vary between projects and production phases. Thus, zone identification through floor labelling and signs can be beneficial, while portable physical dividers can provide flexible structures within zones.

Another aspect of the straightening process is to arrange storing locations in an appropriate manner. Tools and accessories are currently stored at dedicated locations, which appear reasonable due to the stable demand and known characteristics. In the outfitting warehouse the situation is different since the level and characteristics of materials are project and phase dependent. Consequently, a random storage strategy seems more suitable. However, some zoning (for example with respect to yard no., SFI, product characteristics) in the warehouse could be advantageous in order to make order picking more efficient. Nevertheless, maximized space utilization – especially in project-based production where inventory vary periodically more than in mass production – takes place when items are randomly stored in available locations.

Though at the present stage, Ulstein does not have the necessary location specifications to support an efficient random storage strategy and a lot of time is spent searching for components when required, which is clearly a waste according to lean theory. Five storage locations in the ERP-system are too few to locate components quickly, so after installing pallet racks and organizing block stacking and floor storage in zones, it will be critical to provide proper labelling of these, in addition to establishing new locations for them in Multiplus.

Shine

Once storage is organized in the suitable modes, it will be important to ensure tidiness through what might seem as rather obvious actions as for example keeping warehouse facilities clean and ensuring proper lightning. Visibility, another key concept in lean theory, is an additional feature of this process, as it will enable rapid orientation within warehouse facilities. Pallet racks should be accurately labelled (preferably with three coordinates: aisle, column within aisle and level within column) in order to improve physical visibility, while floor storage areas requires signs above zones, as well as painted lines or physical dividers on the floor level. However, visibility can also be achieved through improved record keeping and tracking of inventory in the ERP-system.

Standardize

The previous steps should have permitted for a reduction in the level of inventory and an enhanced storage manner for the remaining items, and processes and procedures should consequently be developed in order to maintain these improvements. In order to achieve lasting improvements, it could for example be valuable to establish formal work task procedures for how operations are handled, and thereby ensure that everyone is performing work in the same manner. Accordingly, it will also be easier to analyze deviations and conduct root cause analysis according to lean theory.

However, in order to standardize processes for further improvements, it is essential that only warehouse personnel handle warehouse processes. Presently, there are no limitations with respect to withdrawal of items from the warehouse, and items are also sometimes received by other personnel, when deliveries arrive outside warehouse opening hours. Additionally, several other departments (carpentry, maintenance etc.) and suppliers utilize warehouse space.

While both withdrawal and warehouse space utilization might be necessary to a certain extent, it would be beneficial to have clearly communicated standards on the matter. It is necessary to specify when and how others than warehouse personnel should have the opportunity to perform warehouse operations. Similarly, if warehouse space is occupied by other department, it needs to be clearly specified – and possibly also physically marked – which areas that are at their disposal. Otherwise it becomes quite difficult for warehouse personnel to pursue a best-practice warehouse, as this requires a certain amount of decision-making authority and control of both processes and facilities within the warehouse.

Sustain

After organizing and developing standards and stability in both processes and warehouse facilities, the key is to maintain achievements and use them as foundation for further continuous improvement. The lean bottom-up approach focuses on employee empowerment, thus warehouse personnel involvement is a key factor to achieving this and monthly *kaizen* gatherings might be a valuable element.

6.1.2 Work Task Scheduling

An aspect that is critical for maximum utilization of warehouse resources, both in terms of personnel and equipment, is the ability to plan for work tasks. Processes as receiving, order picking, in-house transportation and shipping are quite resource demanding. Consequently, these activities need to be planned in advance in order to achieve stability and to avoid what lean methodology refers to as the waste of waiting in situations where the demand on resources is higher than the availability.

In Ulstein's case, the possibility for planning of the work day seems limited, as there is little steered information about future production requests, inbound and outbound transportation. Consequently, production workers and external trucks arrive without notification, and warehouse personnel might be interrupted in their work as these tasks have high priority. This, in addition to queuing due to arrival of numerous trucks or production orders, hinders a smooth levelled workload throughout the work day as encouraged in lean theory. The receiving operation is for example pinpointed as an activity that is given less priority due to time shortage. When the receiving processes is constantly interrupted and warehouse personnel have to give other tasks priority, the consequence is an uneven workflow where items are staged in the receiving area and stay unregistered for several days.

One alternative is to attempt to schedule inbound and outbound transportation for the shipyard, and thereby facilitate enhanced planning of loading and unloading, a strategy observed among others in LCCC & New Breed. Even though complete scheduling of external transport is not a realistic scenario at Ulstein, it might be possible to have some suppliers send information about shipments in advance (which will obviously also make receiving easier, as warehouse personnel know what is going to arrive in advance). Also, transport providers could notify of arrival time for trucks, especially when the load arriving requires considerable warehouse resources for unloading.

Evidently, early notifications of withdrawals from the warehouse would also facilitate planning of workforce and equipment. In the warehouse at STX, Kleven, New Breed and LCCC, planning for withdrawal of items is necessary to ensure efficient order picking and timely delivery of orders. Material requests are preferably communicated through an ERP-system with belonging information on item characteristics, storage location, delivery destination and time. At STX foremen communicate such information when notifying about material requirements electronically, and planning for order picking with respect to batching and allocation of warehouse resources is thereby facilitated.

At the warehouse at Ulstein, the warehouse personnel hold good informal knowledge of the production progress, but there is no steered information regarding material requirements. Consequently, when production addresses the warehouse (usually in person) regarding material requests, the material is needed within a short time frame. A formal and closer coupling with LPS and the WWP meetings could perhaps be beneficial with respect to work task planning. As the WWP outlines "healthy" activities to be finished within 1-2 weeks, and materials is one of the prerequisites for such assignments, it ought to be possible to communicate the material requirements for the upcoming week through these meetings.

With more information about upcoming material requests, the warehouse would be able to plan the impending withdrawals better with respect to personnel and equipment and thereby generate a more levelled workflow encouraged in lean theory. Advance information about withdrawals could also enable more efficient order picking through batching or zoning, improved organization of transport of orders to production (for example by making use of the shipyard's transport department), as well as improved storage allocation, if the withdrawal date of an item is known at the receiving time.

First-rate advance knowledge of material requirements is also a prerequisite for introducing kitting of work packages, as applied by LCCC and Boeing. Kitting has proved to be an efficient logistics strategy for overcoming challenges in fixed position manufacturing, since only material necessary to complete a task is stored within the vessel/aircraft/building. Moreover, it enables skilled craftsmen to use their skills for core tasks the majority of the time, instead of worrying about lack of components and having to wait, look for, pick up and move materials. However, in order to implement such solutions, a warehouse needs to have excellent routines for withdrawal notifications.

6.1.3 Inventory tracking

At the present state, the warehouse function does not have accurate information about the inventory level within its facilities. The only inventory record registration in the ERP-system, takes place at arrival when items are registered according to the purchase order in Multiplus. There is however no registration upon withdrawal of items. Consequently, there is no information of when items were withdrawn, by whom and which other items were withdrawn in the same order, and it is therefore not possible to portray any trends with respect to inventory level, turnaround time, item complementarity etc. From a lean waste perspective this is also dramatic, since the lack of inventory visibility will lead to a substantial amount of time spent on physically searching for items due to the lack of electronic tracking information.

The lack of available information on inventory levels and movement, limits the extent to which warehouse decisions can be identified and justified from a quantitative perspective. Additionally, there is less possibility of lean root cause analysis in case of deviations, since there is no opportunity for tracking inventory. From a warehouse management perspective, such information is critical for controlling and managing a warehouse in the best manner possible, and the warehouse examples from other shipyards show that it is a matter taken seriously in shipbuilding. The practice observed at STX is a good example of how first-class inventory control is achieved through widespread inventory tracking. At Kleven there has also been made substantial investments in order to capture and track inventory movement throughout the shipyard.

In order to achieve improved inventory accuracy and opportunities for tracking, it will be necessary to make better use of the ERP-system. There have been discussions of implementing article numbers at Ulstein; however this might not be an appropriate solution for outfitting components. Tools and accessories which are standard inventory held items with known characteristics and a stable demand, might gain from such a solution. It would for example be possible to make use of Multiplus features for automatic order replenishment through minimum and maximum levels. Outfitting components will however vary considerably between projects, due to vessels' one-of-a-kind nature. The constantly changing product assortment would make administration of article numbers a rather resource demanding activity.

It could therefore be more beneficial to look at the solutions at the two shipyards described earlier, where STX generates unique "tag"-numbers for all outfitting components and link them to SFI-numbers and system drawings, while Kleven utilizes bar code and RFID technology linked to SFI-numbers to keep track of outfitting components.

Both of the above are expensive solutions which are probably best evaluated after initial improvements have taken place. However, a better utilization of the already acquired Multiplus ERP-system could provide quick low-cost solutions that address some of the current inventory tracking issues. The information obtained in appendix VI indicates that there are possibilities for registration of component withdrawal, component transfer between projects (borrowing), as well as component return from projects. In a longer time perspective, component labelling solutions could be a valuable improvement opportunity, as it would both improve tracking opportunities and facilitate a more efficient receiving process.

6.1.4 Inventory Handling Steps

An essential feature of lean theory is the minimization of non value-adding activities in order to shorten lead time, as opposed to focusing on optimization of value-adding activities as traditional manufacturing tends to do. This type of reasoning can also be transferred to a warehouse setting. Consequently, instead of optimizing warehouse operations, one should attempt to organize activities and layout in a manner that reduce the number of non value-adding warehouse activities. This initiative can also be found in warehouse management theory through the touch analysis. Since the amount of handlings are considered to be proportional to the likelihood of damage and increase of time and cost, the objective of the touch analysis is to minimize the amount of material handling.

Direct shipments should be pursued in case of shipments to external locations, while avoiding handling steps as putaway transport, storage and order picking is an alternative strategy for components for own production. Cross-docking is less feasible in the current shipyard situation due to incorporated delivery time buffers; however, temporary storage areas might be beneficial if improved formal information about production progress is achieved. Thereby, items that are needed in production within short time could be placed in a temporary staging area in order to hinder unnecessary warehouse processing.

6.1.5 Inventory Level

While lean theory suggests that all excess inventory is waste and should be eliminated, warehouse management theory state that productivity and safety is dramatically reduced if warehouses are occupied with more than 85-90%. At Ulstein, it is not possible to estimate the exact level of inventory due to the lack of withdrawal routines at the warehouse and the amount of unregistered obsolete material stored. However, visual estimates point towards a rather full warehouse as items are stored at staging areas, in outside locations, and in front of pallet racks or other components.

The red-tagging method suggested in the 5S tool is one method of reducing inventory occupancy, as it removes obsolete items from the warehouses. Another approach is to improve cube utilization by letting pallet racks exploit high ceiling, and thereby reduce the occupancy by adding more storage space.

There might also be potential for decreasing occupancy by pushing inventory backwards in the supply chain and encouraging JIT deliveries from suppliers. This has not been possible in practice in the recent years, due to extensive shortage in supply. However, the current financial crisis and recession can contribute to a shift in power between shipyards and equipment suppliers, as there will be less strain due to reduced activity. Thus, there might be potential for reducing both inventory levels and handling steps by pursuing more JIT deliveries.

Whether JIT deliveries are feasible or not, the observations made at Ulstein’s warehouse facilities show that some components have arrived alarmingly early. Therefore, it will be critical to have a close communication with purchasing, which sets delivery dates and follows up shipments. While some early deliveries might be necessary to ensure timely arrival, the turnaround time in the warehouse should generally be as short as possible, especially with respect to large and space demanding components.

6.2 Managerial Implications

When comparing Lean Shipbuilding theory and aspects from Warehouse Management with the current situation at Ulstein’s warehouse, the contrast to best-practice warehousing outlined in the theoretical framework and practical examples from project-based industry becomes apparent. While warehouse personnel are held in high esteem at the shipyard due to their competence and drive, empirical findings indicate that personnel are not able to perform at their utmost in the current challenging warehouse conditions. The gained knowledge from the theoretical review chapters points towards various concepts that can meet these challenges.

These have been elaborated in the discussion part of this chapter, and the recommendations on potential improvement opportunities are summarized below.

The first recommendation is to organize the workplace in order to create standardized and stable processes in the warehouse. This could be achieved through the 5S tool by:

- Eliminating unnecessary and obsolete items by the red-tagging method
- Installing additional pallet racks to maximize cube utilization
- Organizing more systematic block stacking and floor storage
- Improving visualization by applying labelling and signs
- Creating more storage locations in Multiplus to support random storage within zones,
- Producing standardized procedures in order to stabilize and sustain improvement achieved and facilitate further continuous improvement.

Thereafter, a levelled workflow of warehouse processes should be pursued to accomplish better planning of work tasks and resource allocation. This requires an improved information flow regarding inbound/outbound transports and production progress. The later could be attempted achieved by coupling LPS and WWP meetings to material demand and communicating this to the warehouse well in advance of withdrawal.

Subsequently, implementing withdrawal routines to achieve improved inventory tracking, minimizing the necessary handling steps and eliminating excess inventory should be pursued in order to achieve a smooth material flow coupled with high inventory accuracy. Such initiatives should contribute to release space in the warehouse facilities, facilitate a smoother flow and allocation of warehouse resources, serve as an enabler for continuous improvement, and ultimately, perhaps contribute to reaching Ulstein’s long term vision of delivering material to the work site in terms of JIT deliveries of kitted work packages.

Change can however be difficult to implement since the majority of people can be characterized as change averse. Change is not a natural state for most people and only a minority finds it exiting and vitalizing. A crisis can however facilitate implementation of new measures, since it can be easier to achieve a joint understanding for the necessity of changing in order to survive. Consequently, the current financial crisis and recession troubling the shipbuilding industry can trigger the necessary support for implementation of principles and improvements, and provide an ideal timing for putting changes concerning warehouse management into practice. As with previous introductions of lean tools and techniques at Ulstein Verft AS, it will be essential to ensure bottom-up implementation where warehouse personnel are significantly involved in decision-making.

6.3 Further Research

During the work with this thesis, several areas have outlined themselves as interesting topics for further research. These are typically topics that are briefly described in the thesis, but are not elaborated further due to relevance to the thesis.

First of all, it would be interesting to investigate inventory management and warehouse management processes with more quantitative methods. Presently, the information available is neither sizeable enough nor accurate enough to be utilized for quantitative analysis. Since there is no accurate information on inventory level, on turnaround time or on withdrawal, the possibility of conducting such analysis are limited. If the current focus on the warehouse function introduces measures that contribute to better inventory tracking and information, it could enable optimization of processes through for example ABC analysis, order picking testing, calculations on batching etc.

Another topic for further research is the agile/leagile concept, which has been proposed as an extension of Lean Shipbuilding. This thesis has only described this concept in brief; however, it could be of interest to study the implications that a continuation towards agility/leagility would have for the material flow and the warehouse function. As the concept of agility refers to using market knowledge and responsiveness of supply chain networks to operate in volatile markets, one could also explore further how the maritime cluster, its advantages and the supply chain could be drawn in to enhance an improved material flow. This thesis has, upon request from Ulstein, primarily focused on the material flow within the shipyard, but including the cluster and the supply chain in future studies, could enable improvements in the material flow from point of origin to point of consumption, which again could facilitate lower inventory levels within the shipyard.

Additionally, it could be interesting to conduct further benchmarking, whether it is competitive benchmarking towards other shipyards or external benchmarking towards logistical similar partners. Ideas from external benchmarking can be valuable, but has to be adapted to fit shipbuilding conditions. In competitive benchmarking on the other hand, ideas are directly transferable. Commonly, competitive benchmarking can be difficult to carry out due to sensitivity of information between competing companies. Ulstein however, is a major contributor in the maritime cluster and a participant in the Lean Shipbuilding program, which might facilitate the application of competitive benchmarking with for example company visits and exchange of information with other shipyards within the program.

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APPENDIX I: INTERVIEW GUIDE FOR FAFO/MØREFORSKNING

The following questions were the basis for interview conducted with 12 persons (3 in production management, 2 purchasers and 7 working in the warehouse facilities) at Ulstein Verft by FAFO & Møreforskning in December 2008 (Aslesen 2009):

- Which functions are accomplished by the warehouse?
- Which structures (physical, organizational, technological) are built around these functions?
- Which procedures are followed by the warehouse in relation to receiving, registration, categorization, storage placement of goods, and distribution of materials towards production?
- What are typical bottlenecks that occur in the process of handling, storing and distributing material, and why do they occur?
- How is the warehouse function coordinated towards other functions at the shipyard, with respect to planning, organization, coordination and management of projects?
- Which procedures are followed by the warehouse when it comes to detection, registration and communication of deviation in material deliveries?
- Have there been changes within shipbuilding that also have changed the requirements regarding managing material and inventory. If so, what are these changes, and too which extent are they reflected in the shipyard's present warehouse function?

APPENDIX II: INTERVIEW GUIDE FOR VISIT AT ULSTEIN

The below questions were guidelines for the visit at Ulstein Verft and interviews with key warehouse personnel there (mainly logistics manager Rolf Heltne,, but also shorter dialogue with other employees at the warehouse). The guide was meant as an outline of aspects that I wanted to address, but obviously several other aspects came up during the interviews and were also discussed.

General

- How is the Multiplus module for warehouse structured (inventory level, registration of material flow, replenishment)?
- Are article numbers utilized at the warehouse? If not, how are items identified?
- Is there any formal planning of the work day in advance?
- How many trucks/other transport units are available at the warehouse?

Inbound/outbound transportation

- Is there any scheduling with respect to arriving trucks?
- Is there information available concerning which deliveries that will take place on the present day?

Receiving

- Who conducts receiving at the shipyard (dedicated warehouse personnel, all warehouse personnel, production workers)?
- How is the received items registered in the ERP-system?
- Are there any routines for deciding how thoroughly a delivery is checked at the receiving stage (dependent on supplier, product characteristics)?

Storage

- Which storage locations are utilized in the ERP-system?
- How is the storage location for an item decided after it has been received?
- Are there any elements of dedicated storage, random storage or zoning in the present warehouse layout?
- Are items moved around within the warehouse after being placed at the first storage location?

Picking

- How is material requirements communicated from the production function?
- Which timeframe is given with respect to completion of order picking after an equest for materials is communicated from production?
- Who conducts production order picking (dedicated warehouse personnel, all warehouse personnel, production workers)?
- Is order picking planned or coordinated in any manner?
- How is withdrawal of material registered in the ERP-system?
- How is material requirements for external shipping (to outsourcing locations or after market) communicated and by whom?

Shipping

- How after market handled in the warehouse?
- Do components for external outsourcing locations come by the warehouse before shipments? If so, how are they handled?
- Which transport solutions are chosen for shipments?

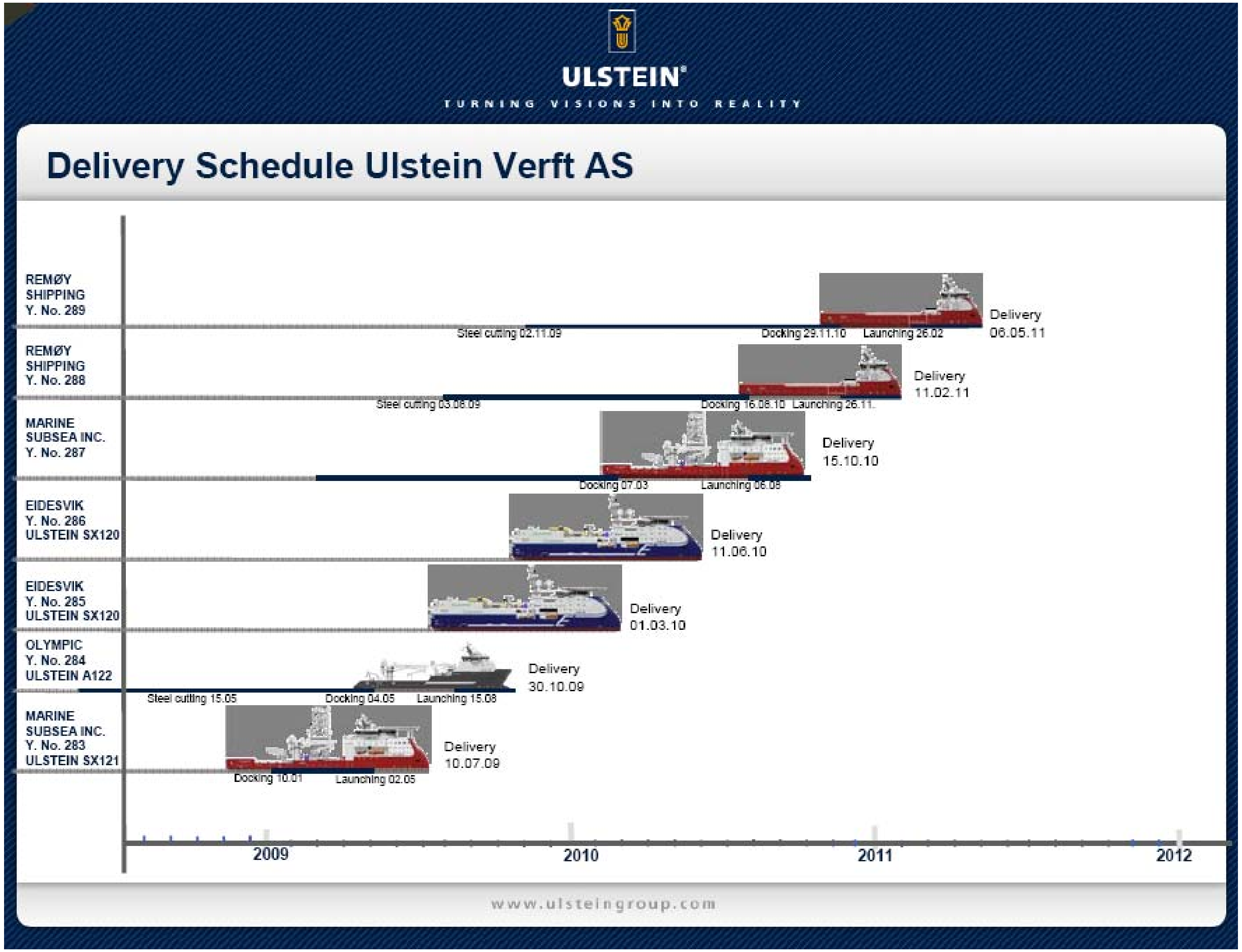
APPENDIX III: EXTRACT OF ARCHIVAL RECORDS

Extract from SFI-group 874 and 875 for yard no. 279 (in total 4288 order lines):

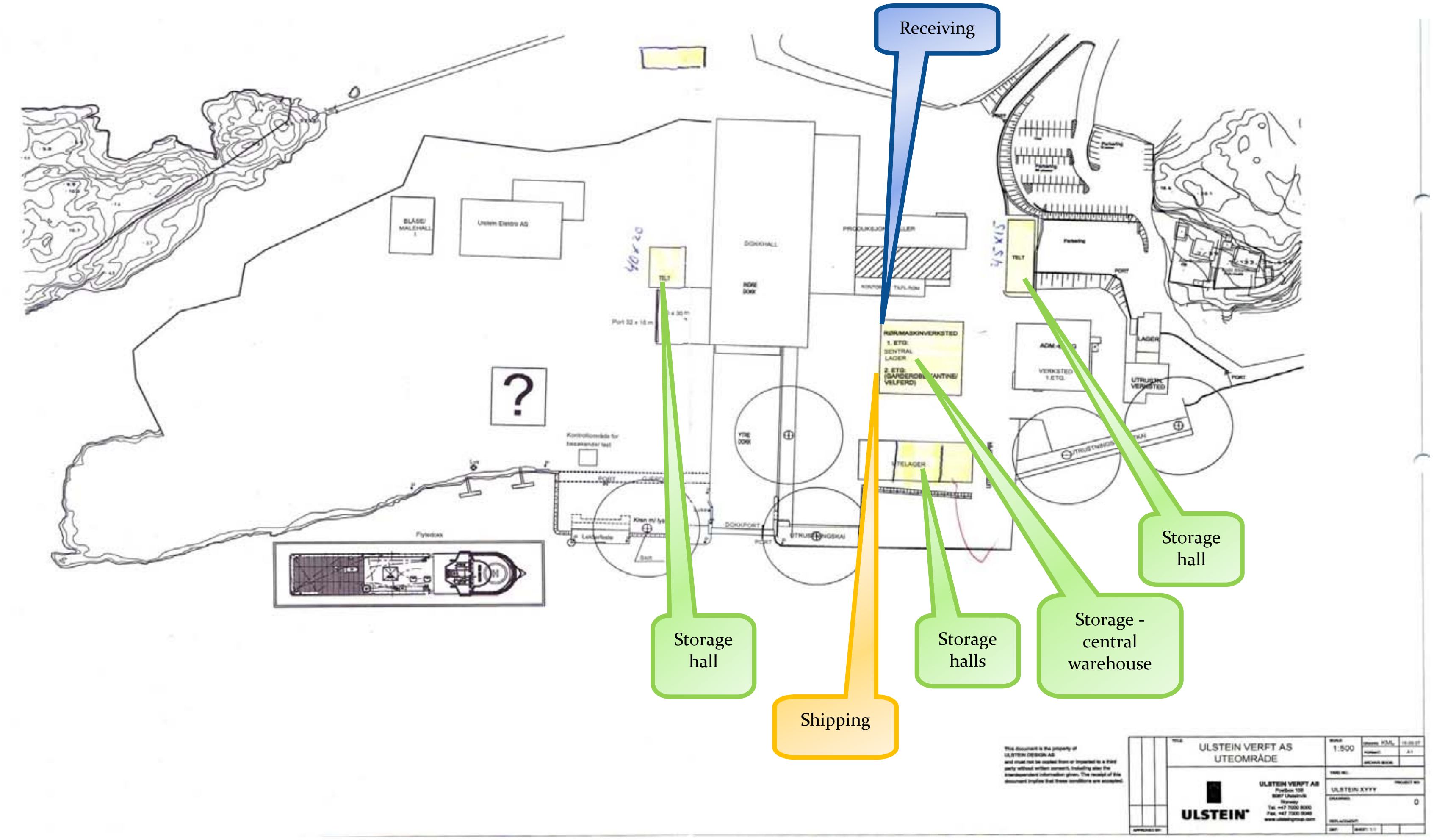
Søk på bestillingslinjer											
Prosjekt	Aktivitet	Best.nr.	Linje	Status	Leverandør	Antall	Enhet	Betegnelse	Verdi	Lev.dato	Innkjøper
10279	874005	78331	10	Sluttlevert	NATIONAL OILWELL	1	PC	SOFT STARTER OFFSHORE CRANE	0	25.02.2008	I3
10279	874005	78662	35	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 1 LO PUMP MAIN AZIMUTH	0	14.12.2007	I3
10279	874005	78662	36	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 2 LO PUMP MAIN AZIMUTH	0	14.12.2007	I3
10279	874005	78662	37	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 1 LO PUMP MAIN AZIMUTH	0	14.12.2007	I3
10279	874005	78662	38	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 2 LO PUMP MAIN AZIMUTH	0	14.12.2007	I3
10279	874005	78662	39	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 1 SERVO PUMP MAIN	0	14.12.2007	I3
10279	874005	78662	40	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 2 SERVO PUMP MAIN	0	14.12.2007	I3
10279	874005	78662	41	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 1 SERVO PUMP MAIN	0	14.12.2007	I3
10279	874005	78662	42	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STARTER 2 SERVO PUMP MAIN	0	14.12.2007	I3
10279	874005	78712	3	Sluttlevert	HOPPE	1	PC	STARTER FOR ANTI - HEELING	0	29.08.2007	I3
10279	874005	78712	4	Sluttlevert	HOPPE	1	PC	STARTER FOR ANTI - HEELING	0	29.08.2007	I3
10279	874005	78773	4	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER TURNING GEAR MAIN ENG.	0	01.11.2007	I3
10279	874005	78773	26	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER FW PREHEATER PUMP NO.2	0	01.11.2007	I3
10279	874005	78773	27	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER FW PREHEATER PUMP NO.3	0	01.11.2007	I3
10279	874005	78773	40	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER LO PRIMING PUMP ME 2	0	01.05.2007	I3
10279	874005	78773	41	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER LO PRIMING PUMP ME 3	0	01.05.2007	I3
10279	874005	78773	80	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER FW PREHEATER PUMP NO.1	0	01.11.2007	I3
10279	874005	78773	81	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER FW PREHEATER PUMP NO.4	0	01.11.2007	I3
10279	874005	78773	92	Sluttlevert	ROLLS-ROYCE BERGEN	1	PC	STARTER LO PRIMING PUMP M.E. 1	0	01.05.2007	I3
10279	874005	78773	93	Sluttlevert	ROLLS-ROYCE	1	PC	STARTER LO PRIMING	0	01.05.2007	I3

					BERGEN			PUMP M.E. 4			
10279	874005	78985	1	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSOMFORMER - FW CARGO	33594	07.08.2007	TA
10279	874005	78985	3	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - BRINE PUMP	33594	07.08.2007	TA
10279	874005	78985	4	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - FW PUMP	33594	07.08.2007	TA
10279	874005	78985	5	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - FW PUMP	33594	07.08.2007	TA
10279	874005	78985	6	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - F0 CARGO	33594	07.08.2007	TA
10279	874005	78985	7	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - F0 CARGO	29887	07.08.2007	TA
10279	874005	78985	8	Sluttlev. og fakt.godkj.	DANFOSS AS	1	PC	FREKVENSONFORMER - MUD DISCH.	33594	07.08.2007	TA
10279	874005	79198	68	Sluttlevert	AERON MILJØTEKNIKK	1	PC	FREQUENCY CONVERTER	0	28.09.2007	TA
10279	874005	79198	71	Sluttlevert	AERON MILJØTEKNIKK	1	PC	FREQUENCY CONVERTER	0	28.09.2007	TA
10279	874005	79518	3	Sluttlev. og fakt.godkj.	ALFA LAVAL NORDIC AS	1	PC	STARTER SW PUMP FOR FW GEN.	0	05.10.2007	I3
10279	874005	79658	5	Sluttlev. og fakt.godkj.	HYDRO MARINE ALUMINI	1	PC	FELLES STYRING, FOR MONTERING	0	07.11.2007	I6
10279	874010	78662	43	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STEERING GEAR FREQUENCY	0	14.12.2007	I3
10279	874010	78662	44	Sluttlevert	ROLLS-ROYCE ULSTEINV	1	PC	STEERING GEAR FREQUENCY	0	14.12.2007	I3
10279	875010	79328	1	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC10 - 24 V WHEELH. PS	37600	13.09.2007	TA
10279	875010	79328	2	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC20 - 24 V WHEELH. SB	37600	13.09.2007	TA
10279	875010	79328	3	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC30 - 24 V ENG. RM PS	37600	13.09.2007	TA
10279	875010	79328	4	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC40 - 24 V ENG.RM. SB	37600	13.09.2007	TA
10279	875010	79328	5	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC50 - 24 V EMERG. GEN.	33400	13.09.2007	TA
10279	875010	79328	10	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	PC	DISTR. DC60 - 24 V AUX. GEN.	32600	13.09.2007	TA
10279	875901	79328	6	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	4	SET	TECHN. DOC. - DISTR. SYSTEM	0	28.02.2007	TA
10279	875907	79328	8	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	4	SET	INSTR.BOOKS - DISTR. SYSTEM	0	25.04.2008	TA
10279	875908	79328	9	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	4	SET	CERTIFICATE - DISTR. SYSTEM	0	25.04.2008	TA
10279	875909	79328	7	Sluttlev. og fakt.godkj.	ANDA-OLSEN AS	1	SET	GREEN PASSPORT	0	15.03.2008	TA

APPENDIX IV: ORDER BOOK



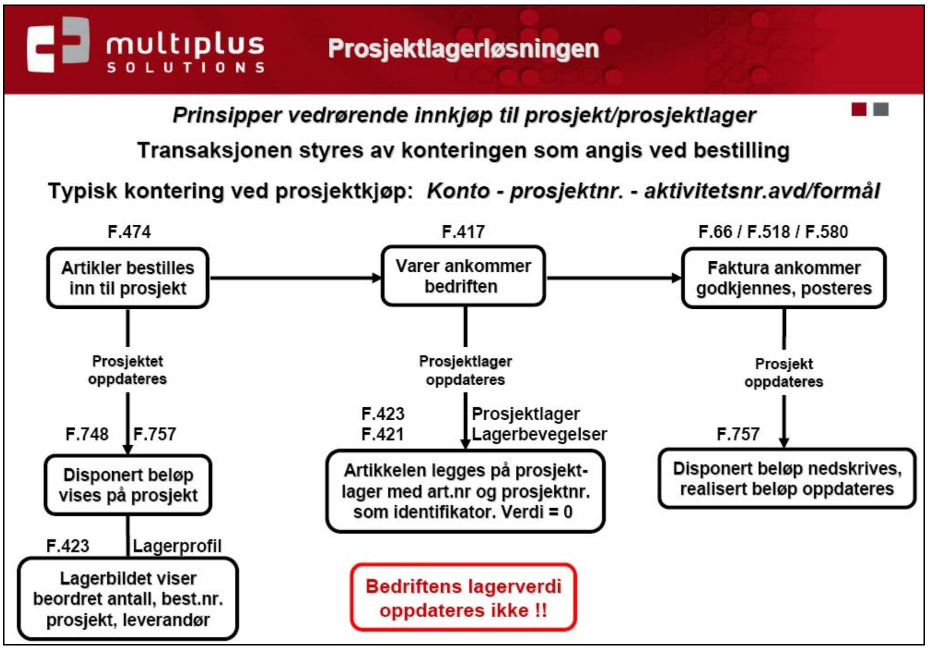
APPENDIX V: MAP OF ULSTEIN VERFT

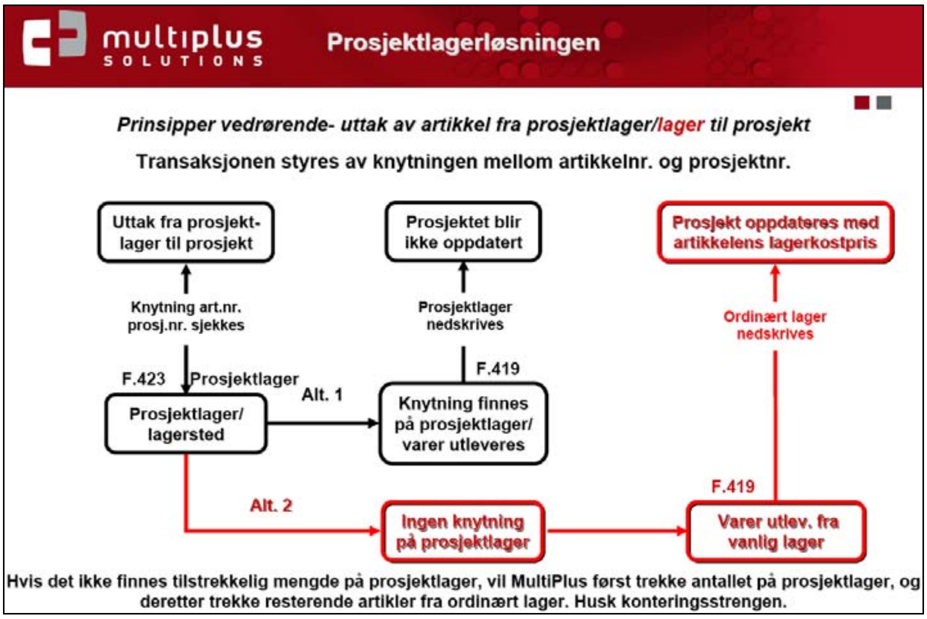


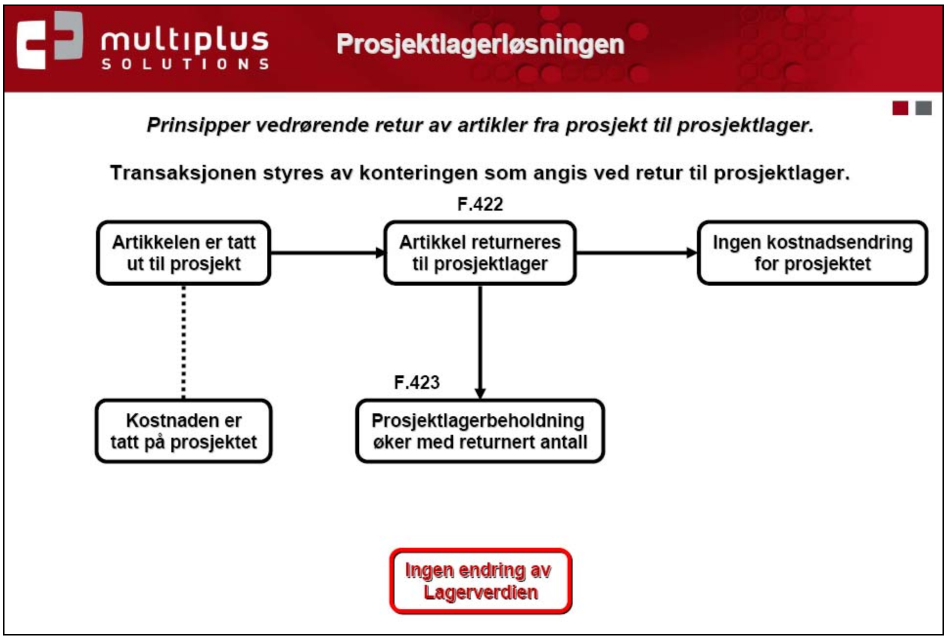
After Aslesen (2009)

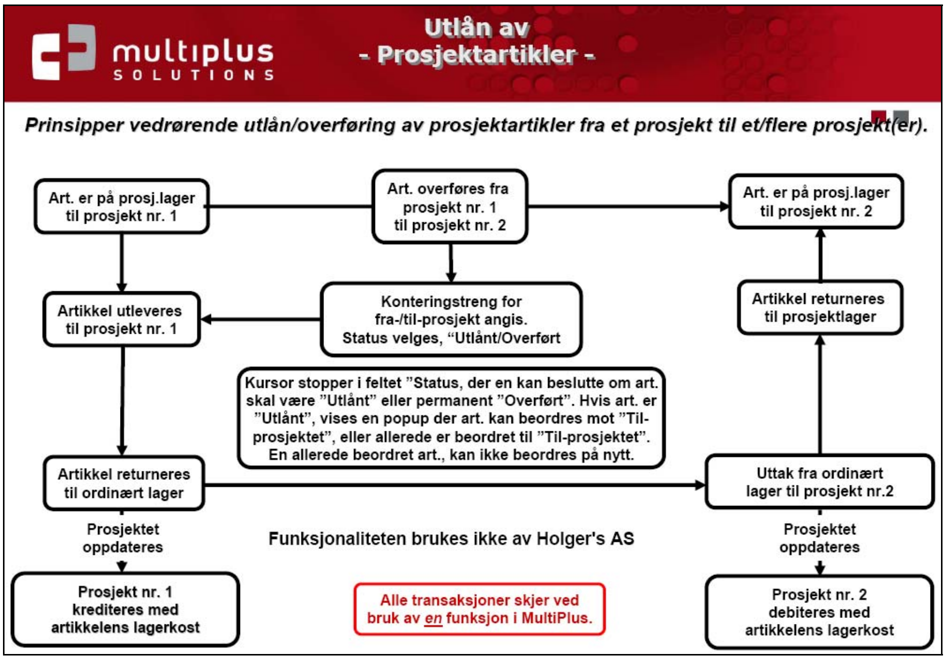
APPENDIX VI: MULTIPLUS WAREHOUSE SOLUTION

Information received from Arild Pettersen at Multiplus Solution:






multiplus SOLUTIONS
Prosjektlagerløsningen
Prinsipper vedrørende retur av artikler fra prosjekt til prosjektlager.
Transaksjonen styres av konteringen som angis ved retur til prosjektlager.
F.422
Artikkelen er tatt ut til prosjekt
Artikkel returneres til prosjektlager
Ingen kostnadsendring for prosjektet
F.423
Kostnaden er tatt på prosjektet
Prosjektlagerbeholdning øker med returnert antall
Ingen endring av Lagerverdien


multiplus SOLUTIONS
Utlån av - Prosjektartikler -
Prinsipper vedrørende utlån/overføring av prosjektartikler fra et prosjekt til et/flere prosjekt(er).
Art. er på prosj.lager til prosjekt nr. 1
Art. overføres fra prosjekt nr. 1 til prosjekt nr. 2
Art. er på prosj.lager til prosjekt nr. 2
Artikkel utleveres til prosjekt nr. 1
Konteringstreng for fra-/til-prosjekt angis. Status velges, "Utlånt/Overført
Artikkel returneres til prosjektlager
Kursor stopper i feltet "Status, der en kan beslutte om art. skal være "Utlånt" eller permanent "Overført". Hvis art. er "Utlånt", vises en popup der art. kan beordres mot "Til-prosjektet", eller allerede er beordret til "Til-prosjektet". En allerede beordret art., kan ikke beordres på nytt.
Artikkel returneres til ordinært lager
Uttak fra ordinært lager til prosjekt nr.2
Prosjektet oppdateres
Funksjonaliteten brukes ikke av Holger's AS
Prosjektet oppdateres
Prosjekt nr. 1 krediteres med artikkelens lagerkost
Alle transaksjoner skjer ved bruk av en funksjon i MultiPlus.
Prosjekt nr. 2 debiteres med artikkelens lagerkost

APPENDIX VII: SFI GROUP SYSTEM

General SFI Structure	
SFI	**SFI_NAME**
1	Ship general
2	Hull
3	Equipment for cargo
4	Ship equipment
5	Equipment for crew and passengers
6	Machinery main components
7	Systems for machinery main components
8	Ship common systems
9	Special Equipment
1.10	Specification, estimating, drawing, instruction, courses
1.11	Insurance, fees, certificates, representation
1.12	Quality assurance, general work, models
1.13	Provisional rigging
1.14	Work on ways, launching, docking
1.15	Quality control, measurements, tests, trials
1.16	Guarantee/mending work
1.17	Ship repair, special services
1.19	Consumption articles
2.20	Hull materials, general hull work
2.21	Afterbody
2.22	Engine area
2.23	Cargo area - hull small vessels
2.24	Forebody
2.25	Deck houses & superstructures
2.26	Hull outfitting
2.27	Material protection, external
2.28	Material protection, internal
2.29	Miscellaneous hull work (not standard)
3.30	Hatches, ports
3.31	Equipment for cargo in holds/on deck
3.32	Special cargo handling equipment
3.33	Deck cranes for cargo
3.34	Masts, derrick posts, rigging & winches for cargo
3.35	Loading/discharging systems for liquid cargo
3.36	Freezing, refrigerating & heating systems for cargo
3.37	Gas/ventilation systems for cargo holds/tanks
3.38	Auxiliary systems & equipment for cargo
4.40	Manoeuvring machinery & equipment
4.41	Navigation & searching equipment
4.42	Communication equipment
4.43	Anchoring, mooring & towing equipment
4.44	Rep./maint./clean. equip. workshop/store outfit, name plates
4.45	Lifting & transport equipment for machinery components
4.46	Hunting & fishing equipment
4.47	Armament, weapon & weapon countermeasures
4.48	Special equipment
4.49	Fish processing equipment

5.50	Lifesaving, protection & medical equipment
5.51	Insulation, panels, bulkheads, doors, sidescuttles,skylights
5.52	Internal deck covering, ladders, steps, railing
5.53	Ext. deck covering, ladders, steps, fore & aft gangway
5.54	Furniture, inventory, entertainment equipment
5.55	Galley/pantry equip., provision plants, laundry/ironing equ.
5.56	Transport equipment for crew, passengers & provisions
5.57	Ventilation, air-conditioning & heating systems
5.58	Sanitary syst. w/discharges, accommodation drain systems
5.59	Passenger vessel cabins & public rooms
6.60	Diesel engines for propulsion
6.61	Steam machinery for propulsion
6.62	Other types of propulsion machinery
6.63	Propellers, transmissions, foils
6.64	Boilers, steam & gas generators
6.65	Motor aggregates for main electric power production
6.66	Other aggr. & gen. for main & emergency el. power production
6.67	Nuclear reactor plants
7.70	Fuel systems
7.71	Lube oil systems
7.72	Cooling systems
7.73	Compressed air systems
7.74	Exhaust systems & air intakes
7.75	Steam, condensate & feed water systems
7.76	Distilled & make-up water systems
7.79	Automation systems for machinery
8.80	Ballast & bilge systems, gutter pipes outside accommod.
8.81	Fire & lifeboat alarm, fire fighting & wash down systems
8.82	Air & sounding systems from tanks to deck
8.83	Special common hydraulic oil systems
8.84	Central heat transfer systems w/chemical fluids/oil
8.85	Common electric & electronic systems
8.86	Electric power supply
8.87	Common electric distribution systems
8.88	Electric cable installation
8.89	Electric consumer systems
9.90	
9.91	SPECIAL EQ. OFFSHORE VESSELS
9.92	SEISMIC & ACEANOGRAFIC EQUIP.
9.93	CABLE AND PLUMBING EQUIP.
9.99	