



# Master's degree thesis

**LOG950 Logistics**

**A study of; Work-time utilization and root causes  
hindering work flow at Ulstein Verft AS**

**Steffen Ugland and Tommy Gjerstad**

Number of pages including this page: 126

Molde, May 2010



**Molde University College**

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**Title:** A study of; Work-time utilization and root causes hindering work flow at Ulstein Verft AS

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**Subject code:** LOG950

**ECTS credits:** 30

**Year:** 2010

**Supervisor:** Bjørn Guvåg

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## **Acknowledgements**

This thesis is a mandatory part of the Master of Science in Logistics program at Molde University College. A research proposal was submitted and accepted December 2009, which was the starting point for this research. The work with the thesis started January and extended through May, 2010.

The authors would like to express our gratitude to the following people:

Bjørn Guvåg – For being an advisor of great value through your comments, feedback, and support.

Karolis Dugnas – For being a co-advisor with your constructive comments and support as well as motivation for the authors.

Runar Toftesund – For the academic discussions related to the research and information you provided throughout the stay at Ulstein.

Reidun Anette Hagen – For all your help, providing the authors with documents, equipment, office and apartment during the stay at Ulstein.

Foremen at Ulstein – For sharing valuable information and comments with the authors through interviews.

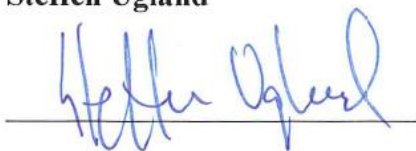
Sven Bertelsen – For hints about methods for measuring work-time utilization.

Our families – For your love and support.

Classmates – For support and inspiring conversations at school.

Molde, May 2010.

**Steffen Ugland**

A handwritten signature in blue ink, appearing to read 'Steffen Ugland', written over a horizontal line.

**Tommy Gjerstad**

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## **Abstract**

The shipbuilding industry worldwide met tough competition in the market for vessels because of overcapacity after the global recession that started in 2008. Being able to produce efficiently is now vital to survive by winning the few contracts on the market. The Norwegian shipyard Ulstein Verft started implementing Lean tools already back in 2006, based on successful cases from the construction industry. But to see if the efficiency in production actually improved they needed a way of measuring it.

Using Lean theory as a framework, this thesis develops a model for measuring the utilization of work-time at the shipyard. More precisely; how much time during a work day that is used for value adding - as well as non-value adding activities among the workers.

A case study was carried out using observation methods from operations analysis, adapted to fit in a construction environment like a shipyard. Different studies were completed using "snap-reading" observations, equipment for measuring effective arching time on welding units as well as interviews with key employees. In addition emphasize were put on revealing root causes hindering the work flow at the shipyard.

The result indicates that 27% of the time spent at the workplace is used for value adding (VA) activities. The remaining 73% are further divided into eight different categories defined within the Lean framework of non-value adding, but required (NVAR) activities and non-value adding (NVA) activities. As observations were carried out without interfering with the workers, an important limitation is the fact that all rework appear as VA in the results.

The conclusion suggests further implementation of Lean tools like Last Planner and Five S. If done right it should help Ulstein cope with the most severe hinders for work flow, and potentially improve the work-time utilization.

The model developed for measuring work-time utilization should also be applicable in other construction based environments.



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## **List of abbreviations and acronyms**

AHTS – Anchor Handling Tug Supply

JIC – Just in Case

JIT – Just in Time

NVA – Non-Value Adding

NVAR – Non-Value Adding but Required

OCV – Offshore Construction Vessel

PPF – Percent Planned Finished

PSV – Platform Supply Vessel

SCM – Supply Chain Management

TPS – Toyota Production System

TQM – Total Quality Management

UPS – Ulstein Production System

VA – Value Adding

VSM – Value Stream Mapping

WIP – Work in Progress

# 1 Introduction

In the first chapter some history of the shipbuilding industry will be presented. Next the background and motivation for the research is presented followed by the research problem. Finally the organization of the rest of this thesis is set out.

## 1.1 Shipbuilding history

While USA dominated the commercial shipbuilding market worldwide no more than 50 years ago with over 50 percent market share, it now maintains a rather insignificant market share of less than one percent. The ships build in the USA are mostly US naval ships and small ships for the coastal trade within the USA. The major reasons behind this shift in market share are poor cost- and schedule performance compared to the best worldwide competitors (Sawhney, Walsh and Storch 2007).

Today most of the ships are built in the Far East countries where South Korea and Japan hold the top positions among nations of shipbuilders. The European shipyards still maintain a highly competitive position in building ships that require a high level of technological know-how (Sawhney, Walsh and Storch 2007, Danish Ship Finance n.d.).

A central explanation for this global division of production is the proportion which manual labor costs represents in the combined cost of building the ship. The more labor intensive the production process is the more important it is that the labor costs are low. In this regard the Far East countries have through an extensive period had a comparative advantage compared to the Western nations. Their market share has increased ever since The Second World War. Overcapacity worldwide compared to market needs and political desires to expand capacity in developing countries as a means for increasing employment, has resulted in extreme competitive pressure. Hence the drive to improve performance and reduce price is strong (Danish Ship Finance n.d., Sawhney, Walsh and Storch 2007).

Many shipyards worldwide, especially in Japan are already using Lean principles in their construction processes (Sawhney, Walsh and Storch 2007). In a report by Hervik et al. (2005) it is claimed that eastern shipbuilders are organized more similar to manufacturing companies,

as they are more specialized in building identical vessels, hence the Lean Manufacturing principles tend to fit much better (Hervik, Oterhals and Bræin 2005).

The Norwegian shipbuilding industry has its strengths in quality delivery precision and in building technically advanced highly complex and customized vessels (Uthaug and Dugnas 2007, Hervik, Oterhals and Bræin 2005).

Norwegian shipbuilders claim the level of cost to be the largest comparative disadvantage towards foreign competitors. In 2002 the cost of one production hour was 27 USD in Norway and Germany, other European countries 15-22 USD, Korea and Singapore 7-8 USD, while China, Romania and Brazil had 2-3 USD pr. hour, or in other words about 10% of the Norwegian level. Even though Norwegian shipbuilders are highly efficient on specific areas, the need for outsourcing more labor intensive operations was obvious (Hervik, Oterhals and Bræin 2005).

### **1.1.1 Previous decade in Norway**

The shipbuilding industry in Norway had a difficult period in 2003 and 2004 with decreasing number of new contracts. The willingness for future development was pessimistic. At that time the Norwegian industry in general experienced loss of competitiveness towards low cost countries as Poland and China.

In 2005 and 2006 the situation changed much due to an increase in oil prices. This triggered oil related activities on the Norwegian continental shelf and worldwide. Extended productivity duration of oil platforms due to possibility of tail production, and new geological oil searches lead to an obvious need for new or modernized vessels. Companies within the oil and gas related area began placing more orders of highly complex offshore vessels, which lead to full order books out 2011. The industry was suddenly facing a capacity problem both in terms of supply and labor (Uthaug and Dugnas 2007).

However in 2008 the world faced a global recession and many if not most industries was affected, which resulted in overcapacity hence lower orders of new vessels. When the vessels already ordered are delivered it will lead to increased overcapacity, hence an even longer period before new vessels are needed.

Several shipyards have already gone bankrupt or dropped out of the segment of new builds. The shipyards with full order books were not immediately affected by the economic crisis; however the after-effects will hit the shipyards hard if no new orders are coming during 2010/2011 (A. Hervik, et al. 2009).

This should be a motivation for shipyards to increase efficiency, as many shipyards will compete for the few new contracts on the market in the coming years.

## 1.2 Background and Motivation

### 1.2.1 Ulstein Group

Ulstein Group began its operations May 4 1999. The company was founded by Ulstein Mekaniske Verksted (UMVH ASA), originally founded in 1917. Ulstein Group is the parent company of a maritime group (see Figure 1) (Ulstein Group n.d.).

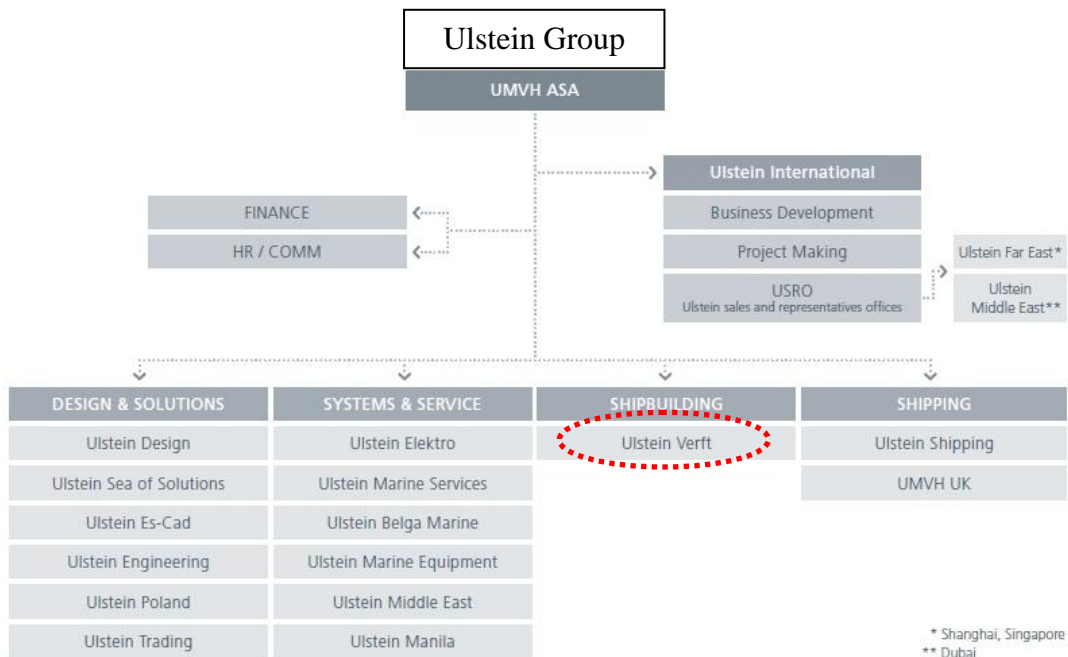


Figure 1: Ulstein Group Organization Chart (Ulstein Group n.d.)

Ulstein Group employs about 800 people and consists of several companies involved in ship design, shipbuilding, engineering, electrical- and control systems, automation, after market service and ship management. The largest of these companies is Ulstein Verft AS (about 380 employees), which build and deliver special-purpose vessels including offshore service, offshore construction, seismic, cable and research vessels. These are state-of-the-art vessels with large amount of advanced equipment, requiring a high level of project management and technical know-how. More details on the basic types of vessels Ulstein offer can be seen in appendix 7.1.

Headquarter of both Ulstein Group and Ulstein Verft AS are located in Ulsteinvik, Norway, but there is also a department in Vanylven, Norway where they build steel-sections for the vessels superstructure. Ulstein cooperates with two shipyards on delivery of ship hulls, Maritime-Shipyard in Poland and Zaliv Shipyard in Ukraine (Ulstein Group n.d.). Ulstein Verft AS will from now on be known as Ulstein.

### **1.2.2 Lean at Ulstein**

Ulstein has a vision of creating a new production system called Ulstein Production System (UPS). They started implementing Lean principles based on successful cases from the construction industry. After carrying out a pre-project at the shipyard, the decision about implementing the Last Planner system was made in collaboration with FAFO, Molde Research Institute and Danish Technical University (Dugnas and Oterhals 2008). Since November 2006 and vessel #277 the Last Planner system has been applied in production of all new vessels at Ulstein (Toftesund 2007).

Ulstein has four purposes for improvement (Toftesund 2007):

- Increase production
- Increase quality
- Reduce project duration
- Reduce cost



As a part of implementing Last Planner Ulstein had a seminar during spring 2008 where foremen should emphasize how they spent the time at work. Two educational figures were presented illustrating the utilization of work-time (appendix 7.4). In these figures there are three main categories of activities; productive activities, non-productive activities and counter-productive activities.

### **1.3 Research problem**

Ulstein wish to carry out a study of the current work-time utilization at the shipyard, showing how much time that is spent on different activities during a normal day at work, and how much of the work-time that is actually adding value to the product. The study may be used for future comparison after having developed UPS further with more Lean tools. In other words they want to be able to measure if they in future succeed in becoming more efficient. As they did not carry out a study like this before the Last Planner method was implemented they struggle to see if they have actually become better concerning the utilization of work-time.

As Ulstein believe there is room for further improvement in the future, this thesis will develop a model for measuring work-time utilization and a description of the current situation for future comparison. In addition to providing such a result the thesis will try to reveal root causes hindering work flow (hindering improvement of the work-time utilization) at the shipyard, and suggest Lean tools for improvement.

#### **Objectives:**

- Develop a model for measuring work-time utilization
- *Provide a result of work-time utilization*
- Reveal root causes hindering work flow
- *Suggest Lean tools for improvement*

## **1.4 Organization of thesis**

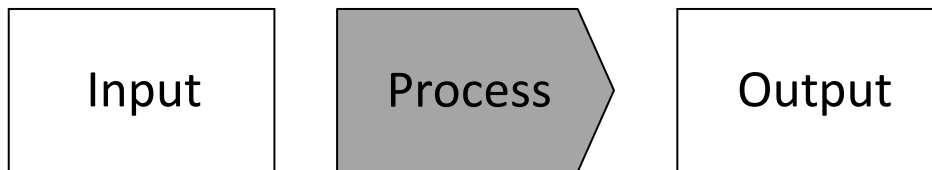
The remainder of this thesis is organized as follows: Chapter 2 presents the theoretical framework, explaining the concepts Lean Manufacturing, Lean Construction and Lean Shipbuilding, as well as different Lean tools. Chapter 3 present and explain the research design which is a result of a synthesis of relevant Lean literature. Several studies were carried out; (1) Work-time utilization study (2) Welding study (3) Walk/Transport study and (4) Personal interviews, all in respect to the research problem. Chapter 4 includes the results of the studies, followed by a discussion of the findings. Chapter 5 is the final chapter and consists of conclusions and recommendations as well as limitations and future research.

## 2 Theoretical framework

In this chapter the theoretical framework relevant for the research work will be presented. First two different types of manufacturing will be explained to illustrate the basics behind Lean opposed to conventional manufacturing. Most emphasis is put on Lean Manufacturing along with the principles and tools. Then the concept Lean Construction will be introduced and explained. This will give a good view of the complexity of “one of a kind production”, and show the similarities to shipbuilding, which will be the last section in this chapter.

### 2.1 Conversion Model vs. Flow Model

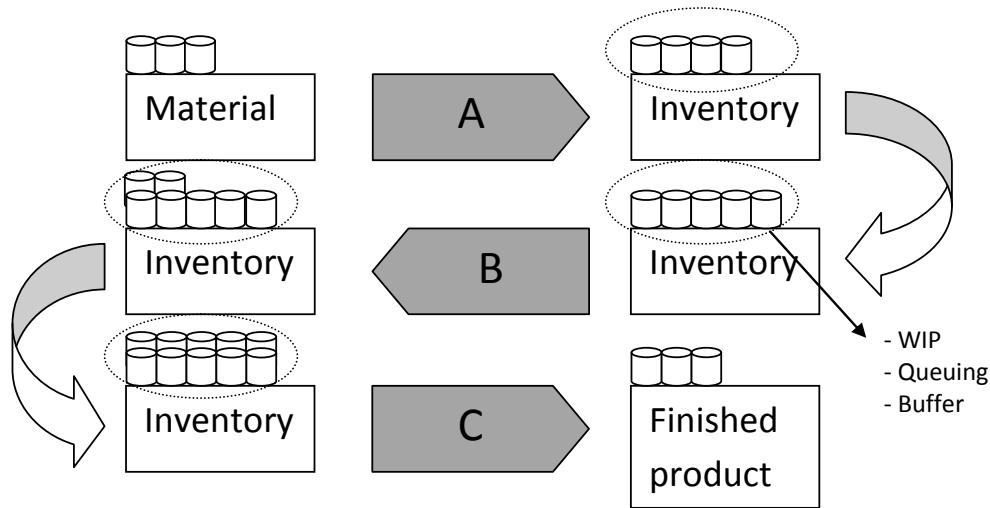
To really understand the concept of Lean production it's important to be familiar with the two basic production systems of the 20th century. Figure 2 illustrates the basis of the traditional conversion model.



**Figure 2: Conversion Process (Diekmann, et al. 2004)**

A manufacturing process the conventional way can be broken down to a series of activities all converting input to output, referred to as the conversion model or transformation model. This is shown in Figure 3 and this type of production system historically uses what is called a batch and queue theory (Womack and Jones 1996).

As a result of this, parts are manufactured in large batches at one process within a plant and then queued for the next process. Batch and queue theory leads to many manufacturing problems, such as bottlenecking and large inventories from high work-in-progress (WIP) levels (Diekmann, et al. 2004).



**Figure 3: The conversion model of production (Diekmann, et al. 2004)**

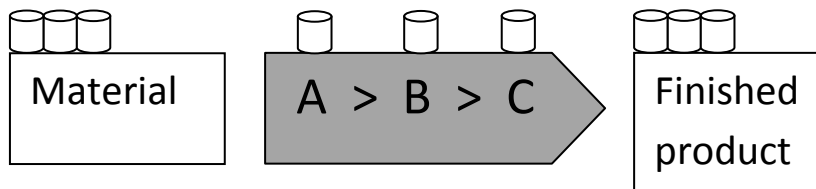
Inventories created by WIP are referred to in manufacturing as buffers (Womack and Jones 1996). Buffers generally reduce the variability of workflows within a plant by shielding downstream activities from uncertainties that might occur upstream, such as machine failure or differing machine output rates. Buffers may be the result of WIP or it might be planned into the manufacturing process (Diekmann, et al. 2004).

Buffers can be viewed as an advantage if high degrees of variability exist within the manufacturing process. Disadvantages associated with over buffering include increased product lead times, increases in required working capital, as well as increased space requirements to produce and store the additional parts and components acting as the buffers. By using such queuing techniques, manufacturers also become vulnerable in cases of quick changes in the marketplace. For example, if demand in the market for a certain product decreases, the manufacturer might get stuck with high levels of WIP. The WIP is acting as buffers and the manufacturer is forced to decide whether it would be financially feasible to complete the production of the product or to terminate production and scrap the partially completed work (Diekmann, et al. 2004).

Womack et al. (1990) provides an excellent descriptive summary of the typical mass producer: *"The mass producer uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines. These churn out*

*standardized products in very high volume. Because the machinery costs so much and is so intolerant of disruption, the mass producer adds many buffers – extra supplies, extra workers, and extra space to assure smooth production. Because changing over to a new product costs even more, the mass producer keeps standard designs in production for as long as possible. The result: The consumer gets lower costs but at the expense of variety and by means of work methods that most employees find boring and dispiriting" (Womack and Jones 1990).*

The view of production as a series of conversions is fundamentally different from the second dominant type of production in the 20th century, the view of manufacturing as a flow model (L. Koskela 1992). Production as a flow process is one of the core ideas of Lean production and Figure 4 below represents a generalized flow model.



**Figure 4: Generalized flow model (Diekmann, et al. 2004)**

Unlike the traditional view of production, the flow process does not view the production stream as just a series of conversions/transformations. The conceptualization of manufacturing as a flow model separates between activities that add value to the process (conversion) and those that do not (L. Koskela 1992).

By defining the different types of activities that occur in production, the focus of improvement does not become compartmentalized as in Figure 3, but rather envelops the entire value stream.

The value stream of a particular product consists of all “*specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer*” (Womack and Jones 2003) as illustrated in Figure 5.

Compartmentalized improvements can become troublesome in the flow model to downstream activities if the particular cycle times of sequential operations are not matched. In other words, if Process A has half the cycle time of Process B, a material buffer will occur at Process B



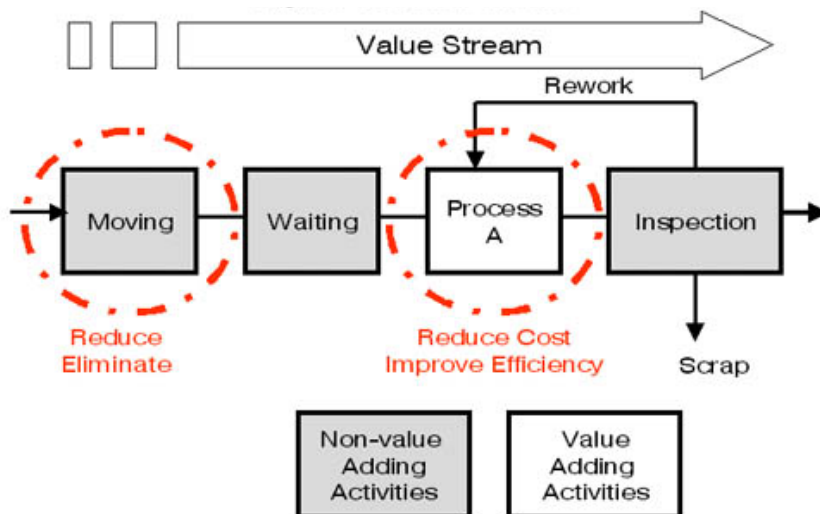
because it cannot keep up with the amount of work produced by Process A (Diekmann, et al. 2004).



**Figure 5: Simplified Value Stream (Diekmann, et al. 2004)**

The flow process tends to focus on the elimination of the large buffers found within mass manufacturing by emphasizing the constant movement of components from one value adding activity to the next. This type of system, also referred to as single-piece flow (Womack and Jones 1996), is associated with several benefits (Figure 6). First, the WIP levels are dramatically reduced, which also reduces the inventory space required as well as the capital to produce and stock extra inventories of partially completed products (Diekmann, et al. 2004).

Combined with reducing equipment setup times, low WIP levels can help a manufacturer become more responsive to market conditions. As a result, the producer lets the customer, or market, pull the production (Diekmann, et al. 2004).



**Figure 6: The flow model of production (Diekmann, et al. 2004)**

Compared to the conversion model, flow operations are much more tightly controlled in terms of production times and supply chain coordination to minimize variability within the process. In fact, the introduction of time as an input to the production process is fundamentally different from the conversion model of production because the process is no longer conceptualized as solely an economic abstraction, but rather as a physical process (L. Koskela 1992). Time was considered important before the advent of the flow model, but the entire production system was not centered on time as a goal.

This view of time is important because the flow process does not contain the buffers necessary to minimize variability within the manufacturing process, and therefore must rely on the coordination of processes both internal and external to the plant (Diekmann, et al. 2004). Figure 7 and Table 1 summarize the major differences between the two predominant production theories of the 20th century.

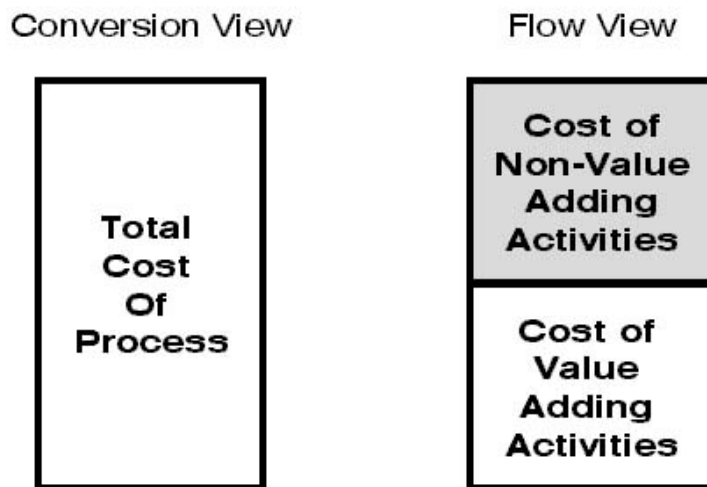


Figure 7: Delineation of activities (Diekmann, et al. 2004)

<b>Description</b>	<b>Conversion Model</b>	<b>Flow Model</b>
<b>Conceptualization</b>	Manufacturing as a series of conversion activities	Manufacturing as a combination of value and non-value adding activities
<b>Basic Queuing Theory</b>	Batch and queue	Single-piece flow
<b>Production Trigger</b>	Products pushed onto the market as a result of forecasted demand	Products pulled onto the market by demand
<b>Inventory Implications</b>	Large inventories as a result of batch and queue production and WIP	Minimal inventories
<b>Focus on Improvement</b>	Improvement focused on lowering cost and increasing productivity of each activity (analytical reductionism)	Improvement focused on lowering cost and increasing productivity of value adding activities and reducing / eliminating non-value adding activities
<b>Variability Control</b>	Buffers used to control variability	Use of coordination among internal operations as well as supply chain management to reduce variability
<b>Focus of Control</b>	Cost and time of activities	Cost, time and value of value adding and non value adding activities

**Table 1: Conversion Model vs. Flow Model (Diekmann, et al. 2004)**

## **2.2 Lean Thinking**

The term Lean Thinking can be seen as a general term for a business philosophy, containing more industry specific terms like Lean Manufacturing (or Lean Production), Lean Construction and Lean Shipbuilding which will be presented below.

## **2.3 Lean Manufacturing**

### **2.3.1 Introduction**

The story begins with The Toyota Production System (TPS), developed after the Second World War by Eiji Toyoda and Taiichi Ohno for the Toyota Motor Company. At this time Toyota was a small company and they needed a production system capable of rapid changes in kinds and models (Liker and Lamb 2000).

After visiting car manufacturers in the United States operating according to the conventional model Ohno saw waste where US managers saw efficiency. While the US approach aimed to minimize the cost of each part, Ohno's objective was to instantly deliver a product meeting a customer's requirements without inventory. Ohno began to develop the principles of a new manufacturing strategy (as opposed to mass manufacturing) as he redesigned the Toyota production process. His pursuit of perfection led to the new form of production later called Lean (Howell and Ballard n.d.). TPS was the next major evolution in efficient business processes after the mass production system invented by Henry Ford, and it has been documented, analyzed, and exported to companies across diverse industries throughout the world (J. K. Liker 2004).

James Womack's book called "The Machine That Changed the World" (1990) was a straightforward account of the history of automobile manufacturing combined with a study of Japanese, American, and European automotive assembly plants. What was new was a phrase - "Lean Manufacturing" (Womack and Jones 1990).

### **2.3.2 Fundamentals of Lean Manufacturing**

The heart of the TPS is; *delivering value by eliminating waste and ensuring undisturbed workflow*. Outside of Toyota, TPS is often known as "Lean", "Lean Production" or "Lean Manufacturing" (J. K. Liker 2004). Lean Manufacturing caught the imagination of manufacturing people in many countries and implementations are now commonplace. The knowledge and experience base is expanding rapidly (Diekmann, et al. 2004).

Taiichi Ohno (founder of TPS) said:

*“All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time by removing the non-value-added wastes”* (Ohno 1988).

What Ohno here refers to as the *time line* from the order is placed to collection of cash consist of many activities and it is often referred to as the value stream. Womack and Jones define it as a set of all the *“specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer”* (Womack and Jones 2003).

An example of a value stream containing value adding and non-value adding activities can be seen in Figure 8.

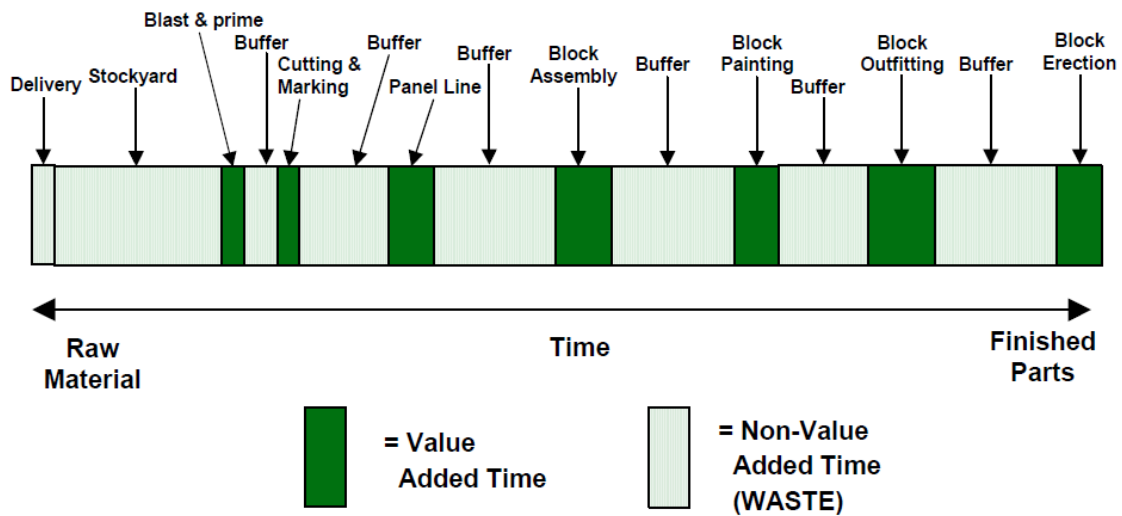
Womack and Jones (2003) define three different types of activities appearing within the value stream:

- *Value Adding*: Activities that create value.
- *Type 1 waste*: Activities that create no value but seem unavoidable with current settings.
- *Type 2 waste*: Activities that create no value and are immediately avoidable.

The goal is to minimize the Type 1 waste and eliminate Type 2 waste.

In the remaining of this thesis these three types of activities will be denoted as; value adding (VA), non-value adding, but required (NVAR) and non-value adding (NVA) (Diekmann, et al. 2004).





**Figure 8: Waste in the value chain (Liker and Lamb 2000)**

## Value

The term value is a critical starting point in Lean theory, and can only be defined by the ultimate customer. Value is only meaningful when expressed in terms of a specific product or service. The purpose of any organization is to create and deliver value to their customers and end users. Value is created by producers and from the customers view it is the only reason why producers exist (Mossman 2009).

Value adding activities can more precisely be defined as “...*activities that change the form, fit or function of a product or service, given the customer is willing to pay for it.*” (Wisc-Online n.d.)

## Waste

Waste can only be defined in terms of value hence we can only know waste by knowing value first. Because of this there is no absolute definition of waste in the theory, it is all relative. Value is defined different for each end user/client/owner, thus the definition of waste will also be different for each of them. Just as one generation’s music is another generation’s noise, one owner’s value can be another customer’s waste (Mossman 2009).

Where TPS focus on eliminating waste, Mossman claims that waste reduction is a by-product of value creation. Creating value and only value is the best way to reduce waste in design and construction (Mossman 2009).

Womack and Jones (1996) define waste as “...*any human activity that absorbs resources but creates no value*” (Womack and Jones 1996).

The definition developed by Walbridge-Aldinger (2000) better conforms to construction production; waste is defined as “...*anything that takes time, resources or space but does not add value to the product or service delivered to the customer*” (Walbridge Aldinger 2000).

Processes either add value or waste to the production of a good or service. “The seven wastes” originated in Japan, where waste is known as “muda”.

The seven wastes is a tool to further categorize muda and were originally developed by Toyota’s Chief Engineer Taiichi Ohno as the core of the Toyota Production System, also known as Lean Manufacturing. To eliminate waste, it is important to understand exactly what waste is and where it exists. While products significantly differ between factories, the typical wastes found in manufacturing environments are quite similar. For each waste, there is a strategy to reduce or eliminate its effect on a company, thereby improving overall performance and quality (Rotaru 2008).

According to Ohno (1988) these are the seven types of waste;

1. Waste of overproduction
2. Waste of time on hand (waiting)
3. Waste of transportation
4. Waste of processing itself
5. Waste of stock on hand (inventory)
6. Waste of movement
7. Waste of making defective products

(Ohno 1988)

The seven wastes are presented below; source: (EMS Consulting Group 2003).

### *1. Overproduction*

Simply put, overproduction is to manufacture an item before it is actually required. Overproduction is highly costly to a manufacturing plant because it prohibits the smooth flow of materials and actually degrades quality and productivity. The Toyota Production System is also referred to as “Just in Time” (JIT) because every item is made just as it is needed.

Overproduction manufacturing is referred to as “Just in Case”. This creates excessive lead times, results in high storage costs, and makes it difficult to detect defects. The simple solution to overproduction is turning off the tap; this requires a lot of courage because the problems that overproduction is hiding will be revealed. The concept is to schedule and produce only what can be immediately sold/shipped and improve machine changeover/set-up capability.

### *2. Waiting*

Whenever goods are not moving or being processed, the waste of waiting occurs. Typically more than 99% of a product's life in traditional batch-and-queue manufacture will be spent waiting to be processed. Much of a product's lead time is tied up in waiting for the next operation; this is usually because material flow is poor, production runs are too long, and distances between work centers are too great. Linking processes together so that one feeds directly into the next can dramatically reduce waiting.

### *3. Transporting*

Transporting product between processes is a cost incursion which adds no value to the product. Excessive movement and handling cause damage and are an opportunity for quality to deteriorate. Material handlers must be used to transport the materials, resulting in another organizational cost that adds no customer value.

Transportation can be difficult to reduce due to the perceived costs of moving equipment and processes closer together. Furthermore, it is often hard to determine which processes should be next to each other. Mapping product flows can make this easier to visualize.

#### *4. Inappropriate Processing*

Often termed as “using a sledgehammer to crack a nut,” many organizations use expensive high precision equipment where simpler tools would be sufficient. This often results in poor plant layout because preceding or subsequent operations are located far apart.

In addition they encourage high asset utilization (over-production with minimal changeovers) in order to recover the high cost of this equipment. Toyota is famous for their use of low-cost automation, combined with immaculately maintained, often older machines. Investing in smaller, more flexible equipment where possible; creating manufacturing cells; and combining steps will greatly reduce the waste of inappropriate processing.

#### *5. Unnecessary Inventory*

Work in Progress (WIP) is a direct result of *overproduction* and *waiting*. Excess inventory tends to hide problems on the plant floor, which must be identified and resolved in order to improve operating performance. Excess inventory increases lead times, consumes productive floor space, delays the identification of problems, and inhibits communication. By achieving a seamless flow between work centers, many manufacturers have been able to improve customer service and slash inventories and their associated costs.

#### *6. Unnecessary / Excess Motion*

This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. These are also health and safety issues, which in today’s litigious society are becoming more of a problem for organizations. Jobs with excessive motion should be analyzed and redesigned for improvement with the involvement of plant personnel.

#### *7. Defects*

Having a direct impact to the bottom line, quality defects resulting in rework or scrap are a tremendous cost to organizations. Associated costs include quarantining inventory, re-inspecting, rescheduling, and capacity loss. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Through employee involvement, there is a huge opportunity to reduce defects at many facilities.

Subsequently other types of waste have been suggested through the years (Mossman 2009):

- behavioral waste - human behaviors that add no value and can be eliminated
- dangerous working practices
- excess information
- figuring what to do or how to do it
- making do
- not speaking - not listening
- not taking advantage of people's thoughts (wasting good ideas)
- not using people's talents
- under-using people's skills and capabilities
- providing something that the customer doesn't value

In the latest edition of the Lean Manufacturing classic *Lean Thinking*, **Underutilization of Employees** has been added as an eighth waste to Ohno's original seven wastes. Organizations employ their staff for their nimble fingers and strong muscles but forget they come to work every day with a free brain. It is only by capitalizing on employees' creativity that organizations can eliminate the other seven wastes and continuously improve their performance (Womack and Jones 2003).

Many changes over recent years have driven organizations to become world class organizations or Lean Enterprises. The first step in achieving that goal is to identify and attack the seven wastes (EMS Consulting Group 2003). Or as Mossman states; focus on creating only value and waste will automatically be reduced (Mossman 2009). In many ways it is the same idea, but different approaches to attack it. As Toyota and other world-class organizations have come to realize, customers only want to pay for value added work, but never for waste (EMS Consulting Group 2003).

There are many successful stories from adopting these principles; however it has been mostly within manufacturing. In the latter it has also been adopted into construction based work environments.

### **2.3.2 Lean Conceptualization**

With the basic idea of flow production systems established, it is important to look beyond core manufacturing ideas to the broader context of “Lean.” Figure 9 illustrates an example of how one might conceptualize Lean production.

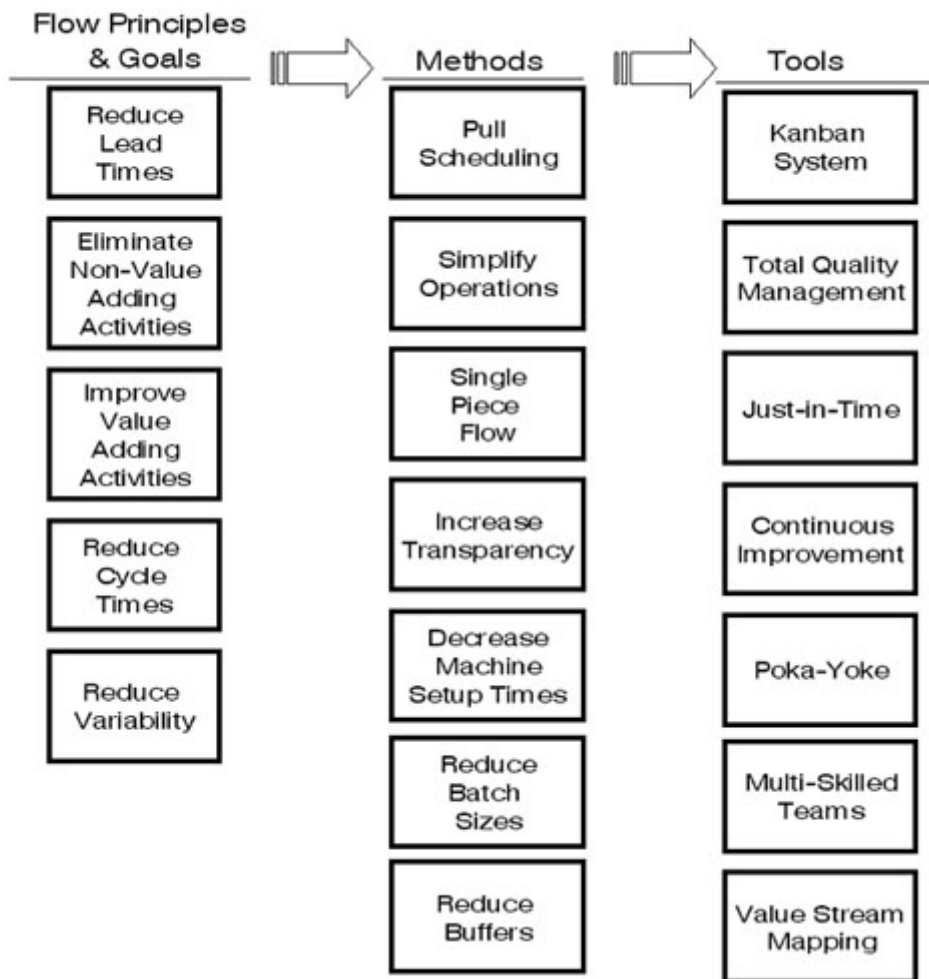
First, it might be conceptualized as a grouping of principles and goals crucial to the operation of a flow system, such as reducing lead times and variability.

Second, it might be conceptualized as a set of methods aimed at facilitating the principles and goals of flow operations, such as pull scheduling.

Third, it might be conceptualized as a set of tools that aid the methods, such as utilizing *Kanban* cards to trigger pull scheduling. The level of detail increases as one view the chart from left to right. Although the figure does not include all elements of Lean production, it does provide a basic outline of the Lean production process (Diekmann, et al. 2004).

It can be concluded that Lean, as it is understood today, is a conglomeration or synthesis of many theories, philosophies, methods and techniques, many of which are individual methodologies within the manufacturing community (Diekmann, et al. 2004).

## Lean Production Generalization



**Figure 9: Lean production generalization (Diekmann, et al. 2004)**

The ideas of Lean can also be conceptualized on the following three levels (Koskela 2000):

1. Process Level - A set of tools, such as *Kanban* cards, *poke yoke*, etc.
2. Project Level - A production planning method, such as JIT (Just In Time).
3. Organization Level - General management theory, such as TQM (Total Quality Management).

Lean implementation may consist of applying Lean principles at any of the three levels. A comprehensive Lean implementation will cover all aspects of the business directly related to production, transport, supply or service activities (dos Santos 1999, Schroeder 1993, Wild 1995).

### **2.3.3 Lean Manufacturing principles**

Liker (2004) presents 14 principles constituting the Toyota Way in the book “The Toyota Way”. The principles are organized in four broad sections (J. K. Liker 2004):

1. Long-Term Philosophy
2. The Right Process Will Produce the Right Results (utilizes many of the TPS tools)
3. Add Value to the Organization by Developing Your People
4. Continuously Solving Root Problems Drives Organizational Learning.

Below the 14 principles are presented within the four sections. For more detailed information the authors refer to the book (J. K. Liker 2004).

#### **Section 1: Long-Term Philosophy**

1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.

#### **Section 2: The Right Process Will Produce the Right Results**

2. Create a continuous process flow to bring problems to the surface.
3. Use “pull” systems to avoid overproduction.
4. Level out the workload (heijunka). (Work like the tortoise, not the hare.)
5. Build a culture of stopping to fix problems, to get quality right the first time.
6. Standardized tasks and processes are the foundation for continuous improvement and employee empowerment.
7. Use visual control so no problems are hidden.
8. Use only reliable, thoroughly tested technology that serves your people and processes.

#### **Section 3: Add Value to the Organization by Developing Your People**

9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams who follow your company’s philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve.



#### **Section 4: Continuously Solving Root Problems Drives Organizational Learning**

12. Go and see for yourself to thoroughly understand the situation (*genchi genbutsu*).
13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (*nemawashi*).
14. Become a learning organization through relentless reflection (*hansei*) and continuous improvement (*kaizen*).

It is quite possible to use a variety of TPS tools and still be following only a few of the Toyota Way principles. According to Liker (2004) the result will be short term jumps on performance measured which are not sustainable (J. K. Liker 2004).

Many managers ask: How does TPS apply to my business? In that context it is necessary to emphasize that Lean is about developing and customizing principles that are right for each specific organization (J. K. Liker 2004).

#### **2.3.4 Lean Manufacturing implementation**

According to Womack and Jones (2003) the implementation of Lean thinking consists of the following steps; Value, Value Stream, Flow, Pull and Perfection (Womack and Jones 2003). The steps are explained below; based on theory from (Womack and Jones 2003, Lean Enterprise Institute n.d., Diekmann, et al. 2004).

##### **1. Specify value from the standpoint of the end customer**

- Understand the customer.
- Target cost.
- Look at the whole.
- Specify value by product/service.
- Value must be defined for each product family, along with a target cost based on the customer's perception of value.

##### **2. Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value**

- Understanding flow is the key technique for eliminating waste (*muda*).

- Create a vision of flow.
- Compete against perfection by eliminating *muda*.
- Identify value adding activities.
- Identify contributory non-value adding but required activities (Type I muda).
- Identify non-value adding activities (Type II muda).
- Rethink operating methods.
- Eliminate sources or root causes of waste in the value stream.

**3. Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer**

- Focus on actual object from beginning to completion and produce continuous flow.
- Ignore traditional boundaries (department).
- Apply all three of these steps at the same time.
- Work on the remaining non-value adding activity (Type I muda).
- Synchronize and align so there is little waiting time for people and machines.
- Match workload and capacity.
- Minimize input variations.

**4. As flow is introduced, let customers pull value from the next upstream activity**

- Communicate.
- Apply level scheduling.
- Release resources for delivery just when needed.
- Practice JIT supply rather than JIT production.
- Continue to work on the remaining non-value adding activity (Type 1 muda).

**5. Continue working on the four first principles and manage towards perfection**

- Increase transparency.
- Form a picture of perfection.

Individually, the principles, methods and techniques have been applied with partial success, but together, they create a powerful framework and philosophy for improving manufacturing performance (Diekmann, et al. 2004).

To succeed in implementing Lean thinking, you have to go through these five steps and keep repeating the cycle to ensure continuous improvement, or *kaizen* as it's called in the Lean framework (Womack and Jones 2003). This is illustrated in Figure 10.



**Figure 10: Lean implementation steps (Lean Enterprise Institute n.d.)**

### **2.3.5 Lean Manufacturing tools**

#### **Value stream mapping**

To understand where value is added in a production process, one must first learn the steps or phases a product goes through to reach a finished state. The developers of the Toyota Production System (Ohno 1988, S. Shingo 1989) and other early adopters of Lean principles have emphasized the importance of mapping out the *entire* production process allowing one to focus on eliminating steps that are not required.

Value stream mapping (VSM) is a method for visualizing the entire flow of materials and information from raw materials to finished product/service delivered to the customer. The goal

is to identify and eliminate waste and thereby improve productivity (ValueBasedManagement.net n.d.).

In general authors within value stream mapping present their creations as the answer, instead of a part of a larger jigsaw. There are several approaches to map a value stream and Hines and Rich (1997) present seven value stream mapping tools listed below (Hines and Rich 1997):

1. Process activity mapping
2. Supply chain response matrix
3. Production variety funnel
4. Quality filter mapping
5. Demand amplification mapping
6. Decision point analysis
7. Physical structure

In the article Hines and Rich (1997) present a table where the methods are listed in correlation with the seven types of waste. They state that the first step is to identify which of the wastes that appears in the considered value stream. After that it should be possible to choose the most suited mapping method Table 2 (Hines and Rich 1997).

Wastes/structure	Mapping tool						Physical structure (a) volume (b) value
	Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H						L
Inappropriate processing	H		M	L		L	
Unnecessary inventory	M	H	M		H	M	L
Unnecessary motion	H	L					
Defects	L			H			
Overall structure	L	L	M	L	H	M	H

**Notes:** H =High correlation and usefulness  
M = Medium correlation and usefulness  
L = Low correlation and usefulness

**Table 2: Value Stream Mapping (Hines and Rich 1997)**

One of the methods called *process activity mapping* originates from industrial engineering and comprises a group of techniques useful for eliminating waste, inconsistencies and irrationalities while providing high quality goods and services easily, quickly and inexpensively. The approach consists of five steps (Hines and Rich 1997):

1. The study of the flow of processes
2. The identification of waste
3. A consideration of whether the process can be rearranged in a more efficient sequence
4. A consideration of a better flow pattern, involving different flow layout or transport routing
5. A consideration of whether everything that is being done at each stage is really necessary and what would happen if superfluous tasks were removed.

Process activity mapping follows these steps; first perform a preliminary analysis of the process under investigation, followed by a more detailed recording of all the items required in each process. The result is a map of the process within the value stream, along with a classification of each process and the time spent on it. The result gives a percent of value adding time in the value stream as seen in Table 3.

#	STEP	FLOW	MACHINE	DIST (M)	TIME (MIN)	PEOPLE	O	T	I	S	D	COMMENTS
							P	R	A	N	S	
							E	R	A	N	S	
							T	R	A	N	S	
							I	N	S	P	E	
							O	T	I	S	D	
							R	A	T	I	O	
							N	O	N			
1	RAW MATERIAL	S	RESERVOIR				O	T	I	S	D	RESERVOIR/ ADDITIVES
2	KITTING	O	WAREHOUSE	10	5	1	O	T	I	S	D	
3	DELIVERY TO LIFT	T		120		1	O	T	I	S	D	
4	OFFLOAD FROM LIFT	T			0.5	1/2	O	T	I	S	D	
5	WAIT FOR MIX	D	MIX AREA		20		O	T	I	S	D	
6	PUT IN CRADLE	T		20	2	1/2	O	T	I	S	D	
7	PIERCE/POUR	O	MIX AREA 12		0.5	1	O	T	I	S	D	
8	MIX (BLOWERS)	O			20	1/2	O	T	I	S	D	BASE MATERIAL, BLOW & ADDITIVES
9	TEST #1	I			30	1+1	O	T	I	S	D	SAMPLE TEST
10	PUMP TO STORAGE TANK	T	STORE TANK	100		1	O	T	I	S	D	DEDICATED RESERVOIR
11	MIX IN STORAGE TANK	O	STORE TANK		10	1	O	T	I	S	D	
12	I.R. REST	I			10	1+1	O	T	I	S	D	STAMP & APPROVE
13	AWAIT FILLING	D			15		O	T	I	S	D	LONGER IF SCREEN LATE
14	TO FILTER HEAD	T		20	0.1	1	O	T	I	S	D	
15	FILL/TOP/TIGHTEN	O	FILLER HEAD		1	1+1	O	T	I	S	D	1 UNIT
16	STACK	T	PALLET	3	0.1	1	O	T	I	S	D	1 UNIT
17	DELAY TO FILL 1 PALLET	D			30		O	T	I	S	D	
18	STRAP PALLET	O			2	1	O	T	I	S	D	
19	TRANSFER TO STORE	T		80	2	1	O	T	I	S	D	
20	AWAIT TRUCK	D	STORE		540		O	T	I	S	D	BATCH 360/ QUEUE 180
21	PICK/MOVE BY FORK LIFT	T		90	3	1	O	T	I	S	D	FORK LIFT
22	WAIT TO UNL FULL LOAD	D	LORRY		30	1+1	O	T	I	S	D	1 OPERATOR, 1 HAULIER
23	AWAIT SHIPMENT	D	LORRY		60	1	O	T	I	S	D	1 HAULIER
	TOTAL		23 STEPS	443	781.2	25	6	8	2	1	6	
	OPERATORS				38.5	8						
	% VALUE ADDING				4.93%	32%						

**Table 3: Process activity mapping (Hines and Rich 1997)**

When eliminating waste and improving the productivity and flow through the value stream, you often reveal underlying factors like poor quality or management problems. This is an ongoing process (ValueBasedManagement.net n.d.).

## Four M

The four Ms focuses team efforts on the man, machine, material, and method issues of value-added process analysis. While these obviously apply to physical processes, Carroll (2008) state that they can be useful in the value-added analysis and improvement of management decision and information/support processes (Carroll 2008).

There are several similar methods suited for different industries. In the service industry you may hear about the Five Ps – People (staff/employees), Provisions (supplies), Procedures (processes), Place (environment), and Patrons (customers/patients) (National Research Council, Canada 2004).

The methods all start with a clear statement of a problem for which you want to find the cause. It may be illustrated quite simple like in Figure 11. You can brainstorm right onto the diagram. To help ensure you really do have a root cause, apply the Five Why (explained later) to each cause.

Identify the factors that most strongly impact the effect. Then you can establish the first root cause to eliminate and attack it using Five S (explained later) or other methods (National Research Council, Canada 2004).

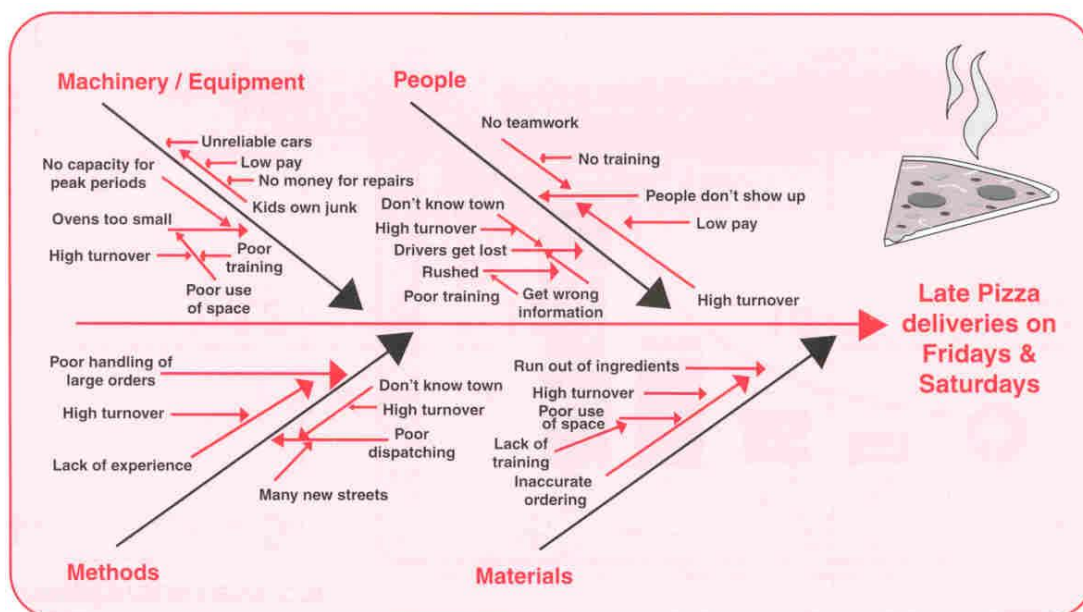


Figure 11: Fishbone diagram (National Research Council, Canada 2004)

## **Five S**

Based on five Japanese words that begin with 'S', the Five S Philosophy focuses on effective work place organization and standardized work procedures. Five S should simplify the work environment reduce waste and non-value activity while improving quality efficiency and safety. Five S is presented below based on data from TPM Online (TPMonline n.d.).

### *1. Sort - (Seiri):*

The first S focuses on eliminating unnecessary items from the workplace. An effective visual method to identify these unneeded items is called red tagging. A red tag is placed on all items not required to complete your job. These items are then moved to a central holding area. This process is for evaluation of the red tag items. Occasionally used items are moved to a more organized storage location outside of the work area while unneeded items are discarded. Sorting is an excellent way to free up valuable floor space and eliminate such things as broken tools, obsolete jigs and fixtures, scrap and excess raw material. The Sort process also helps prevent the JIC job mentality (Just In Case).

### *2. Set in Order - (Seiton):*

The second S focuses on efficient and effective storage methods.

You must ask yourself these questions:

1. What do I need to do my job?
2. Where should I locate this item?
3. How many of this item do I need?

Strategies for effective Set in Order are painting floors, outlining work areas and locations, shadow boards, and modular shelving and cabinets for needed items such as trash cans, brooms, mop and buckets. Imagine how much time is wasted every day looking for a broom? The broom should have a specific location where all employees can find it. "A place for everything and everything in its place."



### 3. *Shine - (Seiso):*

Once you have eliminated the clutter and junk that has been clogging your work areas and identified and located the necessary items, the next step is to thoroughly clean the work area. Daily follow-up cleaning is necessary in order to sustain this improvement. Workers take pride in a clean and clutter-free work area and the Shine step will help create ownership in the equipment and facility. Workers will also begin to notice changes in equipment and facility location such as air, oil and coolant leaks, repeat contamination and vibration, broken, fatigue, breakage, and misalignment. These changes, if left unattended, could lead to equipment failure and loss of production. Both add up to impact your company's bottom line.

### 4. *Standardize - (Seiketsu):*

Now that the first three S's have been implemented, you should concentrate on standardizing best practice in your work area. Allow your employees to participate in the development of such standards. They are a valuable but often overlooked source of information regarding their work. Think of what McDonalds, Pizza Hut, UPS, Blockbuster and the United States Military would be without effective work standards.

### 5. *Sustain - (Shitsuke):*

This is by far the most difficult S to implement and achieve. Human nature is to resist change and more than a few organizations have found themselves with a dirty cluttered shop a few months following their attempt to implement Five S. The tendency is to return to the status quo and the comfort zone of the "old way" of doing things. Sustain focuses on defining a new status quo and standard of work place organization.

Once fully implemented, the Five S process can increase work morale, create positive impressions on customers, and increase efficiency and organization. Not only will employees feel better about where they work, the effect on continuous improvement can lead to less waste, better quality and faster lead times. Any of which will make your organization more profitable and competitive in the market place (TPMonline n.d.).

## **Five Why**

This is a problem solving tool to help you with a root cause analysis. The process starts by asking why a problem or an issue is occurring, and continues when each successive answer is met with another “why” until the root cause is determined, digging down under the obvious reasons (Husby 2007, S. Shingo 2007). Through experience, practitioners learned it rarely takes more than five cycles to locate the root cause (Husby 2007).

This method can be seen as putting yourself in a 10-year old mindset. Children ask repetitive why-questions to make sense of the world around them, because they are eager to learn. Somewhere along the way adults lose that craving and often settle for the easy answer on the surface. This means you waste a lot of time and energy because you end up addressing a symptom instead of the real problem. If the real problem is not dealt with the same symptoms will probably return in the future (Velaction n.d.).

However the Five Why method has its limitations. It is not at all scientific, and is based exclusively from opinions and observations of the people doing the tasks. In fact, several workers in the same group may come to different root causes, or even the same person might come to a different conclusion if the Five Why's were done again a short time later. Because the tool is not repeatable, it's not recommended to use for itself in critical situations. The Five Why's can be used to get the analysis going; however the results should be confirmed with more robust methods (Velaction n.d., S. Shingo 2007).

## **Operations analysis**

According to Shingo (1988) there are two types of operations analysis;

- *Principal-operation analysis*: studies only the main operations/activities in a process
- *Ratio-delay studies*: studies all operations/activities in a process

### **Principle-operations analysis**

Principle-operations analysis can be divided into two types; *motion studies* (devised by Gilbreth) taking only motion into account and *time studies* (devised by Taylor) taking into account time as well (S. Shingo 1988).

## **Motion studies**

In the Japanese writing system, the character (kanji) for work can be divided into three parts:

Person + Weight + Strength = “a person exerting strength on a weighty task.”

In other words we should not assume just because a man is in motion that he is working. Rather, we should confirm that he is exerting his strength in a productive way. In the context of manufacturing this is precisely the sort of action that should be maximized in the movement of personnel. To accomplish this, we must first establish a means of analyzing movement and assessing how it contributes to overall productivity (S. Shingo 2007).

In the early 1900's Frank Gilbreth and his wife Lillian studied individual human motions involved in performing a task. They developed a system of different standardized motions as well as moments of delays to identify unnecessary and inefficient motions so they could be eliminated.

At the abstract level these motions are repeated from the cradle to the grave. Gilbreth called these elemental motions therbligs (their name spelled backwards) and organized them with respect to manufacturing into those that add value and those that are wasteful (S. Shingo 2007).

The system was invented and refined between 1908 and 1924. Several authors have adjusted the system since then, but only minor changes have been made and it is still a work in progress (Ferguson 2000). The system now consists of 18 different motions, and only three of them are considered to be value-adding (S. Shingo 2007, Tesla2-Inc. 2003, S. Shingo 1988).

Shingo (1988) further divided the 18 therbligs into four classes (S. Shingo 1988):

- *Class 1:* These represent the essence of an operation. Generally, they have the highest value.
- *Class 2:* These are preparatory motions for or follow up motions to class 1. They have secondary importance.
- *Class 3:* These are incidental to class 2 motions and make a lower contribution than class 2.
- *Class 4:* These make an even lower contribution than class 3 and should be eliminated to the extent possible.

A major advantage of motion studies is that the division into four classes leads to the uncovering of waste (S. Shingo 1988). All the 18 therblig's are presented in Table 4 and explained further in the following pages by theory from Ferguson (2000).

**Therbligs**

Class	No.	Name	Symbol	Description
1	1	Assemble	≡	Shape of combined rods
	2	Disassemble	⊕	One rod removed from a combined shape
	3	Deform (use)	∪	U for "use," or a cup placed upright
2	4	Transport empty (extending or retracting your hand)	∪	Shape of palm opened up
	5	Grab	∩	Shape of hand grabbing
	6	Transport	∪	Shape of object being transported with hand
	7	Release	∩	Shape of object with hand facing down
3	8	Search	👁	Symbol of searching eye
	9	Find	👁	Symbol of eye having located object after search
	10	Select	→	Symbol of finger pointing at selected object
	11	Inspect	👁	Shape of a lens
	12	Regrasp (reposition)	👁	Symbol of regrasping object held by finger tips
	13	Hold	∩	Shape of rod held with hand
	14	Prepare	👁	Shape of a cuestick standing erect
4	15	Think	👁	Shape of a thinking person with hand by head
	16	Rest	👁	Shape of a person sitting on chair
	17	Unavoidable delay	👁	Shape of tripped person on ground
	18	Avoidable delay	👁	Shape of person lying down

**Table 4: Therbligs (S. Shingo 1988)**

### *Assemble*

This Therblig starts when two or more parts are placed together and ends when either the assembled object is Transport Loaded or when the hand reaches for another part, Transport Empty.

### *Disassemble*

This motion is essentially the opposite of Assemble, depending on the circumstances. While it could be used where a mistake was made in Assemble, it could also be the act of removing a part from a jig or clamp, which held the part during the Use or Assemble motion.

### *Deform (Use)*

This Therblig should not be confused with Assemble. Use is when an object is being operated as it was intended, and typically denotes a tool. For example, we would assemble a drill by placing a drill bit in the chuck and tightening it, but we Use the drill to bore holes. Operation of controls on a machine would also be considered Use.

### *Transport Empty / Unloaded*

This is the motion of moving the unloaded hand from the point of Release Load, to the next function within the sequence. It can also be considered the hand motions involved between Select and Grasp, where the eye identifies the object and the hand moves towards it to grasp.

### *Grab*

In simplest terms, Grab is when a worker's hand grabs an object. The Therblig ends when the next Therblig, of Use or Transport Loaded, begins. The Gilbreths also recognized that when Grab was a static position, such as holding a block of wood while a screw was being inserted, it should be eliminated by using a jig or foot-activated clamp or other holding device. They felt that the hand was a poor vise and caused great fatigue. Alan Mogensen and Ralph Barnes separated this into a new Therblig, namely Hold.

### *Transport Loaded*

This Therblig begins after Grab where the hand is doing "work" by moving the weight of an object, and ends when just before the Release Load, Use or Assemble Therbligs. The main objective of this Therblig is to reduce the distance and subsequent time involved for transport.

### *Release*

This motion involves releasing the object when it reaches its destination. The actual time taken will be fractions of a second.

### *Search*

The Search motion starts when the eyes and/or hand start to seek the object needed and ends just as the object is located. To reduce time spent for Search, tools and parts should be arranged in a sequence of use, or more adapted to construction it means the workplace should be well organized.

### *Find*

Dr. Ralph M. Barnes has eliminated this Therblig, explaining that it was a mental reaction, at the end of the Search cycle. While other mental processes are included as Therbligs, this one is so momentary that the time taken for the Find function would be hardly worth measuring. It has been left in, since it may be utilized in other situations.

### *Select*

This Therblig may be considered a part of Search. However, through usage by the Gilbreths, it was found to indicate locating an object from a group of similar objects. The important thing to remember is that the Search, Find and Select Therbligs may or may not be separate elements, depending entirely on the type of work being analyzed.

### *Inspect*

This Therblig involves the act of comparing the object with a predetermined standard. This act can employ one or all human senses, depending on the object and the desirable attributes being checked. The inspection can be for quantity (amount or size) or quality. The motion starts when the item is first picked up or viewed and ends when it is either released or used in assembly.

### *Regrasp (Re-position)*

This motion is the act of placing the object in the proper orientation for Use. For example, a screw lies on the workbench in a horizontal orientation, but is to be used in a vertical position. Regrasp would occur when the screw is picked up and rotated into the vertical position for inserting it into an object. This function may be completed during Transport Loaded or be a totally separate Therblig.

### *Hold*

Dr. Ralph Barnes said this Therblig was "...the retention of an object after it has been grasped, [with] no movement of the object taking place." To clarify, we can call Hold a Grab, of an object, occurring in one hand, while the other hand performs a Use or Assemble function.

### *Prepare*

This is the motion of replacing an item in the proper orientation for its next Use. In the example of the pen being in a holder on the table, the act of replacing the pen, in the proper Position for its next use would be Prepare. Like Regrasp, it can be performed during Transport Loaded.

### *Think (Plan)*

This Therblig is a mental function, which may occur before Assemble (deciding which part goes next) or prior to Inspection, noting which flaws to look for. The extent of the use of Think varies greatly with the type of job performed. However, in routine jobs, the time spent in the Think Therblig should be kept to a minimum through arrangement of parts and tools.

### *Rest*

This Therblig is actually a lack of motion and is only found where the rest is prescribed by the job or taken by the worker. In the Gilbreths' scheme of Fatigue Reduction, after you had eliminated all unnecessary motions and made necessary ones as least fatiguing as possible, there would still be the need to rest.

### *Unavoidable Delay*

This Therblig is measured from the point where a hand is inactive to the point where it becomes active again, with another Therblig. These delays were defined by Gilbreth, as being out of the control of the particular worker being studied. They could involve a lack of raw materials being available or repair of a tool, etc. While these delays might be dealt with by the overall factory/business system, they were not considered the responsibility of the individual operator.

### *Avoidable Delay*

This counterpart to *Unavoidable Delay* involves inactive time the worker encounters over which he/she has control. For example, if the worker is required to do inspections of their tools and report problems, and the result is a tool that breaks in the middle of the shift, the worker is responsible for the delay.

Most of the therblig's can be related to time, measuring how much time the worker spends doing each therblig. However Gilbreth was not concerned with Time Study and never assigned time for each of his basic elements of motion. He was interested only in eliminating unnecessary movements, believing the shortest cycle time would follow (S. Shingo 2007).

### **Ratio-delay studies**

This is an analytical method in which all of an operation's elements (preparation, after-adjustment, the operation itself and margin allowances) are considered in order to analyze the operation's status. However, because principal operations (mounting, cutting, removing) are captured in *principal-operations analysis* the purpose of *ratio-delay study* is to analyze phenomena that occur irregularly, such as preparations, setup, marginal allowances for fatigue and personal hygiene needs at the workplace (S. Shingo 1988).

There are two ways of performing a ratio-delay study (S. Shingo 1988);

- *continuous ratio-ratio delay study*
- *snap reading or work sampling*



In a *continuous ratio-delay study*, the entire working time is continuously measured using a stopwatch, and because a ratio-delay study is generally performed continuously for an entire day or week it is a laborious process.

To solve this problem, inductive statistics were used to develop *snap reading* and *work sampling*, which are sampling observations. With these methods, four to five observations are made per hour, which makes observations much easier.

Ratio-delay studies are generally conducted for two reasons, (1) to improve the operation rate by studying the preparation work, setup and margin allowances, or (2) to establish the proper margin allowances (S. Shingo 1988).

### **2.3.6 Lean Manufacturing Critique**

Scientists have different opinions about Lean practice and some claim it will result in negative side effects. The consequences for employees are specially emphasized.

Bård Karlsen (Lean Consultant at Ernst & Young) believe that many companies choose Lean methods, because it's a way to heal itself rather than hiring consultants to give them a solution right away. The important is that it provides considerable results and it's popular among employees when it's done right. Lean is about doing more with fewer resources and removing waste. In practice it's actually an alteration of the company culture. It is about involving and respecting every worker, because in the end it's the workers themselves that have to solve the problems (Amundsen and Haugsbø 2010).

Asmund Høigaard (Lean Director at Ringnes) agree and states the importance of the fact that the measures cannot come from people sitting behind an office desk, they have to seriously involve the workers in the process. He also claims that Lean is actually just about common sense put into a system (Amundsen and Haugsbø 2010).

Atle Nordli (associate professor at Norwegian School of Management) claims Lean is nothing but the Emperor's New Clothes; it's nothing new. Nowadays all efficiency measures are called "Lean", it's a consultant driven hype. Most efficiency measures give good results, it's really just good old methods. One main problem with the theory is the principle of minimizing

inventory. Companies have gone bankrupt as a result of reducing inventories too much. Companies can get very vulnerable with a low inventory (Amundsen and Haugsbø 2010).

Parker (2003) has conducted a three years quasi-experimental field survey of an English production company, where she studied which effects Lean principles have on the company's employees. Parker concludes that Lean production will result in a reduced commitment towards the employer, reduced work freedom, increased stress level, increased group pressure from colleagues and weakened motivation as a result of unclear work tasks (Parker 2003).

Berggren (1993) claims that Japanese car manufacturers can offer its employers better work safety, fewer levels of hierarchy in the company, professional pride and a high level of involvement in improvement processes compared to American car manufacturers. On the other hand Berggren states that such a production system results in unlimited performance requests and work hours, recurring health and safety complaints and a fully rigid production regime (Berggren 1993).

Further Mehri (2006) criticize Toyota and Lean production in general, for hiding disadvantages in the production systems behind a curtain of formalities and reports from management. Mehri has been working within the Toyota Corporation earlier and states that TPS limits the potential for creativity and innovation and also contributes to covering up for work accidents. In addition he claims TPS and Lean leads to hazardous working conditions along the production line, narrow work tasks, excessive use of overtime, isolation of employees as well as bullying and lower quality of life among the workers (Mehri 2006).

Vidal (2007) claims the lack of buffers in the system and increased area of responsibility as a result of Lean implementation often generates increased level of stress and frustration among the employees (Vidal 2007).

## **2.4 Lean Construction**

### **2.4.1 Introduction**

Lean Construction is a translation and adaptation of the Japanese Lean Manufacturing principles and practices to the end-to-end design and construction process. This approach tries

to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela, Howell, et al. 2002). The goal is to eliminate waste (non-value adding activities) by organizing interdependence, improving reliability, reducing uncertainty and integrating production management (Bertelsen 2004, Dugnas and Oterhals 2008).

While Lean Manufacturing was successful in car manufacturing industry, many believed it would not be applicable in the dynamic and complex world of construction. Manufacturers make parts that go into products. While the design and construction of unique and complex projects, in highly uncertain environments under great time and schedule pressure, is fundamentally different (Daeyoung 2002, Dunlop and Smith 2004).

The goal of a project meeting specific customer requirements delivered in zero time sounds like the objective for every project. So how does the Toyota system apply in construction?

## **2.4.2 Fundamentals of Lean Construction**

Lauri Koskela lists these differentiating characteristics: “...*one of a kind nature of projects, site production, and temporary multi-organizations*” (L. Koskela 1992).

In construction, the concept of site production refers actually to a bundle of features:

- Site as a resource: the site is a necessary input resource for production;
- Creating the production infrastructure: the production infrastructure (machines, manpower, etc.) has to be planned, procured and set up on site;
- Space needed by production (workstations move on the product): the spatial flow of workstations (teams) has to be coordinated (in contrast to a factory, where only material flow through workstations is planned).

Lean Construction has the following essential principles (Chitla 2003, L. Koskela 1992):

- Clear set of objectives to be established for the delivery process. Customer needs and requirements are well understood;

- A cross-functional team designs product and process concurrently, to give more value to the customer needs – this process of parallel design helps positive iteration within the process and negative iteration is reduced;
- Shifting design work along the supply chain to reduce the variation and match the work content;
- Reducing cycle times. The different ways to reduce cycle times include eliminating work-in-progress, reducing batch sizes, optimizing plant layout, reducing variability, changing activities from sequential order to parallel order, and isolating the main value-adding sequence from support work;
- Build continuous improvement into the process. The effort to build continuous improvement into the construction process is to reduce waste and ensure continuous and sustainable workflow.

Ballard (1994) states that one of the most effective things managers can do to improve construction productivity is to improve planning. Subsequently, a well-executed project mirrors its production planning. Good production planning comprises planning elements that can effectively be executed (G. Ballard 1994). However being flexible and able to readapt your production plan taking into account eventual deviations observed during the daily sequence of jobsite operations is just as important as planning projects itself (Conte and Gransberg 2001).

Because construction's objects are rooted in place, the relationship with customers is different than perhaps for any other type of production. The customer is not intimately involved in the extraction of minerals or the production and harvesting of timber. But construction's customer often walks through the construction site as the object is being produced. Because the objects are rooted in place, it is much more difficult to find alternative customers (Ballard and Howell 1998).

Construction at the site is now a combination of fabrication and assembly (Ballard and Howell 1998). Industrialization initiatives advocate simplifying site construction to final assembly and testing in order to shift as much work as possible into shop conditions where it can be done more efficiently. Given that construction is essentially site production, final assembly will always be done on site, although the extent of that work will vary with the stage of

development and the facility being assembled. The key to efficient site assembly is planning and control, the processes that produce directives, thereby conditioning discretionary work choices and coordinating flows so those choices can be closer to optimal (Ballard and Howell 1998).

Koskela and Huovila (1997) have proposed three ways of conceiving design:

- as a process of converting inputs to outputs (conversion process)
- as a flow of information and materials (flow process)
- as the generation of value for customers

All are necessary, but the conversion process model has dominated thinking and practice about both manufacturing and construction until recently. The Lean revolution is essentially a conceptual revolution, at the heart of which are the flow and value models. The flow model facilitates waste reduction. The value model facilitates value maximization. To date, most Lean thinking in construction has concerned waste reduction (Koskela and Huovila 1997).

Below there is a table showing the translation of the seven types of waste from manufacturing to construction as presented by Diekmann, et al. (2004).

<b>Type of Waste</b>	<b>Manufacturing</b>	<b>Construction</b>
1. Over-production	Production of too many units or parts due to push nature of manufacturing.	Overbuilding a particular aspect of a project, either because it was over engineered or a process was started before it was really needed.
2. Waiting	Time spent waiting for the next batch of parts to arrive from the previous conversion process. Time spent waiting for an aching to finish.	Time spent waiting for other work crews to finish their particular conversion process so that the next conversion process may begin. Time spent waiting on crew members of a specific team. Time spent waiting for parts or instructions.
3. Transport	Wasted effort to transport materials, parts or finished goods into or out of storage between processes.	Wasted effort to transport building components or tools into or out of job trailers or storage between processes.
4. Extra Processing (Operations)	Doing more work than is required.	Waste associated with rework, re-handling or storage caused by defects in design, fabrication or construction activities.
5. Inventory	Maintaining excess inventory of raw materials, parts in process or finished goods.	Maintaining excess inventory of construction components, equipment or tools.
6. Motion	Waste associated with unnecessary worker/equipment movement between work stations.	Waste associated with unnecessary worker/equipment movement around the construction site.
7. Defects	Repair or rework.	Deficiencies in the finished product that require additional work or rework to correct punch list items.

**Table 5: Waste in Lean Manufacturing vs. Lean Construction (Diekmann, et al. 2004)**

In conventional construction, production is conceived as a series of activities and efforts to improve are aimed at each activity paying little attention to how value is created and flows to the customer (G. Howell 1999).

Lean construction is the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project (Diekmann, et al. 2004).

In the report by Diekmann et.al (2004) it was determined that Lean behavior among construction contractors is rare, even with contractors who are actively pursuing the Lean ideal, because being truly Lean requires changes to every aspect and level of a company (Diekmann, et al. 2004).

### **2.4.2 Lean Construction principles**

In various subfields of the new production philosophy, a number of heuristic principles for flow process design, control and improvement have evolved. There is ample evidence that through these principles, the efficiency of flow processes in production activities can be considerably and rapidly improved (L. Koskela 1992).

The principles were formulated after nearly ten years of work by Koskela 2000 and in more detail by Ballard in 2001. During the development of the guiding principles Bertelsen (2004) states that from the beginning the idea was generally: “*While delivering the project, maximize the value for the client and minimize the waste*” (Bertelsen 2004). The principles are believed to be crucial to Lean Construction however most of them also apply to Lean Manufacturing (L. Koskela 2000).

In general, the principles apply both to the total flow process and to its sub-processes. In addition, the principles implicitly define flow process problems, such as complexity, in-transparency or segmented control. The 11 principles are presented below.

1. Meeting the Requirements of the Customer
2. Reducing Non-Value Adding Activities
3. Reducing Cycle Time
4. Reducing Variability
5. Increasing Flexibility
6. Increasing Transparency

7. Maintaining Continuous Improvement
8. Simplifying by Minimizing the Number of Steps, Parts, and Linkages
9. Focusing Control on the Complete Process
10. Balancing Flow Improvement with Conversion Improvement
11. Benchmarking

Experience shows that these principles are universal: They apply both to purely physical production and to informational production, like design. Also, they seem to apply both to mass production and one-of-a-kind production (L. Koskela 1993). These 11 principles are quite similar to the 14 principles of Lean Manufacturing, just sorted in another way.

It is also necessary to emphasize that Lean is about developing and customizing principles that are right for each specific organization and diligently practicing them to achieve high performance that continues to add value to customers and society (J. K. Liker 2004).

### **2.4.3 Lean Construction implementation**

Becoming a Lean contractor is difficult in part because of the dynamic nature of construction, but mostly because construction contractors control such a small portion of the construction value stream.

Implementing Lean Construction has certain key differences from implementing Lean Manufacturing including (Howell and Ballard n.d.);

- Decentralized decisions
- Controlling processes
- Managing for throughput not point speed
- Improving reliability

For those wishing to start the Lean journey in their company, a Lean workplace can be created using the following steps (Diekmann, et al. 2004):

- Identify waste in field operations
- Drive out waste



- Standardize the workplace
- Develop a Lean culture
- Involve the client
- Continuously improve

Becoming Lean is a long-term, comprehensive commitment; it amounts to a cultural change for the company. Construction is no simple deterministic system, hence Lean principles must be understood and applied in a context and require a comprehensive understanding of a complex interacting and uncertain construction system. Many Lean principles can be understood as attempts to increase preplanning ability, improve organizational design and increase flexibility (Diekmann, et al. 2004).

In this light, the final conclusion is that Lean cannot be reduced to a set of rules or tools (Diekmann, et al. 2004). It must be approached as a system of thinking and behavior that is shared throughout the value stream. Given that contractors control such a small portion of the construction value stream (as compared to their manufacturing counterparts) this is the challenge that faces the potential Lean contractor. If successfully applied, however, Lean has the potential to improve the cost structure, value attitudes and delivery times of the construction industry (Diekmann, et al. 2004).

Implementing Lean Construction does not require making construction manufacturing by standardizing products or using standard Lean tools explicitly. Implementing Lean means adopting a “project-as-production-system” approach to construction, defining the objective in customer terms, and decentralizing management to maximize throughput and reduce inventories (Ballard and Howell 1998).

The Last Planner system is considered to be a very important part of Lean Construction, as it has showed an efficient way of understanding and managing the flow aspect of the construction process (Bertelsen 2004).

## **2.4.4 Lean Construction tools**

### **The Last Planner system**

In conventional planning the basis is predictable production, hence it can be planned with an expectation that the plans will be followed. On the contrary the world is complex and dynamic, and systems designed to cope with such complexity are often chaotic (Fafo n.d.).

This is the basics behind the Last Planner system, an important method within Lean Construction. Last Planner advances the actual production planning until as late as possible in the process, and at the same time place the plans as close as possible to the operations, physically, mentally and organizationally. This plan should also be fairly reliable, and the reliability is continually measured in a simple way with PPF (Percent Planned Finished). PPF measures the percent of the planned completed work packages that are actually completed within the planning horizon. Failing to fulfill the planned operations will immediately trigger an investigation of causes for the failure, and if possible the cause is removed to avoid a recurrence of the failure (Fafo n.d.).

Ballard (1994) states; Construction requires planning and control done by different people, at different places within the organization, and at different times during the life of a project. To plan from high up in the organization tends to focus on global objectives and constraints, governing the entire project (G. Ballard 1994).

These objectives drive lower level planning processes. Ultimately, someone (individual or group) decides what physical, specific work will be done. That type of plans has been called "assignments". They are unique because they drive direct work rather than the production of other plans. The person or group that produces assignments is called the "Last Planner" (G. Ballard 1994).

## **2.5 Lean Shipbuilding**

### **2.5.1 Introduction**

The worldwide research in this area is limited. Firstly, such limitation is due to the fact that Lean Shipbuilding is actually quite similar to Lean Construction. Secondly, the term itself has not yet become a concept with a solid theoretical base (Dugnas and Oterhals 2008).

### **2.5.2 Lean Shipbuilding in Norway**

Both branches (construction and shipbuilding) are project-driven and deliver products which normally are one-of-a-kind. However, there are some characteristics that differentiate Norwegian shipbuilding from constructing buildings, roads, tunnels, etc.

The shipbuilding industry in Norway bases its production on different phases due to the specific competition conditions. The key-trend now is to outsource the hull fabrication and primary outfitting to the low-cost countries. The remaining work is done at outfitting yards in Norway. Hence, there are usually four key-production phases (Dugnas and Oterhals 2008):

- Hull fabrication
- Primary outfitting
- Final outfitting
- Testing

Such production set-up is believed to be one of the reasons why phase-based project management, supply chain management, project logistics and planning are the areas with the highest potential for improvement. While SCM and planning are widely known issues, the remaining two are relatively specific regarding shipbuilding in Norway. Dugnas and Otherhals (2008) give brief descriptions of both, project logistics and phase-based project management – in the shipbuilding context (Dugnas and Oterhals 2008).

Within the Lean Shipbuilding program the concept of project logistics is understood as the flow of parts and components *within* a shipyard facility. The focus is on optimization of internal logistics by analysing and modelling the following;

- transportation times and equipment;
- pre-fabrication and assembly times;
- facility layout;
- storage of parts and components.

Simplification, visualization, and information flow are the key-words.

While project logistics is dealing with internal issues, phase-based project management has a wider scope and mainly addresses project (construction) activities which are carried out in later project phases than initially planned. Having in mind the complexity of such one-of-a-kind projects which contain thousands of work packages, the lack of control of phases and their transition poses a significant threat. In Norwegian shipbuilding context it means a significant increase in project cost, disruption of workflow and planned work sequence, overburdening of workforce, and ultimately, can result in late delivery of the final product.

Global supply chains make the situation even more complex. Hence, emphasis in phase-based project management is put on (Dugnas and Oterhals 2008):

- identifying project phases
- identifying problems in different phases and tracking reasons for plan non-conformity at project level
- identifying the scope of loss due to activity movement to later project phases – rises the motivation for countermeasures
- preventing problems from re-occurring in future projects by developing an improved planning system.

Such system should take into consideration all the above mentioned issues and ensure that all of the activities are performed in their respective phase. All these elements fit to Lean Shipbuilding program framework quite well. Hence, Phase-based Project Management would hopefully become one of the specific Lean Shipbuilding methodologies (Dugnas and Oterhals 2008).

The above mentioned production set-up and “focus areas” require a specific approach while attempting to define the Lean Shipbuilding concept. Dugnas and Oterhals (2008) believe that

further outlined characteristics of shipbuilding as an industry will be enhanced as worldwide research progresses.

So why cannot shipbuilding be treated exactly the same way as construction, when it comes to transfer and implementation of Lean principles? Dugnas and Otherhals (2008) present the following characteristics:

- Design, Supply Chain Management and production activities are integrated and carried out simultaneously – it is rather a rule than exception
- Production facilities are the same and their layout is usually optimal for different projects with similar logistics requirements
- Significant prefabrication and pre-outfitting of units and modules off-site
- Advantage of supply network within the Norwegian Maritime Cluster
- Significant customization and innovation – also during the construction phase (change orders are common)
- Capacity constrained industry (lack of workforce, critical lead times)
- There is less randomness in shipbuilding projects' organisation if compared with construction
- Even if shipbuilding belongs to “one-of-a-kind” industries, there are some features similar with mass-production, e.g. production line for pipe fabrication

All the above issues make a background for analysis on researchers' way towards definition of the Lean Shipbuilding concept (Dugnas and Oterhals 2008).

In addition, each shipyard has its specific strategy, organization and facility layout. Hence, in order to assess long-term feasibility and sustainability, it is necessary to consider similar issues, such as proposed by (Quarterman 2007):

- Do we need the entire list of “tools” and techniques?
- If not, which do we employ?
- Which elements come first?
- What brings quickest benefits and strengthens motivation immediately?
- Do we implement plant-wide or in focused areas?
- How does kaizen fit into the picture?

- How detailed should the plans be?
- How do we know when we are really Lean?

## **2.5.2 Shipyards Internationally**

When the Japanese restarted shipbuilding after World War II they were not as productive as the world leading shipyards in Britain and Northern Europe. They also had a reputation of lacking innovation/creativity and delivering poor quality products. However from 1960 to 1965 Japanese shipbuilders improved their productivity by 100%. They did this by further developing the structural block construction approach and pre-outfitting that was started in the U.S. and Europe during World War II.

From 1965 to 1995 they improved their productivity by 150%. This was accomplished by perfecting the structural block construction approach and developing advanced zone outfitting. This was further aided by their excruciating attention to every detail in design and construction to eliminate waste.

A major factor was their involvement of all employees in the continuous improvement effort, not just management and some technical employees. Other important factors (now Lean manufacturing principles) were standardization, one piece flow, flow smoothing, focus on elimination of waste, group technology and part families, dedicated interim product lines, continuous improvement, and multi-task assignment for employees. They have also applied Five S to some level (Liker and Lamb 2000).

A comparison showed that US shipyards was half as productive as European shipyards and one third as productive as Asian shipyards. This was based on the internationally accepted productivity metric Compensated Gross Tonnage (CGT), which accounts for differences in size and complexity of the ships (Liker and Lamb 2000).

This indicates that Asian shipyards have come closer to practicing Lean Shipbuilding than US and Europe. However the productivity metric (CGT) might not sufficiently account for the differences in technology and complex equipment used on the vessels, neither the number of change-orders and level of customization. It's not proven that an Asian shipyard can actually build a vessel like Ulstein 287 much more efficient than a European or Norwegian shipyard.

For Ulstein the competitive advantage is to offer one-of-a-kind, high-tech, highly customized vessels, which many of the Asian shipyards cannot and will not do.

## **2.6 Theoretical summary**

This chapter has presented the theoretical concepts relevant for the research and analysis later in the thesis. The wider concept of Conversion model vs. Flow model was presented, before moving into Lean Manufacturing, looking deeper into the relevant principles and tools. Then the similarities as well as the important differences between Lean Manufacturing and Lean Construction have been pointed out, before introducing Lean Shipbuilding as a fairly new concept.

The theory regarding Lean Manufacturing presents the relationship between value and waste (with seven types of waste), to help outline the difference between VA, NVAR and NVA activities. Together with operations analysis and motions studies (therbligs) these theoretical concepts give a good indication of how the work-time utilization model should be defined.

Further the Five Why and Four M tools were applied to reveal root causes hindering work flow. And finally the tools Last Planner and Five S play an important role in the suggestions for improvement in relation to the seven types of waste.

## 3 Research design

### 3.1 Introduction

In this chapter methods for answering the research problem will be presented. The focus has been on carrying out a case study at Ulstein.

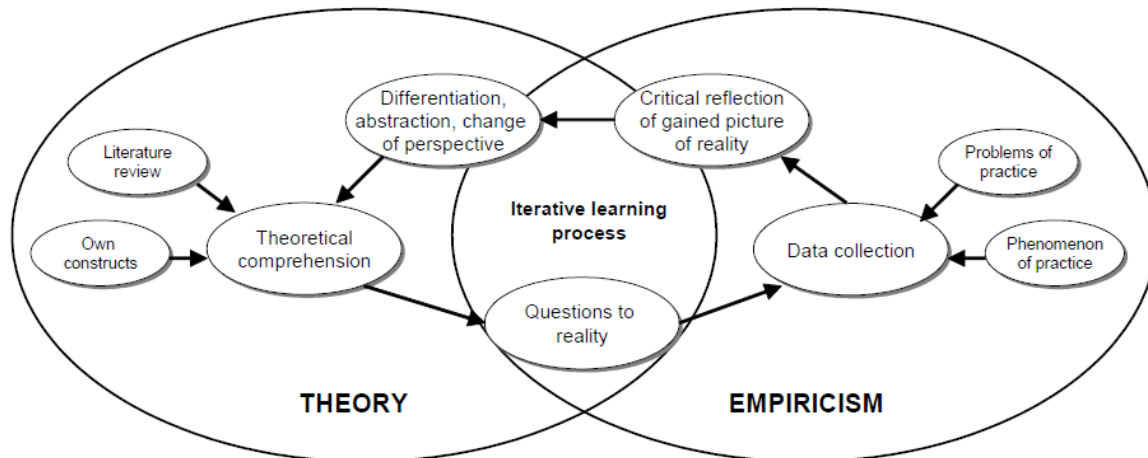
#### 3.1.1 Case study method

Case studies is important in the field of logistics and operations management for new theory development because eventually, the explanation of quantitative findings and the construction of theory based on those findings will ultimately have to be based on qualitative understanding (Meredith 1998). Meredith (1998) cites these three strengths of case studies originally presented by (Benbasat, Goldstein and Mead 1987):

1. The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing actual practice.
2. The case method allows the much more meaningful question of *why*, rather than just *what* and *how*, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon.
3. The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

Figure 12 describe the case study as an iterative process between theory and empiricism, as presented by (Angerer 2005):





**Figure 12: Iterative learning process**

Stake (1995) and Yin (1994) identifies at least six different sources for evidence in case studies and it may require different skills to use them. Not all sources are required in every case but the importance of multiple sources of data to the reliability of the study is well established (Stake 1995, Meredith 1998).

- Documents
- Archival records
- Interviews
- Direct observation
- Participant-observation
- Physical artifacts

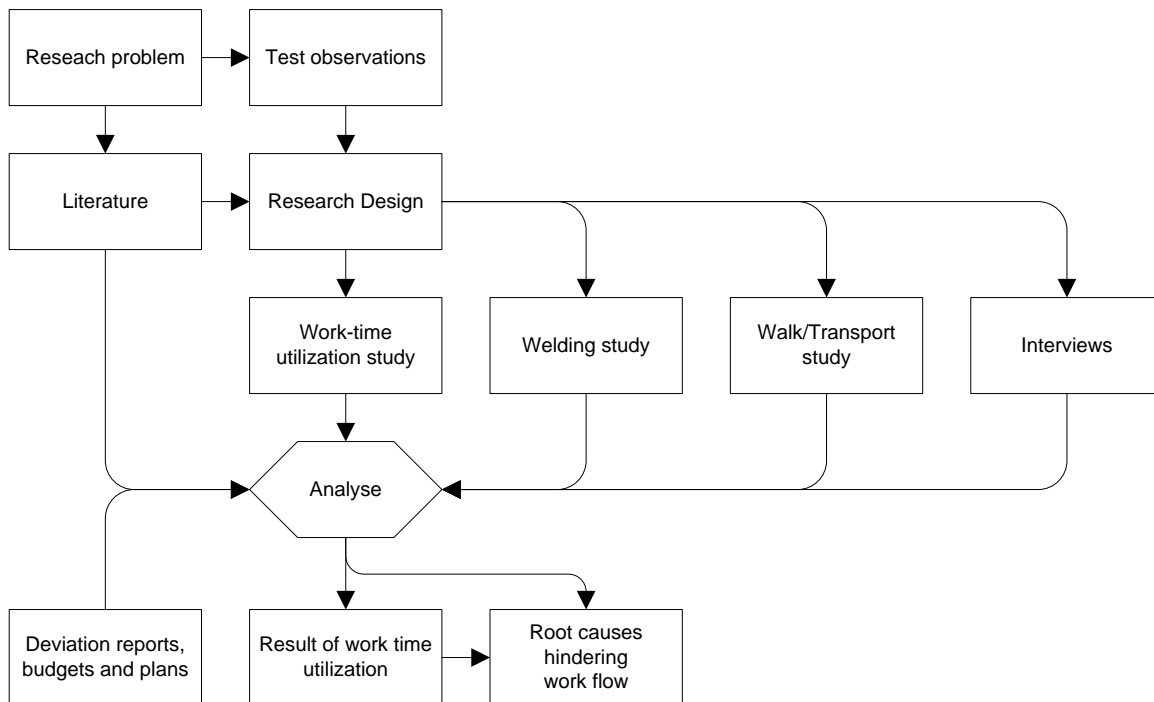
In this research four of the six sources are used. A work-time utilization study was conducted by observing workers at the site. To support the work time utilization study a measuring of effective arcing time in welding were completed. In addition a study of walk/transport patterns in and out of the vessel were carried out after discovering what seemed to be more than necessary walking back and forth at the site. All of these can be seen as sources of direct observations.

Four key contacts at the shipyards were interviewed to underpin the findings from the observations (interviews).

Deviation reports from weekly meetings have been reviewed looking for main causes for deviation in planned operations vs. finished operations (archival records). Also budgets of needed work hours per vessel have been reviewed for calculations (documents).

- Primary data: Observation studies and interviews
- Secondary data: Deviation reports, budgets, plans and Lean theory

Figure 13 illustrates how the research problem was attacked.



**Figure 13: Research approach**

### 3.2 Work-Time Utilization Study

In this study the goal was to create a picture of what workers spend time doing at work, and how much of the time that is spent on the different activities. In a Lean perspective it was interesting to find how much time that was spent on value adding vs. non-value adding activities. In addition Ulstein wanted to know about how the time was spent on more specific activities like; plan, walk, clean, wait, rest, ect. inspired by the figure in appendix 7.4.

### **3.2.1 Vessel #287**

In collaboration with Ulstein the decision was made to focus on vessel #287 in the research work. The vessel will basically be constructed identical to the sister ship #283 (appendix 7.2 and 7.3), however some changes will often occur in a large project like this. The master schedule for vessel #287 is attached in appendix 7.9. However the schedule does not include a lot of information about the different activities onboard or the sequence between them. The general phases of building this kind of vessel is described below.

- Signing contract
- Planning phase, design and technical specifications
- Empty hull is fabricated in Ukraine
- Superstructure fabricated in Vanylven, Norway
- Tow empty hull to Ulstein, Norway
- Empty hull arriving at Ulstein
- Hull placed into dry dock
- Cut out openings for in-transport
- In-transport of engines and other large equipment
- Mount equipment and seal openings
- Installing pipes for plumbing / air-condition
- Insulate walls and floors inside accommodation part of the vessel
- Paint inside of vessel
- Wiring electric cables and equipment
- Hull out of dry dock
- Testing

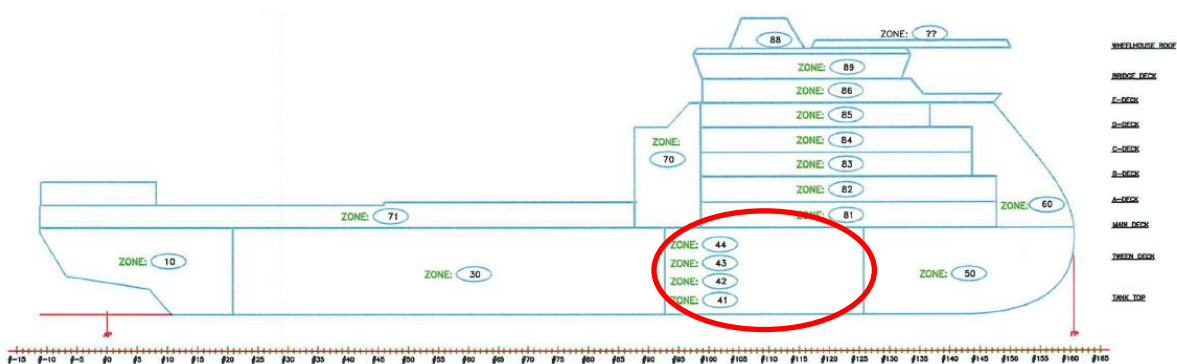
As the observations in this thesis were carried out in the start phase of the construction the activities listed below are the most common to observe:

- Welding
- Cutting
- Grinding
- Transport of materials/equipment into vessel
- Assembly and fitting of pipes/equipment

- Installation of pumps/equipment
- Insulation of walls and floors
- Laying of floors
- Painting

### 3.2.2 Planning phase

After the first visit at Ulstein the plan was to carry out a value stream mapping (VSM) in form of a *process activity mapping* like the one illustrated in Table 3. It gives a good basis for measuring VA- and NVA activities in a Lean perspective. In collaboration with Ulstein it was agreed to perform it within a limited area on vessel #287, namely the machine room (Figure 14), because this is an area with a lot of activity in the early phase of the construction. The *process activity mapping* would be following a few projects within that area. After completing the VSM a portion of the activities can be summarized as VA and NVA. This approach however requires the use of observations, stopwatch and a very good overview of all the processes and people involved in the operations observed.



**Figure 14: Machine room, vessel #287**

When visiting Ulstein the second time to start test observations the idea of a *process activity mapping* seemed too ambiguous. Many of the projects onboard at the early stage is large and involve many workers as well as several different disciplines, hence it would be easy to get confused and lose track during the measuring. The method would probably work better in a manufacturing company with a more transparent production line where you can follow the product through the value stream, or at least a part of it. Like one of the contact persons at

Ulstein stated: “*It’s not like we are manufacturing matches here at Ulstein. It is a bit more complex.*”

Another issue influencing the decision of moving away from the idea about *process activity mapping* was the fact that Ulstein did not want any measuring of workers with stopwatches or interfering with the workers more than necessary.

The authors have the understanding that there are two main ways of performing a study of VA vs. NVA time:

- Follow the product(s) through the value stream and see how much of the time they are being worked on or added value. A relevant method would be *value stream mapping*.
- Follow the workers and see how much of the time they spend at work that is actually adding value to the product(s). A relevant method would be *operations analysis*.

The objective of the thesis is to measure utilization of work-time among the workers. Not the VA portion of a products total cycle time through the value stream. The authors realized that VSM was not the most convenient way to carry out a study like this, so instead the focus was aimed at *operations analysis*.

To investigate this, the theoretical framework presents two main methods for operations analysis; *principal-operations analysis* and *ratio-delay study*.

To repeat the main differences from the theory:

- *Principal-operation analysis*: studies only the main operations/activities in a process
- *Ratio-delay studies*: studies all operations/activities in a process

In this thesis it was interesting to measure not only the main repeated activities in a process. However it will not focus on observing all the rare activities either, so the solution might be somewhere in between. It is interesting to observe all activities occurring during a normal working day. *Principle-operation analysis* presents therbligs which define the different motions in relation to the Lean framework. Ratio-delay studies present *snap reading* as a method of carrying out observations. In other words a combination of tools from the two methods might be applied.

There are several ways to carry out this kind of observations;

- Follow one worker for an entire day and measure his/her activities
- Observe “all” workers from a high platform, and log their movements/activities over a certain period of time
- Observe workers along the way taking “snap shots” of workers as you see them

To follow one worker up close is a laborious process and it would violate Ulstein’s wish of not interfering in the construction. Besides it would give results for a single worker and a single project, and as a result the data collected would be impossible to generalize.

Observing all workers for a period of time is difficult because a lot of the work occur inside the vessel, hence you cannot see them from the outside. This means you will only see one portion of the workers and not all of them.

To make sure the research was carried out in a way that could provide sufficient results a key person was contacted. Sven Bertelsen, a Danish expert within the field of Lean Construction had ideas about the most convenient methods for carrying out these kinds of observations. Bertelsen has been working with Ulstein for several years in their activities towards a Lean approach. What Bertelsen recommended as an observation approach was to simply observe workers along the way, and note what they seem to be doing in the split second you see them (snap reading). If they work, note work, if they walk, note walk or if they rest, note rest. Putting this down for every worker will give an impression of the general situation on the worksite, in other words how much time that is spent on different activities.

Walking around the vessel carrying out *snap reading* observations of workers seemed like a convenient method to carry out the study. *Operations analysis* is like most of the Lean tools best suited in a manufacturing environment. However as it focus on the workers instead of the product, the authors believe it will be easier to adapt for use in a construction environment where a large complex vessel is the product. According to Bertelsen this method is not especially scientific. With that in mind emphasis has been put into approaching the study in a scientific way with clear definitions and easily repeatable methods to get a satisfactory result.

As described several factors were emphasized in the choice of research method:

- Limited time frame of the thesis

- Complexity of carrying out the observations
- Possibilities for a good result which could be generalized
- Comments and wishes from Ulstein

The authors felt therbligs represented a logical starting point as the different motions are already defined within the Lean framework. Although some of the motions seem insignificant in a construction environment the authors will try to adapt it in a sensible way in the next section.

### **3.2.3 Definitions**

The definitions in this research are built on the framework of therbligs, the review of an earlier work-time utilization illustration at the shipyard (appendix 7.4), definitions of VA, NVAR and NVA activities by (Diekmann, et al. 2004) as well as wishes and suggestion from Ulstein.

To put the results in a Lean perspective the authors chose to define different categories to place the workers into depending on what they were doing, and then further determine the categories to be VA, NVAR and NVA. The definitions are very important, but difficult to do accurate. For instance; *transport* can be both NVAR and NVA, depending on the purpose of the transportation. And for a third party that is difficult to determine without more information.

The illustrations from a seminar at Ulstein (appendix 7.4) do not fit well enough into a Lean perspective in the way they are presented. The way productive-, non-productive- and counter-productive activities are divided it lacks a solid linkage to Lean.

*Example: Walk is defined as a productive activity, and it is certainly not value adding according to Lean.*

The basic 18 therbligs cannot be employed either without some modifications, because several of them are insignificant in a construction environment.

*Example: Find and Select are mental states, hence impossible to observe at a construction site.*

So before the real measuring started, some test observations were carried out. Through the tests categories for observations and the route used was decided. The categories are linked up with the framework of therbligs and the seven types of waste from TPS by Ohno (1988), and they are sorted according to the three main types of activities occurring in a value stream, namely VA, NVAR and NVA (Womack and Jones 2003, Diekmann, et al. 2004).

In the following section the different categories used during observations will be explained along with their relation to therbligs and the types of waste. A summary of the categories can be found in Table 6.

### **Value adding activities (VA)**

In this research, the term VA activities will be defined as “...*any activity that changes the shape, form, or function of materials or information to meet customer’s needs*” (Walbridge Aldinger 2000). This definition excludes common construction work such as material handling, inspection or temporary structures. Another less precise way of thinking about VA activities is that they are those activities that the client is actually interested in purchasing (Diekmann, et al. 2004).

According to the framework of therbligs, three of the 18 motions are potentially value-adding (Class 1); namely *Assemble*, *Use* and *Disassemble* (S. Shingo 2007, Tesla2-Inc. 2003). Only one category in this study is considered VA, and it is called Process. The therbligs within each category are presented in *italic* and wastes are presented with underline.

#### **Process**

##### *- Assemble*

Assembling equipment like pumps, engines, pipes, wiring ect. either by mounting with nuts and bolts or welding it to the foundation. Most assembly is defined as VA as long as it’s not disassembled in a later step before delivery to customer.

##### *- Use*

Use of tools or machines might add value if it is used to modify the product towards a finished state. Examples: Welding, grinding, cutting, connecting, wiring ect.



The therblig *Disassemble* does not seem to be VA within a construction context. An example of when disassembly is value adding is in cases where an animal has to be disassembled in order to produce a steak. When disassembling something that's earlier assembled it does not add value.

So from both the framework of therbligs and the definition of value adding activities by Walbridge-Aldinger (2000) the basis for VA in observations were developed.

The authors realize one factor left out, which is the fact that all rework will appear as VA during observations. In reality rework is pure waste, because it should have been done right in the first place. Overproduction, production of defects which leads to rework and inappropriate processing will not be taken into considered in the observations as it is difficult if not impossible to see the difference for the observers. In most cases not even the workers know if they are producing defects or performing VA activities.

Some rework may however be VA, as change-orders from the customer after deadline leads to extra work and billing. So the rework does add value for the customer, because he wants it to be changed and is willing to pay for it.

### **Non-value adding, but required activities (NVAR)**

These are activities that do not add value to the final product; however they are necessary for finishing the product, at least to a certain extent. Four categories are defined and used in this research work (Prepare, Inspect, Clean and Transport).

#### **Prepare**

##### *- Assembly*

Example: When the assembly is related to temporary structures meant to be disassembled at a later stage before delivery to the customer, or changing tools on the grinder.

##### *- Use*

Example: Using tools and machines for building or assembling temporary structures is defined as preparing.

- *Disassemble*

Example: When disassembling something that's earlier assembled it does not add value. Disassembly of scaffolding is a NVAR activity.

- *Prepare*

Example: Putting a drill back in the toolbox.

- *Regrasp*

Example: Moving a ladder to continue working.

- *Think (plan)*

Example: Study technical drafts, measuring, adjusting welding unit ect.

To assemble scaffolding the wrong way lead to rework because of defects, while other preparations might be done using inappropriate processing.

## **Inspect**

- *Inspect*

Inspect is when a worker is inspecting finished work up against technical drafts and predetermined standards. If there is no need for inspection there is both excess motion by the inspector and could be waiting by the worker that will continue the work after inspection.

It can often be difficult to differ between the categories prepare and inspect, because they might look similar from a third party's point of view. However they are both a part of NVAR and that is most important.

## **Clean**

- *Use*

Example: Using a broom or vacuum cleaner for cleaning the worksite either to be able to continue working or to put the finishing touch to an area.

If a worker is cleaning when there is strictly no need for it, he/she perform waste in form of excess motion. Other workers might also have to wait for the one cleaning before being able to continue working.

## **Transport**

### *- Transport Loaded*

Example: Carrying tools, material, equipment or scrap somewhere else.

### *- Grab*

Example: Picking up something for transport.

### *- Release*

Example: Releasing the load that has been transported.

Transport is one of the seven wastes; however material handling and transport necessitated by the relocation of work are unavoidable in construction. It's the unnecessary movement of materials that is considered wasteful which includes excessive, multiple and suboptimal movements of material (Diekmann, et al. 2004). In this study all transport will count as NVAR as it is normally impossible to see if the transport is excessive or not.

Transport certainly is a large part of building vessels like #287. The vessel arrives at the shipyard as an empty hull, ready to be fitted with all the needed parts. So a significant part of the time spent constructing the vessel is transporting equipment inside the hull for installation. As most of the floors are already built before arrival, the equipment has to be lifted in and down through cutouts in the vessels hull or through doors.

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

The definition developed by Walbridge-Aldinger (2000) fits well for construction production; waste is defined “...as anything that takes time, resources or space but does not add value to the product or service delivered to the customer.” (Diekmann, et al. 2004). NVA is divided into four different categories; (Walk, Search, Wait and Rest).

## **Walk**

### *- Transport Unloaded*

Everyone walking onboard the vessel without transporting anything is placed here. The reasons for walking can be many; walk to the storage for parts, going for the toilet, ect.

Excess motion is one of the seven wastes which are highly related to transport unloaded, as it refers to unnecessary movement of people. Extra movement by employees caused by inefficient layout, remote lay-down areas or improper work sequences (Diekmann, et al. 2004).

After just a few days of observations the authors noticed all the walking amongst workers at the shipyard. Where were they all moving? What was the purpose of the movement? All in all it seemed like an area of possible improvement. With that in mind, it was conducted closer observations on walk/transport in and out of vessel #287.

### **Search**

- *Search*

Workers clearly searching for parts, tools, ect.

As the observations are done without asking workers and interfering in the activities it can be difficult to determine who is actually searching for something. Excess motion and waiting will often occur when searching for something.

### **Wait**

- *Unavoidable Delay*

Waiting for materials, equipment, other workers ect. that is not the responsibility for each worker, but the entire business.

- *Avoidable Delay*

This is delays which the individual worker is responsible for. It can be tools that break because of insufficient maintenance by the operator.

- *Hold*

Example: A worker standing holding a part or tool without making use of it.

Waiting is one of the seven wastes and might occur because of poor scheduling, production control or unbalanced crew size (Diekmann, et al. 2004).

## Rest

- *Rest*

Example: Taking a break from work because of overcoming fatigue, lack of job motivation to smoke a cigarette. This will also count as one of the seven wastes, namely waiting.

In Table 6 the categories are presented along with the value definition, related therbligs and the potential types of waste. All the therbligs have been related to the nine categories, however two of the 18 therbligs (Select and Find) were not considered when observing because they both represent a mental state, hence it is impossible to measure visually. They are marked out with red in the table.

Definition	Category	Therbligs	Potential wastes
VA	Process	Assemble, Use	Defects, Overproduction, Inappropriate processing
NVAR	Prepare	Assemble, Use, Disassemble, Prepare, Regrasp, Think	Defects, Inappropriate processing
NVAR	Inspect	Inspect	Waiting, Excess motion
NVAR	Clean	Use	Waiting, Excess motion
NVAR	Transport	Transport loaded, Grab, Release	Transport
NVA	Walk	Transport unloaded	Excess motion
NVA	Search	Search, <b>Select, Find</b>	Excess motion, Waiting
NVA	Wait	Unavoidable delay, Avoidable delay, Hold	Waiting
NVA	Rest	Rest	Waiting

**Table 6: Categories of observation**

### 3.2.4 Data Collection

The same routine was used during all the observation rounds, which started with walking all the way to the top floor of the vessel. At the top of the vessel the observations of workers started by walking down floor by floor through all the rooms (Figure 15) observing the workers in action, noting what each worker was doing in the split second they were observed. The nine predefined categories were used to describe the workers behavior on average. The collection of data was done in tables with all categories. Table 7 shows an example of one

already filled out after three rounds of observations. The observations were usually carried out after lunch between 1:00PM and 3:00PM, but also a couple of days before lunch (see appendix 7.7 for the data). It was not emphasized to observe at the exact same time each day because the same activities are going on each day all the time.

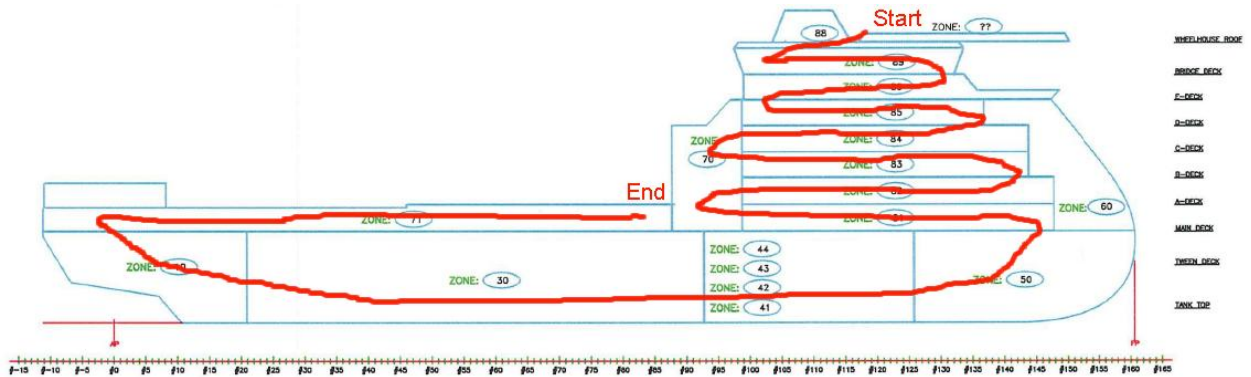


Figure 15: Data collection routine

Value	Category	03.03.10	04.03.10	05.03.10
VA	Process			
NVAR	Prepare			
NVAR	Inspect			
NVAR	Clean			
NVAR	Transport			
NVA	Walk			
NVA	Search			
NVA	Wait			
NVA	Rest			

Table 7: Example of data collection sheet for work-time utilization study

### 3.3 Welding Study

During the stay at Ulstein some very interesting information came up regarding equipment for measuring effective arching time on welding units. It means the actual time the welding unit is active or in other words how many minutes the worker is welding.

The measuring equipment had been used at the shipyard some years ago; unfortunately no data from those studies were saved for later review. The idea came up that such equipment could be used for measuring work time utilization by measuring the effective arching time compared to the total hours at work each day.

### **3.3.1 Definitions**

The definition of activities in this study is simply VA and NVA. This is because the equipment can only measure the effective arcing time of the welding unit.

#### **Value adding activities (VA)**

This will be the number of minutes of actual arching time during a day.

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

This is the total number of minutes spent at work during the same day, minus VA.

Just like in the work-time utilization study all rework will count as VA activities also in this study, as the equipment is simple and deterministic, differing only between VA and NVA. Another limitation is the fact that the equipment can only measure one welding unit hence one worker and the results might give very different results dependent on the type of tasks to execute. Because of this the results cannot be generalized, however they can support the other studies.

### **3.3.2 Data collection**

An agreement was made with one foreman within welding about putting down results each day on behalf of this thesis. One specific worker on one project was measured and the results of effective arching time were taken down every day for comparison with the total time at work each day. The data was collected for 10 days.

## 3.4 Walk/Transport Study

The decision of carrying out this study was done after a few days of testing the work-time utilization study. The authors noticed what seemed to be more than necessary walking around by the workers at the shipyard generally and specially in and out of the vessel. Where were they all going? After some discussions about methods for capturing data for the amount of walking at the shipyard, the decision was made to observe the movement in and out of vessel #287.

This study was done independently alongside with the work-time utilization observations. The goal was not to find out where workers were walking, or why. But to get quantifiable data of workers walking in and out of the vessel, and then form an impression of the actual amount of movement and how many that actually had a good reason for moving around.

### 3.4.1 Definitions

The categories in this study are *in* and *out*, and under both of them further divided into *walk* and *transport*, namely how many of the workers were carrying anything when they walked in and out of the vessel. The two categories walk and transport are the same as the ones used in the work-time utilization study.

#### **Non-value adding, but required (NVAR)**

- *Transport/In*

Example: Workers walking onto the vessel carrying parts or equipment.

- *Transport/Out*

Example: Workers walking out of the vessel carrying parts or equipment.

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

- *Walk/In*

Example: Workers walking onto the vessel without carrying anything.

- *Walk/Out*

Example: Workers walking out of the vessel without carrying anything.



In this way the results assume the workers transporting something are performing a NVAR activity while the workers just walking without anything are doing an NVA activity.

Foremen were not included in the observation as they are usually just inspecting and not processing. As all the foremen use green helmets in contrast to the workers, hence they are quite easy to separate.

The time was also noted during these observations so the average workers per hour could be calculated for each of the categories.

One limitation is the fact that workers that look like they are walking may have been at the storage and are carrying small parts in their pockets. In that way they are actually transporting something. Another limitation is the fact that some of the people observed might have been walking onboard the vessel just to have a conversation with somebody onboard. They were not necessarily workers belonging to the specific vessel, thus they should not have been included in the results.

### 3.4.2 Data collection

The observations were carried out by noting the movements on the gangway from land and onto the vessel, observing the workers to see if they were carrying anything or not. The observations were typically done for a period of about 30 minutes. An example of the table used for data collection is presented in Table 8.

	IN		OUT	
Date	Walk	Transport	Walk	Transport
03.03.10	 	 	 	
04.03.10	 		 	
05.03.10	 	 	 	

**Table 8: Example of data collection sheet for walk/transport study**

## 3.5 Personal Interviews

To support the studies at the shipyard four key employees were interviewed after the observations were completed. These interviews were thought to serve as a means for tying together the results from the different studies at the shipyard.

During the time at the shipyard the authors attended weekly planning/status meetings to find ideas for research as well as coming in contact with key persons within the building of vessel #287. Present at the meeting were the project planners along with about 20 foremen for the different disciplines working on vessel #287. Under the meetings some of the foremen were participating more than the others, either by coming with constructive critique and ideas or just complaining about problems. From this impression the authors asked four of the most enthusiastic foremen for an interview after finishing the other studies. The intention was to get;

- Their impression of the utilization of work-time at the shipyard/vessel #287
- Their thoughts around the study results and comments
- A discussion around issues picked up when running the observations
- Main reasons hindering improvement of work flow at the shipyard
- Suggestions for improvement of work flow

According to Yin (1994) there are three types of interviews; *open ended*, *focused* or *structured* (Yin 1994). When the goal is to get the respondents to discuss and propose solutions the only right way is to perform an open ended interview with room for some derailing from the interview guide.

The foremen were chosen from different disciplines working on vessel #287, namely; welding, piping, electrics and rig. The reason for choosing foremen from different disciplines was to see if they had the same or different opinions on various topics.

### 3.5.1 Interview method

The interview guide is attached in appendix 7.5, and the structure can be described as following:

First the background for this study was explained along with the nine categories defined for observations. Next the respondents were encouraged to estimate the values within each of the three categories VA, NVAR and NVA.

After having guessed the values the respondents were confronted with the results of the studies and asked to comment on it. They were also encouraged to discuss and present thoughts around the largest hinders for work flow as well as suggestions for improvement. More questions were asked and discussed as described in the interview guide (appendix 7.5).

During the interviews *Five Why* were applied when trying to determine reasons for issues and problems observed in the work-time utilization study.

### **3.6 Deviation Report Study**

After every weekly meeting with foremen and planners a deviation report is formulated containing the tasks not completed and the premises responsible. There were seven different premises for assigning deviations; *Resources, Documentation, Material, Dependent task, Tools, Area* and *Other*. They can be related to the *Four M* tool although this is another version of the model, more specified towards construction.

In this thesis the thought was to review the deviation reports looking for the most common causes of failures to meet planned operations week by week. This may give hints for where hinders of work flow appear most frequently.

## **4 Analysis**

In this chapter the results from the different studies and interviews will be presented. Next the results will be taken together and discussed in light of relevant theories.

### **4.1 Results**

In this chapter findings from the work-time utilization-, welding- and walk/transport studies will be presented. Some findings from interviews and the review of deviation reports will also be shown, while the rest of information from interviews will be taken further in the discussion.

#### **4.1.1 Work-time utilization study**

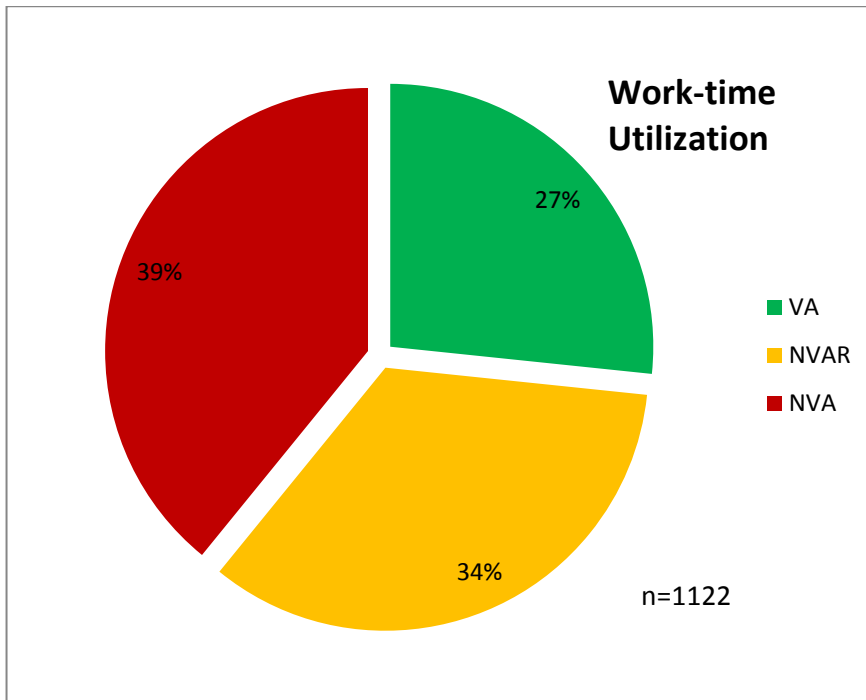
A total of 1122 observations were collected during a period of about one month, and although the results varied from day to day they gave the same tendency over time.

The number of workers observed on the observation routine differed from 29 to 86, with an average of 59. Some of the reason behind the large deviations is the fact that the first two weeks of observations the level of activity onboard the hull was lower than the two last weeks. This is because the observations started a short while after the empty hull arrived at the shipyard, and before the vessel were put into the dry dock. The number of activities onboard is naturally lower at that point because the main operations (engines, thrusters, ect.) require the hull to be located in the dry dock. This factor however did not seem to affect the relationship between categories in percent, which is the important thing in this study. Table 9 shows the total number of observations within each defined category. All the data from observation used for calculation are included in appendix 7.7.

Value	Category	Total	Percent	VA	NVAR	NVA
VA	Process	299	27%	299	-	-
NVAR	Prepare	215	19%	-	215	-
NVAR	Inspect	33	3%	-	33	-
NVAR	Clean	20	2%	-	20	-
NVAR	Transport	116	10%	-	116	-
NVA	Walk	151	13%	-	-	151
NVA	Search	10	1%	-	-	10
NVA	Wait	171	15%	-	-	171
NVA	Rest	107	10%	-	-	107
<b>Total</b>		<b>1122</b>	<b>100%</b>	<b>299</b>	<b>384</b>	<b>439</b>
<b>Percent</b>				<b>27%</b>	<b>34%</b>	<b>39%</b>

**Table 9: Result numbers walk-time utilization study**

To illustrate the result graphically the results are also presented in form of a pie-diagram in Figure 16.



**Figure 16: Diagram result of work time utilization**

The total results are presented within the three main categories of VA, NVAR and NVA.

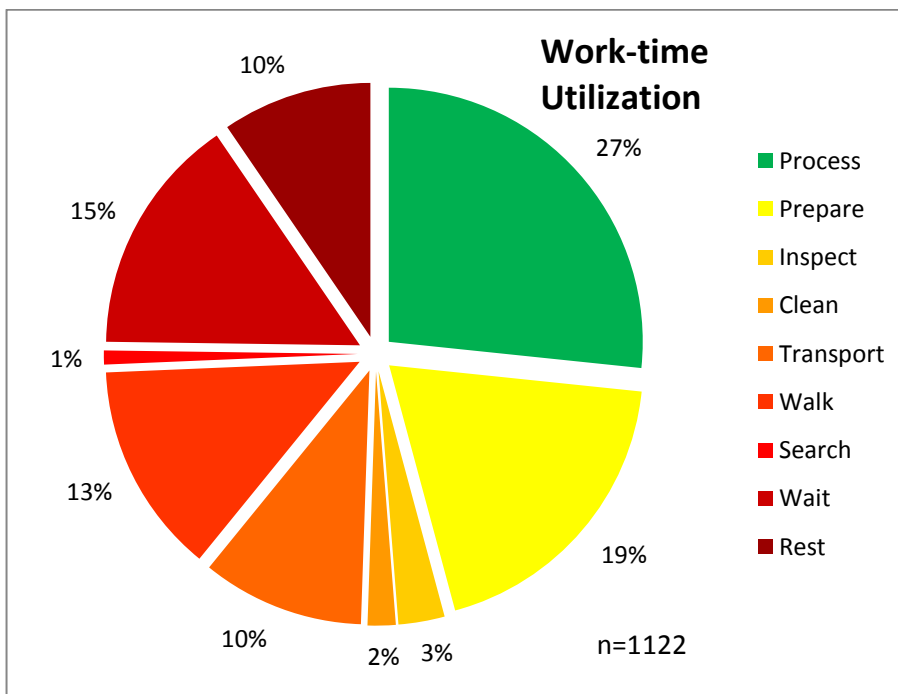
According to Mossman (2009) and Diekmann et al. (2004) the VA portion of the typical field construction value stream is exceedingly small, comprising approximately 10% of all crew

level activities (Mossman 2009, Diekmann, et al. 2004). However these statements are made from the view of following the product and not the worker. This was discussed in the research design as the two types of observation methods considered.

Koskela (1993) claims the portion of working time spent on NVA activities are about 2/3, hence VA 1/3. The fact that he is using the word “working time” indicates that his focus is on the effort of workers and not just the VA time from the products point of view. The result of 27% is not far from  $1/3 = 33\%$  claimed by Koskela.

When it comes to NVAR and NVA Mossman (2009) present a figure where activities “supporting” value adding activities are 30-35% while waste is 55-65%.

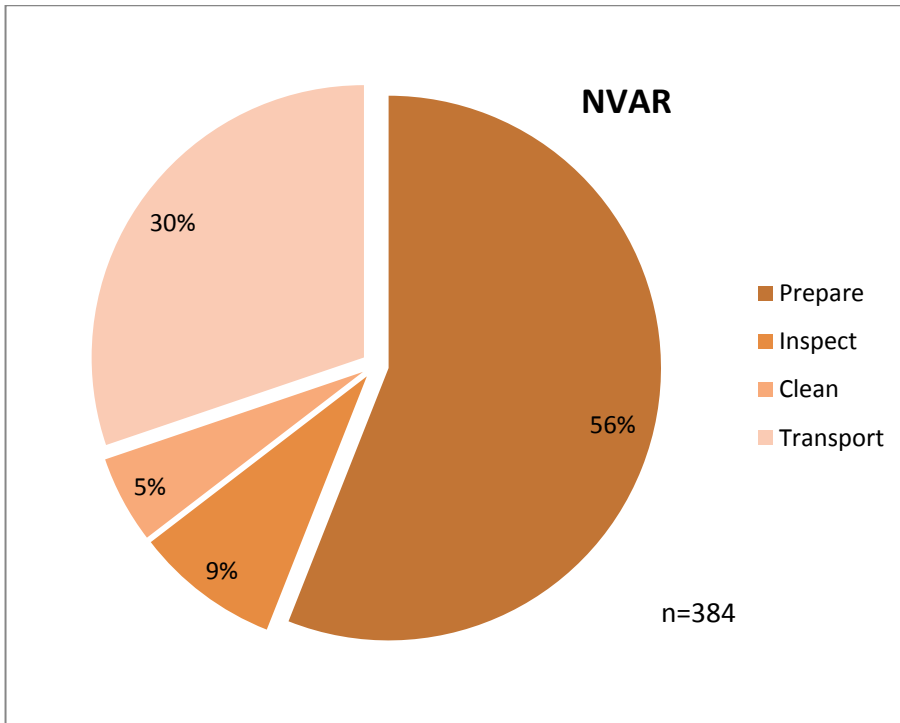
The further division of NVAR and NVA are also interesting so all the categories are shown in Figure 17.



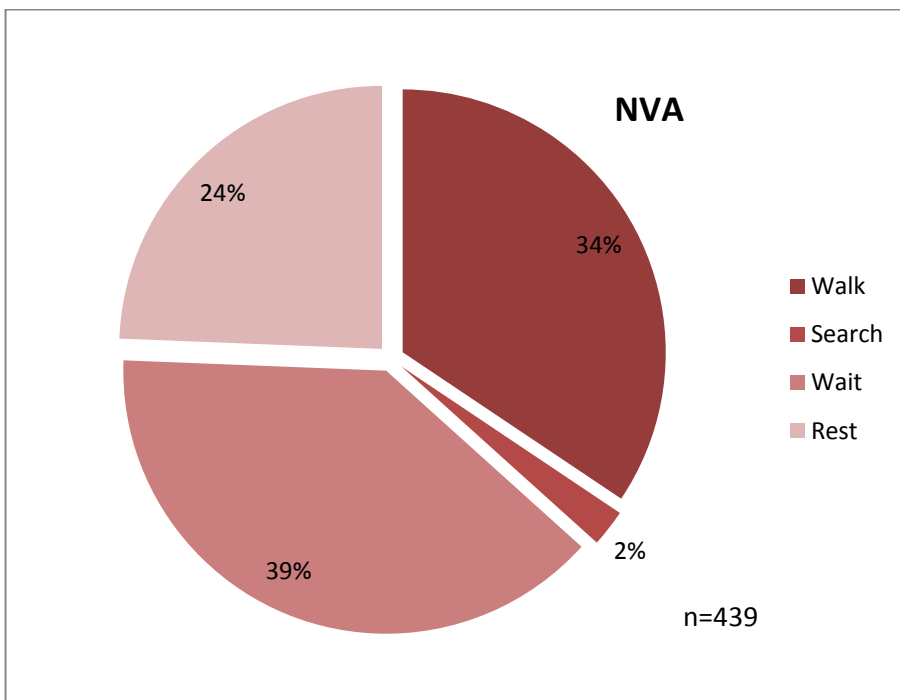
**Figure 17: Diagram result of work time utilization all categories**

The total result illustrated with all the nine categories in the same diagram, show the entire picture in a way similar to the figures that originally came from Ulstein (appendix 7.4).

Further, the NVAR and NVA categories can be shown in their own diagrams like Figure 18 and 19.



**Figure 18: Diagram of NVAR result**



**Figure 19: Diagram of NVA result**

In theory much of the time spent on NVA activities should be possible to allocate to the other categories, so there is definitely potential for improvement. The results can be presented in hours and minutes, in Table 10 assuming a normal working day of 7.5 hours:

Category	Percent	Hours/Minutes
VA	27%	02h and 00min
NVAR	34%	02h and 34min
NVA	39%	02h and 56min
<b>Total</b>	<b>100%</b>	<b>07h and 30min</b>

**Table 10: Result of work time utilization study in hours/minutes**

This means only 2hours out of 7.5 is spent on VA activities, while the rest 5hours and 30minutes is not directly adding any value.

In Table 11 all the categories are included; also here assuming a normal working day of 7.5 hours.

Category	Percent	Hours/Minutes
Process	27%	02h and 00min
Prepare	19%	01h and 26min
Inspect	3%	13min
Clean	2%	08min
Transport	10%	47min
Walk	13%	01h and 01min
Search	1%	04min
Wait	15%	01h and 09min
Rest	10%	42min
<b>Total</b>	<b>100%</b>	<b>07h and 30min</b>

**Table 11: Result of work time utilization categories in hours/minutes**

Spending over one hour *waiting* each day seems like a lot and should at least be a possible area to improve. It is possible to aggregate the numbers up to total work hours spent on a vessel, which illustrates significant values. The sister ship (vessel #283) had a budget of 171 206 work hours (Ulstein Group 2009), illustrated in Table 12.



Category	Percent	Hours
Process	27%	46226
Prepare	19%	32529
Inspect	3%	5136
Clean	2%	3424
Transport	10%	17121
Walk	13%	22257
Search	1%	1712
Wait	15%	25681
Rest	10%	17121
<b>Total</b>	<b>100%</b>	<b>171206</b>

**Table 12: Result of work-time utilization hours on vessel**

Here is an example which illustrates the amount of possible savings by a relative small improvement: If Ulstein were able to allocate *one* of the 15 percent spent on wait over to process we are talking about just 4.5 minutes each day per worker. But for the entire vessel budget it amounts to 1712 hours, which is almost one man-year in pure processing. Considering one worker spends 27% of the time for processing, it means a total of four workers are needed to perform 1712 hours of pure processing. In other words, the allocation of this *one* percent means having four extra workers for one year on the project!

To illustrate the variation in observations in the work-time utilization study, the confidence interval for the three main categories is presented in Table 13.

Category	Lower (95%)	Mean	Upper (95%)
<b>VA</b>	19%	27%	34%
<b>NVAR</b>	19%	34%	50%
<b>NVA</b>	25%	39%	53%

**Table 13: Confidence interval work-time utilization study**

The confidence interval shows the stability of observation results. It indicates that in 95% of the cases the results of observations will be within the lower and upper limit.

### 4.1.2 Welding study

This study follows the most scientifically valid method of all the studies as it is based on accurate measures from a reliable device. However the results are based on data from only one person, hence it cannot reflect the general picture at the shipyard or specific vessel.

The measuring of these results should definitely have been done over a longer period and with several workers on different projects for comparison, however the results in Table 14 is what the authors managed to get from Ulstein.

Weekday	Date	Arch time	Total time	VA time
Friday	21-Mar	3.06	7.5	40.80%
Monday	22-Mar	2.03	7.5	27.10%
Tuesday	23-Mar	3.56	9.5	37.50%
Wednesday	24-Mar	3.02	7.5	40.30%
Thursday	25-Mar	3.24	7.5	43.20%
Friday	26-Mar	2.84	7.5	37.90%
Tuesday	6-Apr	2.68	7.5	35.70%
Wednesday	7-Apr	2.56	7.5	34.10%
Thursday	8-Apr	3.12	7.5	41.60%
Friday	9-Apr	3.42	7.5	45.60%
<b>Total</b>		<b>29.53</b>	<b>77</b>	<b>38.40%</b>
<b>Standard deviation</b>				<b>5.30%</b>
<b>Confidence interval (95%)</b>			<b>Lower: 28%</b>	<b>Upper: 49%</b>

**Table 14: Welding study results**

The results indicate significantly higher work-time utilization than what was measured in the first study. However these results are based on one single person, working on one project.

The confidence interval indicates that in 95% of additional observations the VA portion in observations will lie between 28% and 49%.

### 4.1.3 Walk/Transport Study

In the study of workers walking in and out of the vessel there is a total of 1066 observations. All the numbers and calculations can be found in appendix 7.7.

From what seemed intuitive the number of workers transporting into the vessel should be significantly higher than workers transporting out, and that is also what the results show. The total result is shown in Table 15.

	IN	OUT	Total
<b>Walk</b>	342	471	<b>813</b>
<b>Transport</b>	180	73	<b>253</b>
<b>Each</b>	<b>522</b>	<b>544</b>	<b>1066</b>

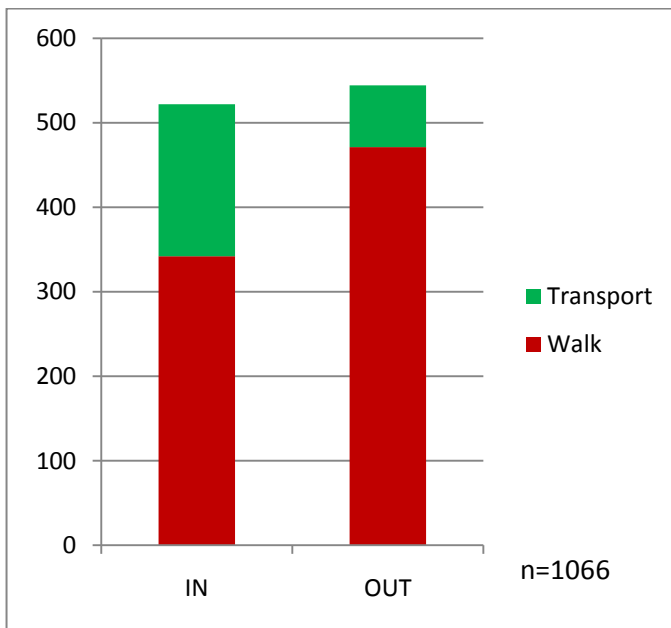
**Table 15: Total number of observations walk/transport**

The results are calculated in percent in Table 16.

	IN	OUT	Total
<b>Walk</b>	66%	87%	<b>76%</b>
<b>Transport</b>	34%	13%	<b>24%</b>
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

**Table 16: Total percent of observations walk/transport**

The results are easier to see with diagrams, and in Figure 20 the total result is illustrated in a bar diagram.



**Figure 20: Result walk/transport (IN/OUT)**

To get an even better picture of the results they may be presented in separate figures for *in* and *out*, (Figure 21 and Figure 22) to emphasize the difference in the amount of *walk* and *transport* under each.

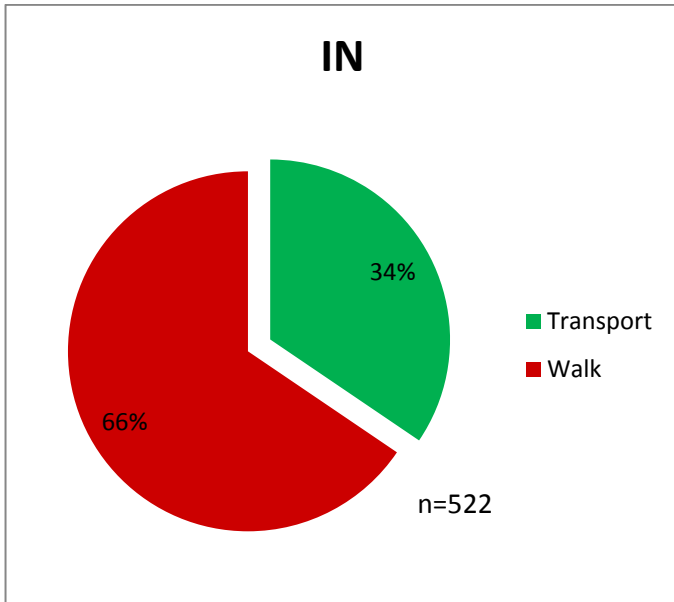


Figure 21: Result walk/transport (IN)

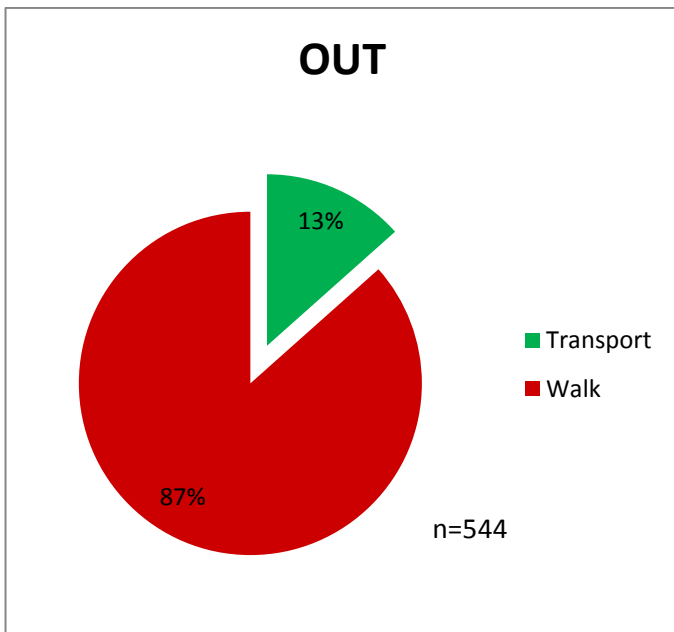


Figure 22: Result walk/transport (OUT)

The results show that 34% of the workers walking into the vessel are transporting something normally parts or equipment, while 13% of the workers going out are carrying scrap or equipment for use elsewhere. As expected the transport *in* is higher than *out*, however the authors thought the difference would have been even more. The result indicates that many workers are just walking out and back in again, not transporting anything.

- What about the workers walking out and back in again without transporting something? What are they doing, what is the purpose of their movement?
- Can measures be taken to prevent unnecessary walking back and forth?

Even the workers transporting equipment into the vessel should be minimized. They should ideally have most of what they need onboard. Most equipment is transported onboard with cranes.

As the time was taken down during all of the observations the results can be presented in relation to time, like in Table 17 below.

	<b>IN</b>	<b>OUT</b>	<b>Total</b>
<b>Walk</b>	1.10	1.52	<b>2.62</b>
<b>Transport</b>	0.58	0.24	<b>0.82</b>
<b>Sum</b>	<b>1.68</b>	<b>1.75</b>	<b>3.44</b>

**Table 17: Frequency of walk/transport per minute**

From Table 17 it can be seen that on average 3.44 workers are observed within any of the categories each minute. It means on average every 18 seconds a worker is observed either walking or transporting something in or out of the vessel.

To take it even further you could say that since 1.75 workers on average move out of the vessel every minute, it indicates about 105 moving out per hour. The average number of workers observed onboard the vessel during the observations was 59. (Adding 11 workers (for simplicity) to compensate for the workers already out walking). Assuming about 70 workers onboard the vessel at any given time during the working day, it means every worker is walking out of the vessel every 40 minutes on average. Of course not all workers do this; however it only means some of them do it even more often. When putting it in perspective like this, the amount of movement seems unnecessarily high. Number behind calculation can be found in appendix 7.8.

#### 4.1.4 Interviews

Interviews with foremen were carried out at the shipyard after completing the three fore mentioned studies. After explaining the definitions and categories, the foremen were asked to estimate how much time they thought were spent on VA-, NVAR-, and NVA-activities. The results are presented in Table 18.

	<b>Welding</b>	<b>Piping</b>	<b>Electric</b>	<b>Rig</b>
<b>VA</b>	60%	50%	50%	25%
<b>NVAR</b>	20%	20%	25%	40%
<b>NVA</b>	20%	30%	25%	35%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>
<b>Rework</b>	10%	10%	10%	5%

**Table 18: Estimates from respondents**

These results show that three out of four foremen interviewed estimated the amount of time spent on VA activities to be much higher than the studies indicate. However one of them was quite close. They all believed other disciplines in the project might have lower work-time utilization than their own. This seems to indicate a tendency towards how they see their own discipline as better flowing than others, or they believe the problems in other disciplines to be more severe. The results are also illustrated in Figure 23.

Other issues discussed during interviews will be brought up in the discussion part.

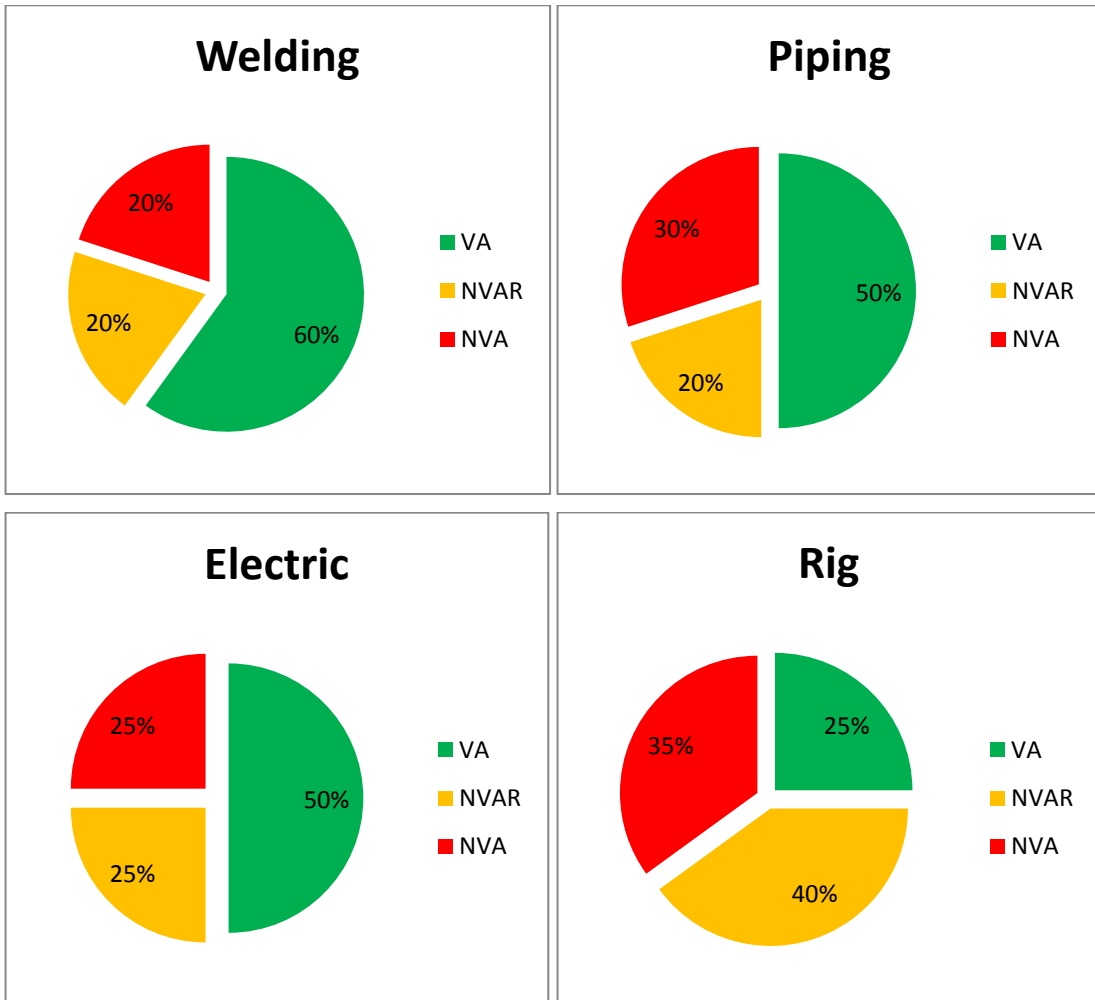


Figure 23: Estimates of work-time utilization

#### 4.1.5 Deviation Reports

After reviewing the deviation reports for seven weeks the most common causes responsible for delays or uncompleted work are *Resources* and *Dependent tasks*. On average, Ulstein and vessel #287 have 85% PPF (completion rate) each week on all planned tasks. The specific causes hiding behind the broad category *Resources* are difficult to determine without more information. See appendix 7.6 for the summary of the deviation reports.

## **4.2 Discussion**

Through the studies and interviews a picture of the situation at the shipyard was formed. This part includes a discussion around different causes hindering work-flow; hence hindering improvement of work-time utilization at the shipyard. The discussion is arranged according to seven types of waste. Definitions are taken from Table 5.

### **4.2.1 Overproduction**

*Definition: Overbuilding a particular aspect of a project, either because it was over engineered or a process was started before it was really needed.*

#### **Production of drafts and technical specifications**

Waste in form of overproduction occurs within the technical department, where they produce drafts long before they are needed. This leads to extra processing when changes are made at a later point in time.

Last planner is a lower level planning system that advances the actual production planning until as late as possible in the process and at the same time places the plans as close as possible up to the operations (Fafo n.d.). Ulstein have used this method in production planning since 2006, however the method could also be implemented in the production of technical drafts. In this way the technical drafts do not have to be developed before they are strictly needed. Today many drafts are developed months in advance of the vessels arrival hence they often need to be changed if change orders come at a later time.

Sometimes when change orders come in, foremen correct the changes at the site without contacting the technical department through the established feedback system. That means the same errors might appear in the next build, in form of old drafts which never was updated according to the last changes, as many of the vessels are built on the same basic x-bow design. Some foremen felt the process of informing technical department and waiting for new drafts were time consuming and unnecessary.



## 4.2.2 Waiting

*Definition: Time spent waiting for other work crews to finish their particular conversion process so that the next conversion process may begin. Time spent waiting on crew members of a specific team. Time spent waiting for parts or instructions.*

### **Wrong or missing drafts/technical specifications**

Waiting occur in production when drafts are not updated with the latest changes from the technical department. Drafts have to be redesigned and the production department has to wait before starting the actual work.

### **Utilization of cranes**

An issue all respondents touched was the capacity of cranes in the dock hall. They see it as a limitation of utilization and cause of waiting. There are currently three cranes in the dock-hall and they cannot cross each other when loaded. As the cranes are often standing still either with or without load, more cranes would probably not be the solution. However the planning should be better when it comes to coordinating the in-transport of different equipment. Large parts may take hours to adjust and get in place, while others take just minutes. This indicates Ulstein should emphasize coordinating these activities even more than they are currently doing to reduce the time spent waiting for cranes.

Shingo (1988) did a study of the operation of cranes at a shipyard, as an engineer claimed that reduction of construction time were practically impossible because of crane capacity. Shingo decided to measure the utilization of the four cranes for a week. The result is given in Table 19.

	<b>Loaded</b>	<b>Empty</b>
<b>Moving</b>	25.4%	27.8%
<b>Stopped</b>	18.5%	28.3%

**Table 19: Crane utilization (S. Shingo 1988)**

As Shingo states; one month is about 8% of a year, so the cranes are actually operating “VA” only three months of the year. When the engineer was introduced to the results he managed to improve utilization by reducing waste in crane operations (S. Shingo 1988). This kind of study

could be interesting to carry out also at Ulstein to see how much room for improvement it may be. This research did not look closer into it because of a limited time frame.

### **Late deliveries from suppliers**

Another cause of waiting at the shipyard mentioned during interviews was late deliveries from external suppliers of parts and equipment. Foremen suggested stricter follow-up and penalties for suppliers as late deliveries quite often hindered the work flow. Another option is to engage in closer relationships with some suppliers, including better follow-up to reduce late deliveries.

### **Deviations in Last Planner**

The deviation reports from Last Planner meetings indicate an average of 85% PPF each week. This leads to postponement of the activities that were planned carried out after the ones already delayed. When deviations occur, it should automatically trigger an investigation and elimination of the cause. At Ulstein the most frequent cause of deviations in Last Planner is *Resources*. Resources might be a lot of things, thus the cause should be specified more in detail. It would definitely ease the work looking for the root causes.

#### **4.2.3 Transport**

*Definition: Wasted effort to transport building components or tools into or out of job trailers or storage between processes.*

#### **Transport of small parts**

The head of planning at Ulstein estimated that workers on average spent about one hour each day walking to get parts or equipment they need. Seen in connection with the results from the study it seems likely that this is close to the real situation. When parts or equipment is needed the workers normally *walk* out of the vessel to get it and *transport* it back. The walk/transport study revealed the amount of transport to be significant.

## **Work packages**

The use of prepared work packages has been tested at Ulstein. It means dividing projects into smaller tasks (work packages) with clear instructions and planned deliveries. All parts and equipment needed for the task is provided, hence a worker only need to perform the task. Preparing the work packages in advance should minimize walking to get small parts and waiting because parts are missing.

In practice it showed that workers felt less responsible for completing the task. The reason was; if something was missing or wrong in the provided parts or drafts, workers had a good reason for not doing anything. Someone else was responsible, so the workers did not feel bad about taking a break. To put it another way the workers seemed to feel less responsible for the completion of the task. For this method to work in respect to improving the utilization it is important that drafts and technical specifications as well as the provided parts and tools are correct.

## **Mobile storages**

To reduce the amount of transport Ulstein have earlier tried out mobile storages onboard the vessel. These are storages in the form of a container with tools and equipment frequently used onboard the vessel. When the vessel is located outside at the dock all the foremen agreed that these storages might significantly reduce time spent on *walk* and *transport*. However the containers need daily follow-up when it comes to refilling parts. This was not sufficiently emphasized when using these storages; hence the amount of walk was even higher than before. This is because workers first checked the mobile storage and when it was empty they had to walk all the way to the main storage anyway. But the potential of this kind of storages should call for reconsideration when it comes to using them. In the dock hall there are storages with tools and small parts located beside the vessel, hence the savings will be limited when the vessel is located inside the dock hall.

#### **4.2.4 Extra processing**

*Definition: Waste associated with rework, re-handling or storage caused by defects in design, fabrication or construction activities.*

#### **Rework**

Ballard and Howell (1994) claim rework traditionally has been defined in terms of *errors requiring work to be redone*. Components of rework can be listed as following (Ballard and Howell 1994):

- Design errors
- Design changes
- Vendor errors
- Installation errors
- Damage by other crafts

The actual amount of rework is difficult to determine, and it is not the objective of this thesis. Ballard and Howell (1994) states the amount of time spent doing work over has never been accurately measured, but can safely be said to be substantial, absorbing perhaps as much as 25% of paid labor time.

During interviews foremen were asked to estimate how much of the category *process* they believed was spent doing rework. Three of the foremen estimated the rework to be around 10% of process, while the last guessed maximum 5%. It indicates that foremen are aware of the rework and see that it actually constitute a significant portion of the work done. However if 10% of process is rework then 10% of the other categories should also be related to rework, because doing rework will most likely also results in more preparation, transport, walk, and wait as well.

There might be several causes why rework occur, however the most frequently mentioned during interviews are drafts and technical specifications that are either wrong or missing. This problem is caused by overproduction of draft and specifications as well as poor communication between technical- and production department when it comes to changes.

It should also be mentioned that some rework might be value adding in form of change orders from the customer; hence the “rework” is justified by the customer and will be paid for.

#### **4.2.5 Excess inventory**

*Definition: Maintaining excess inventory of construction components, equipment or tools.*

Inventory level is not an issue focused on in this research.

#### **4.2.6 Excess motion**

*Definition: Waste associated with unnecessary worker/equipment movement around the construction site.*

### **Disorder**

The respondents all believe that the category *search* should constitute a larger portion of the result. They estimate search to be closer to 10%, and in the study the problem is that much of the category *walk* includes people searching. The model cannot easily capture the people searching, as most people searching are walking around looking for what they are missing. However it's important to emphasize that this issue should not affect the distribution between the categories VA, NVAR and NVA as both *walk* and *search* is within NVA.

Searching often leads to walk, transport and wait. If a worker is missing a bolt when assembling something, he might first search for it where he is standing, that is what the category search have been defined as. However after this he will probably walk to the storage, wait for someone to find the bolt, and then transport it back to the vessel before being able to continue assembling.

When a worker is walking to get some equipment or parts, often one or two other follows just to keep him company. This is clearly excess motion, and may be caused by low job motivation.

A lot of disorder at the workplace was observed during observations. There was an attempt to establish a cleaning routine by Ulstein some time ago. Every worker was supposed to use two

hours each Thursday for cleaning and preparing. However this was not sufficiently emphasized and workers quickly ignored it.

One tool for reducing time spent on excess motion generally and help give a well organized workplace is Five S. Ulstein has already applied Five S to some extent in inventory management where it has improved control and overview according to Ulstein.

## **Toilets**

The toilets in the dock hall are dirty and as a result workers walk all the way to the administration building (at the other end of the shipyard) when in need of a toilet. This leads to more excess motion at the shipyard which amounts to a significant number of minutes in total every day.

### **4.2.7 Defects**

*Definition: Deficiencies in the finished product that require additional work or rework to correct punch list items.*

Defects are highly related to generation of rework (extra processing). As mentioned the foremen claimed the most common cause for rework is poor technical drafts and specification from the technical department.

## **Low job motivation**

During the interviews an issue of job motivation among workers came up. It was claimed that many of the hired workers who has been at Ulstein for several years show poor job motivation for making an effort at the worksite. This leads to more rest, waiting and generally lower work-time utilization among some employees. Issues like; surfing the internet on a computer in the main storage and taking extra long lunch brakes might be caused by low job motivation.

Lean theory state that workers should be involved in the development of Lean activities. The goal of Lean Manufacturing is achieved though the human resources of the company, using the machinery as tools to meet the goal (Lean Manufacturing Guide n.d.). One big advantage for workers in a Lean Manufacturing system is that they are a major part of the company's decision making process. In order to improve operations and prevent waste employees are

actively encouraged to make suggestions and take action. This level of employee involvement helps to improve morale and employee performance (Lean Manufacturing Guide n.d.). However when it comes to Construction things might change.

Locke and Latham (1990) state as tasks become more complex, performance becomes less dependent on mere motivation and more dependent on the quality of task strategies, that is work methods. The most popular way of setting goals in assigning work assumes that "do your best" is the best that can be done. It is also widely held that motivation is more important than the quality of planning and know-how.

It is also important to note that there is no support in research for the widely-held belief that participation in goal setting increases motivation to achieve goals. Understanding goals might be more important for performance than participating in goal setting. That does not mean workers have no role in planning. However, it is not increasing motivation, but improving plan quality that is the reason for involving direct workers in planning; especially in planning how to do the work (Locke and Latham 1990).

## **5 Conclusions and recommendations**

This final chapter lists the two main objectives presented in the research problem, before briefly answering them by summing up findings from the research work. Finally limitations are presented followed by further research.

### **Objective 1: Develop a model for measuring work-time utilization and provide a result of work-time utilization.**

A model for measuring work-time utilization was developed and the result provided a description of the current situation of work-time utilization at the shipyard for future comparison. The results presented in Chapter 4 show that 27% of the time spent at work is spent on VA activities, while the rest (73%) adds no value to the end product. According to Koskela (1993) the portion of working time spent on NVA activities are about 2/3 of all activities, hence VA 1/3 = 33%. That is close to the result provided in this study and it is the only written material the authors have found relevant for comparison.

### **Objective 2: Reveal root causes hindering work flow and suggest Lean tools for improvement.**

In addition to providing such a result the thesis has revealed some of the most severe hinders of work flow at the shipyard. These are presented below with some suggestions for future improvement.

#### **Defects, extra processing (rework) and waiting caused by poor communication between technical and operational departments**

Possible measures for improvement could be to implement Last Planner in technical department to reduce errors and need for changing technical drafts and specifications.

Simplify information flow between technical and operational departments to improve transparency and reduce time to perform changes in technical material.

Emphasize the identification and removal of root causes for deviations in the plans. Actions for revealing causes should automatically be triggered when deviations occur.



### **Waiting caused by resources and dependent tasks**

Develop more detailed specification of causes responsible for deviation in the deviation reports. This will make it easier to identify and remove the root causes for deviation in the planned operations.

Consider carrying out a study of crane utilization to reveal waste in crane operations, followed by waste reduction. And focus even more on planning and coordination of crane activities.

Engage in closer relationships and introduce better follow-up of suppliers to reduce late deliveries causing waiting at the shipyard.

### **Excess movement caused by missing small parts and equipment**

Investigate the possibility for increased use of prepared work packages for specific operations as well as the use of mobile storages onboard the vessel. However these measures require continually follow up to function as intended.

Look into further extension of Five S into several areas within the construction to improve order, organization of tools, materials and other equipment.

Think about cleaning toilet in the dock hall to reduce the distance needed for workers to walk for using the toilet.

## **5.1 Limitations**

### **Work-time utilization study**

This study has not focused on the separation between process (value adding) and rework (waste) as it is difficult for a third party to determine without more information. This means all rework has been defined as value adding.

The fact that observations were carried out without asking/interfering with workers limits the possibility of assigning workers in the correct categories every time.

Workers searching were difficult to identify hence many of them probably ended up under the category walk instead of search.

### **Walk/transport study**

Workers carrying small parts in pockets will be observed as walk, not transport in the walk/transport study.

Some inspectors from other companies, visitors and others might have been noted as workers when they were walking in and out of the vessel, even though only workers were supposed to be observed. The reason is that the authors had no chance of knowing every peoples role at the shipyard.

### **Welding study**

Just as in the work-time utilization study rework has been included into the value adding part of the results.

The study is based on one person and one specific project, which limits the possibilities for a generalization of the results.

### **Sister ship effect**

The fact that vessel #287 (the vessel this thesis focus on) is identical to the sister ship #283 built right before might have an effect on the efficiency of the workers, as many of the workers and foremen are familiar with the tasks and the sequences to perform them.

## **5.2 Further research**

Here are some issues that could be subject for further research to help Ulstein improve their production and reduce waste.

### **Study of causes for waiting / Utilization of cranes in the dock-hall**

A study investigating the most common reasons for waiting at the shipyard could be carried out. During the interviews one issue all respondents touched was the capacity of cranes in the dock hall. They see it as a limitation of utilization, causing a lot of waiting at the worksite. It could be interesting to map the current utilization of cranes and study how to optimize the utilization of cranes in the dock hall.

### **Storage: What is being picked up?**

At the main storage there are a lot of workers picking up small parts. A study could look into what kind of parts that are most frequently picked up using an ABC-analysis. Then see which parts/equipment that could be of interest to place in a mobile storage onboard. The study could also look into the possibility for picking and preparation of work packages by employees at the storage, reducing the need for transport by each worker.

### **Follow up of this research**

A follow up of this thesis should be done, and here is also the possibility to do an extended welding study involving more workers, over a longer period of time.

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## 7 Appendices

### 7.1 Types of vessels offered at Ulstein Verft AS

Ulstein Verft builds some of the most sophisticated vessels for marine operations. With high focus on innovative technology solutions, high level of expertise in project management and good logistics they are able to deliver high quality and on-time delivery.

They produce 3 main categories of vessels: (Ulstein Group n.d.)

**1. Anchor Handling Tug Supply (AHTS)** are offshore vessels within areas such as;

- Anchor handling service
- Towing Offshore oil platforms to location
- Supply oil platforms (wet and dry cargo)
- Standby, Rescue, Fire Fighting and Oil Recovery Operations (ORO)



2. **Platform Supply Vessel (PSV)** are designed to supply offshore oil platforms, and transport cargo such as;

- Various fluids such as freshwater, fuel oil, brine, mud and chemicals
- Dry bulk such as cement, barite and bentonite
- Pipes for drilling and pipe-laying activities



3. **Specialized / Multifunctional vessels** can be offshore construction vessels (OCV), pipe laying vessels and seismic vessels. Ulstein Verft also has an aftermarket section which can offer rebuilding of vessels for new operations.



## 7.2 Vessel #283 “Sarah”

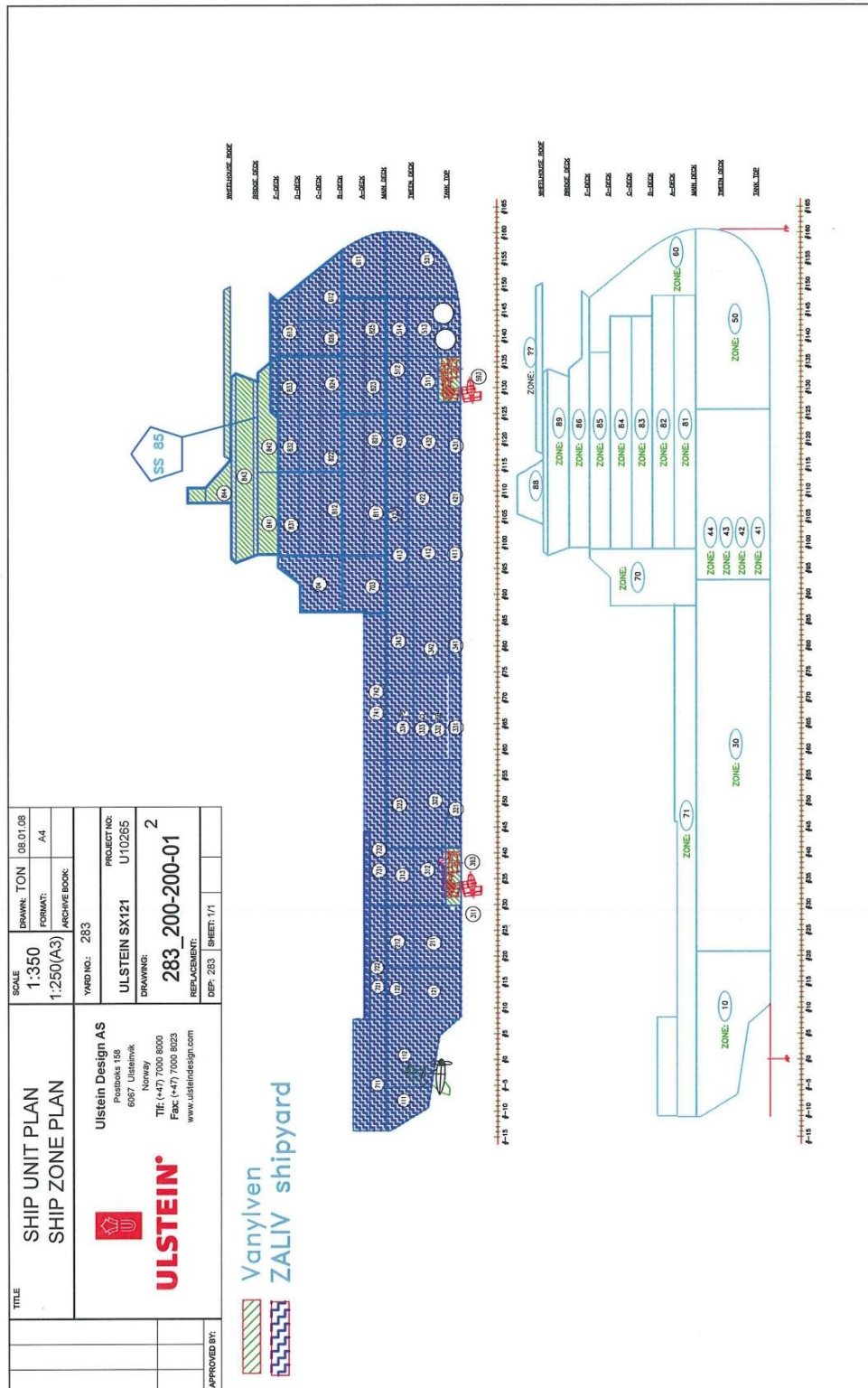
Sarah is an Inspection Maintenance and Repair / Offshore Construction and Light Well Intervention Vessel, designed by Ulstein Design AS. The hull form, with the ULSTEIN X-BOW®, combined with diesel electric propulsion system, ensures exceptional performances with regard to fuel consumption, sea keeping, station keeping, speed, and cargo capacity.

The main propulsion system comprises two azipull thrusters of controllable pitch propeller type; each driven by frequency controlled variable speed electric motor. Two retractable/swing-up azimuth thrusters and two tunnel side thrusters forward are installed, ensuring the vessel to obtain the best station keeping capabilities with ERN 99, 99, 99. The vessel is equipped, built and certified according to IMO Class III for Dynamic Positioning.

The vessel is equipped a 150 ton offshore crane and a module handling tower for performing subsea riser less well intervention services. The MHT system is designed to work in cooperation with the AHC main hoisting winch, the moon pool doors, and the horizontal skidding system (Ulstein Group n.d.).

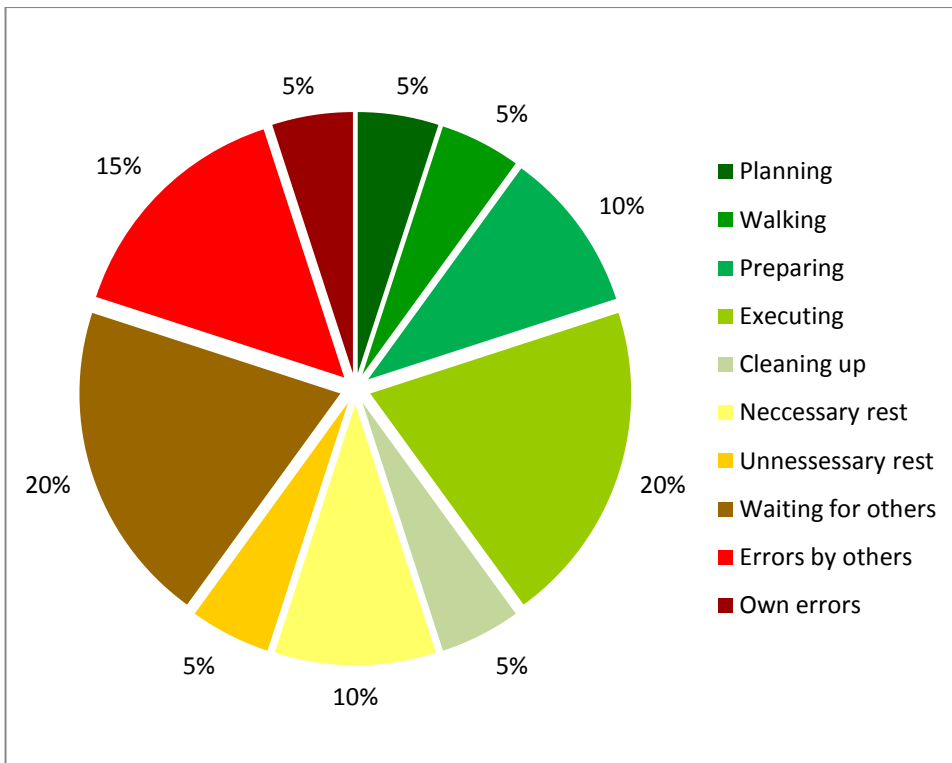
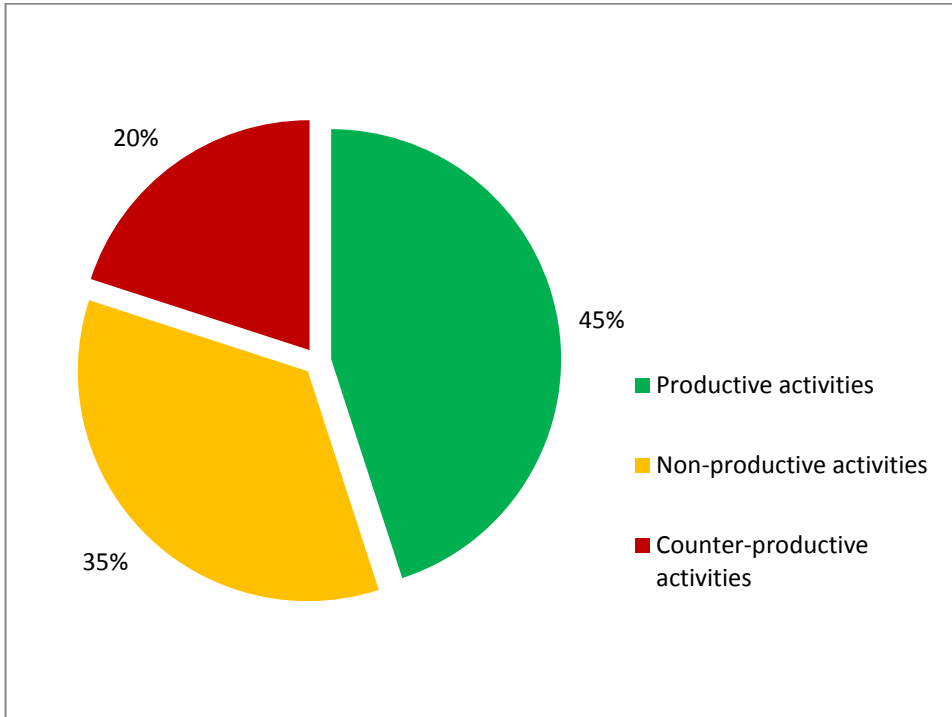


## 7.3 Ship Zone Plan for vessel #283 “Sarah”



## 7.4 Work-time utilization figures

These are figures which inspired Ulstein Verft AS to closer examine their production.



## 7.5 Interview Guide; Ulstein Verft

*Name:*

*Age:*

*Employed since:*

*Title/responsibility:*

*Number of workers under your command:*

**Present authors and what they are doing at the shipyard as well as definitions for categories used in observation study.**

- How do you believe the work-time is allocated between the different categories listed?

**Present results from the work-time study.**

- Do you believe this to be a realistic picture of the situation at this shipyard/vessel 287?
- How many percent of the processing done do you believe is rework?
- Do you feel there is a need for more inspections onboard to prevent errors at an earlier stage?
- Do you think more errors could be avoided by more frequent inspections?
- What do you believe is the main hinder for improving the productivity at the shipyard?
- What do you think is the most usual cause of delays and waiting at the shipyard?
- Which discipline on the vessel do you think has most rework, and which has most delays?
- Do you have any suggestions about how to increase the productivity? Anything that might be done differently.

**Authors have noticed many workers walking around at the shipyard. Surprisingly few are actually carrying something, and if they are it is often small equipment. It has been claimed that workers on average spend about 1 hour each day just walking.**

- What do you think of that statement?
- Do you believe the walking to get small parts could be reduced if workers spent 5-10 minutes each morning to prepare/pick equipment needed during the day, collect it in a small container and transport it onboard?
- Other comments, thoughts?

## 7.6 Deviation reports summary

The results from deviation reports received from Ulstein are listed in the table below. On the top row you can see the different categories for assigning deviations from planned.

Week	Dependent task	Other	Tools	Area	Resources	Documents	Materials	Deviation work packages	Planned work packages	Completed work packages	Percent Planned Complete (PPC)
6		2						2	13	11	85%
7	1	1			2			4	24	20	83%
8								0	16	16	100%
9	1		1			1		3	42	39	93%
11	8	1			2		1	12	72	60	83%
13	1				3			4	13	9	69%
15		1			4			5	21	16	76%
<b>Total</b>	<b>11</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>11</b>	<b>1</b>	<b>1</b>	<b>30</b>	<b>201</b>	<b>171</b>	<b>85%</b>



## 7.7 Work-time utilization data

Date > Time >	18-Feb		19-Feb		25-Feb		26-Feb		2-Mar		3-Mar	
	1330	1400	1445	1440	1330	1440	1400	1250	1420	1015	1340	
VA Process	9	7	9	11	10	11	11	20	22	20	17	
NVAR Prepare	4	4	4	7	3	7	15	13	12	14	15	
NVAR Inspect	2	2	4	1	1	1	1	3	2	1	1	
NVAR Clean	1	2	3	1	1	1	1	5	8	1	8	
NVAR Transport	6	3	3	4	2	4	5	5	8	8	7	
NVA Walk	4	5	6	5	10	5	8	7	11	9	7	
NVA Search	1			1		1						
NVA Wait	4		3	4	3	4		13	5	7	4	
NVA Rest		6	3	5	4	5	5	8	10	5	10	
<b>Total</b>	<b>31</b>	<b>29</b>	<b>35</b>	<b>39</b>	<b>34</b>	<b>39</b>	<b>45</b>	<b>69</b>	<b>70</b>	<b>65</b>	<b>62</b>	

Data work time utilization (part 1)

Date > Time >	4-Mar		8-Mar		9-Mar		10-Mar		11-Mar		16-Mar		19-Mar		Total
	1340	1430	1450	1450	1405	1320	1355	1335	1335	1335	1000	1000	1000		
VA Process	12	14	25	25	20	27	16	17	17	14	18	299			
NVAR Prepare	9	13	10	10	13	16	11	17	17	24	11	215			
NVAR Inspect	3	1			5	2	2	2	1	2		33			
NVAR Clean	1	1			2	1	3	1	1	1		20			
NVAR Transport	8	10	4	4	6	7	4	11	11	7	7	116			
NVA Walk	7	12	13	13	8	8	8	8	8	9	6	151			
NVA Search		2	1	1	1	1	1	1	1	1	1	10			
NVA Wait	9	15	22	22	12	21	9	11	11	14	15	171			
NVA Rest	3	12	11	11	7	2	2	4	4	3	7	107			
<b>Total</b>	<b>52</b>	<b>80</b>	<b>86</b>	<b>86</b>	<b>74</b>	<b>85</b>	<b>56</b>	<b>70</b>	<b>70</b>	<b>75</b>	<b>65</b>	<b>1122</b>			

Data work time utilization (part 2)



## 7.8 Walk/Transport data

Date > Time >	25-Feb 1440-1500		26-Feb 1400-1430		3-Mar 1015-1045		3-Mar 1340-1410		4-Mar 1340-1410		4-Mar 1425-1455	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
NVA Walk	19	20	27	19	18	32	22	61	46	60	38	50
NVAR Transport	11	5	9	7	15	3	21	8	24	3	25	16
Each	30	25	36	26	33	35	43	69	70	63	63	66
Total	55		62		68		112		133		129	

Data walk/transport (part 1)

Date > Time >	8-Mar 1450-1520		9-Mar 1405-1435		10-Mar 1320-1350		10-Mar 1355-1415		11-Mar 1335-1405	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
NVA Walk	32	48	54	41	34	50	18	38	34	52
NVAR Transport	11	10	30	7	11	5	11	3	12	6
Each	43	58	84	48	45	55	29	41	46	58
Total	101		132		100		70		104	

Data walk/transport (part 2)

	IN	OUT	Total
Walk	342	471	813
Transport	180	73	253
Each	522	544	1066

Data walk/transport (total)

Total minutes of observing walk/transport: 310

## 7.9 Master schedule vessel #287

