Waste in Lean Construction

– A case study of a PEAB construction site and the development of a Lean Construction Tool

Master of Science Thesis in the Master of Supply Chain Management

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Abstract

The Swedish construction industry is a pillar of the Swedish economy, contributing to roughly 10% of the GDP. For years the cost of construction in Sweden has increased faster than inflation making it more and more expensive to build. Earlier research has pointed to the potential of the lean philosophy and its methods in construction to make it more efficient and overcome the uncertainty and complexity that categorize the construction industry. Certain tools and methods have been conceptualized in the field of Lean Construction, which lacks research based on quantitative data. It is therefore this master's thesis purpose to develop a tool in how to identify and measure waste, guide in how to prioritize eventual waste reduction activities and facilitate estimations of potential economical and environmental consequences.

Through theory, interviews, time studies and observations the authors gained insight into activities and processes in construction and what parts of these that was waste. It was shown that only 43 % of work is value adding and gives value to the customer. Considering the size of the construction industry there is much to gain from increased efficiency; increased profitability for the company, improved work environment for the workers and from a society perspective, decreased environmental impact and lower prices of buildings.

Knowledge of construction activities, processes and waste together with lean theory gave way to a tool that can be used within the construction industry as was aimed for. The tool is a first step to understanding waste in a construction project or company together with an approach to prioritize where waste reduction activities are most crucial.

KEYWORDS: construction industry, lean construction, value adding, value stream mapping, waste

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The process of working on and writing this thesis has been very exciting. We gained helpful insight into an industry we had limited knowledge about, and for that we thank PEAB who took wonderful care of us. We would however, not have a finished product as good as this had it not been for the generous input from a number of people. We are utterly grateful to everyone who has helped us during the writing of this thesis.

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Special thanks goes out to the workers at Clarion Hotel Post who let us follow them around like shadows for an extensive period of time, we hope we did not bother you too much. The data we collected was extremely helpful in our thesis. A thank you also goes out to Sandra Marrero who helped out with anything else we needed at the site.

Finally, we feel that we would like to give a big thank you to our girlfriends who have been putting up with us during the long time that we have been distracted by writing our thesis; often working from early in the morning into late in the evening.

Gothenburg, May 2011

Henrik Kristensson | Jens Arleroth

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List of Abbreviations

Abbreviation	Explanation
JIT	Just-In-Time
KPI	Key Performance Indicator
NVA	Non-Value Adding
NW	Necessary Waste
PPC	Percentage of Planned activites Completed
RFID	Radio Frequency IDentification
RQ	Research Question
TPPSP	Toyota Practical Problem-Solving Process
TPS	Toyota Production System
VA	Value Adding
VSM	Value Stream Mapping

1 Introduction

The introductory chapters will give the reader a description of the study's background along with the purpose, problem analysis, research questions and finally the thesis' delimitations.

1.1 Background

Regardless of how prices and costs have changed over time and how companies stand up in an international context it has been noted that all the parties involved in construction processes carry out countless activities that add no value to the product. According to Hines and Rich (1997) these non-value adding activities (e.g. waiting time, stacking intermediate products, double handling, etc.) are pure waste and involve unnecessary actions that should be eliminated completely. This is substantiated by Vrijhoef and Koskela (2000), who noted that operational waste (henceforth denoted merely as waste) in resource flows in the construction industry is extensively present and persistent, making the operations inefficient. This efficiency issue in the construction industry is something that has been pointed out by many researchers (Gadde & Dubois, 2002; Stewart & Spencer, 2006; Li, Lu, & Huang, 2009; Bankvall *et al.*, 2010).

In a study conducted by Josephson and Saukkoriipi (2005) a group of workers were followed and observed for 22 working days. It turned out that 33.4% of the workers' time was registered as waste, including activities such as rework, waiting, idle time and disruptions. If better ways were found in how to improve the construction processes and the resources utilization, economical benefits could be gained. This is concurred by Doloi (2008) who stated that one of the major causes of cost overruns and running behind schedule is poor worker productivity. In the study it was estimated that if a third of the construction workers' and the mechanics' time is wasted on non-value adding activities (staff cost is close to 25 % of a construction project (Statistics Sweden, 2004)), this would correspond to approximately 7% of the projects production cost. This can be argued to be a relatively high cost for construction companies since the Swedish construction industry is struggling with low profit margins, approximately around two percent (Olsson, 2000; Andersson & Ohlsson, 2007). The level of the profit margin is also true in an international context (Fortune, 2008).

An intense industrial debate about construction costs in Sweden has been going on for several years (Josephson & Saukkoriippi, 2005). Figure 1 visualizes the Construction Cost Index (CCI) compared to the Consumer Price Index (CPI). The CCI measures the prices of construction production factors such as labor, materials, machine utilization, transport, energy and other cost. The CPI covers the changes through time in the prices paid by the public for consumer goods and services (Statistics Sweden, 2011). The graph shows that the yearly percentage increase of the CCI is always more or less greater than the CPI. This means that the cost for performing a construction project (wage drift and VAT excluded) is increasing faster than inflation; hence, it is getting more and more expensive to build. This construction cost increase seen in the graph goes in line with a report by the Swedish Agency for Public Management (2009) where it is stated that the cost for material and fuel has increased in recent years and that the cost of building started to increase more than the CPI in the late 1980's. This view is shared in an international perspective as well (Arditi & Mochtar, 2000). Therefore, it could be assumed that these allegedly inefficient operations and cost increases might affect the end-customer in a negative way.

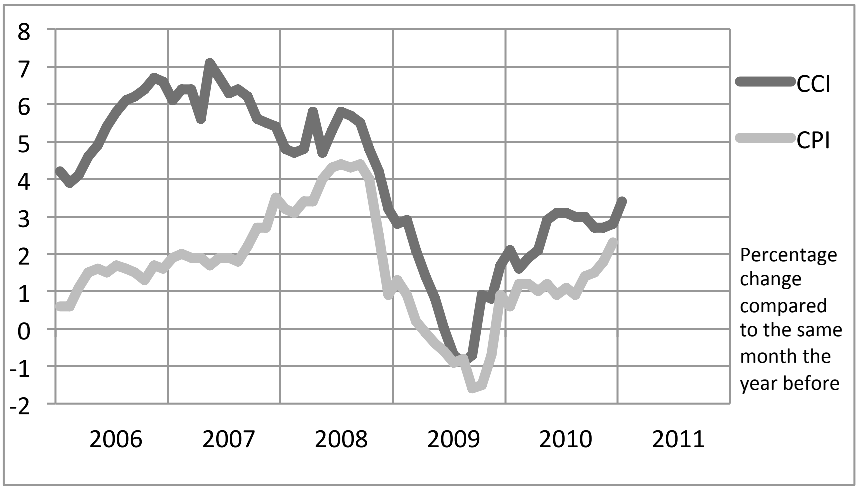


Figure 1 - Construction Cost Index and Consumer Price Index (Statistics Sweden, 2011)

As a result of being criticized as inefficient the construction industry has propelled the debate on the undeveloped construction operations in several nations around the world leading to start-ups of many national initiatives (Smyth, 2010). The British improvement program called Constructing Excellence is one such project and was initiated after a report on the scope for improving the quality and efficiency of U.K construction (Department of Environment Transportation and the Regions, 1998). The report was followed up by the report Accelerating Change (Strategic Forum for Construction, 2002) and the organization Constructing Excellence is still active today. The Swedish Government is another example where several investigations within the subject matter have been conducted during the latest years, e.g. the Construction Commission in 2002, the Committee on Construction in 2007 and Construction Process Investigation in 2008 (Government Offices of Sweden, 2011). Thus it seems that different kinds of stakeholders in the construction industry are well aware of the efficiency issue.

This view on inefficiency in the construction industry is shared by the Swedish Construction Federation (2007), which emphasize that the Swedish business sector is facing tougher international competition, a rapid restructuring process and tougher environmental standards. Stewart and Spencer (2006) argue that in recent years, globalization and deregulation of markets has led to increased foreign participation in domestic construction, placing further pressure on leading firms for major reforms. This coincides with a later report by Josephson and Saukkoriipi (2009) who claim that Swedish companies have to respond with more effective processes in order to compete against global competition. However, Josephson and Saukkoriipi (2005) are concerned that the emphasis has come to be on the cost issue and the potential scope to reduce costs and not on how to inform people about all the numerous activities that are carried out without adding any value to the final product. It is the customer who will have to pay for these non-value adding activities.

The view there is too much of a cost focus is shared by Modig (2004), who also stated that time is a crucial performance variable and might sometimes be more imperative than money. During one project where there was lack of space, Modig (2004) found in her research that one of the largest construction firms in Sweden paid extra to the transport carrier for on-time service since it was estimated that they saved money by having materials available at the right time. That way costly standstills and delays could be avoided.

Due to the earlier described efficiency issues concerning non-value adding activities (waste) it is fair to assume that construction companies that do not follow the development in the market might face predicaments in the future. Nevertheless, the efficiency issue is not unique for the construction industry. Within the manufacturing industry non-value adding activities and value adding activities have been studied and the lean manufacturing approach has come to offer tools to reduce operational cost through reduction of waste (Liker, 2004). Lean manufacturing is the idea of producing goods by using less of everything in terms of resources and time. This is a process management philosophy derived mostly from the Toyota Production System (TPS) as well as other industrial best practices (Wang, 2011). As a result of successfully improving businesses worldwide lean has become renowned for its focus on reducing wastes in order to improve overall customer satisfaction.

1.2 Problem Area

According to Jörgensen and Emmit (2008) much of the lean construction literature has focused on trying to define what lean construction actually is. This includes discussions on the complexity in construction and if this complexity will make it difficult to adopt management techniques originally aimed at other industries (Gadde & Dubois, 2002). According to Paez *et al.* (2005) researchers and practitioners within the field have looked at similarities and differences between the context of construction and the context of manufacturing in order to develop a more suitable set of practices aimed more at the construction industry.

The area is "immature" according to Eriksson (2010) who further states that the lean construction literature have been criticized for lacking scrutiny based on unbiased theoretical reasoning and instead been based on "enthusiastic arguments in management books" (Green S. , 1999; Green S. , 2002; Green & May, 2005; Fearne & Fowler, 2006; Jörgensen & Emmit, 2008; Eriksson, 2010). The emphasis within lean construction literature has mainly been on concepts of lean construction and less on practical examples and studies on how lean has been implemented within the construction field. Jörgensen and Emmit (2008) demand a larger focus on quantitative data and the use of rigorous research methods for validating the descriptions of the practices reported. This is needed to show how lean can become as successful as it has in other industries. For example, the lean philosophy and lean tools have been used successfully in various industries such as life insurance (Swank, 2003), retail (Ferdows, MacHuca, & Lewis, 2004), healthcare (Spear, 2005; Black & Miller, 2008) and customer relations (Womack & Jones, 2005) as well as in high variety, low volume industries (Slomp, Bokhorst, & Germs, 2009). Allway and Corbett (2002) state how a lean approach can be used to improve operations in various service industries, which is becoming increasingly important as service industries mature.

The reason why the lean approach within this area is seen as immature is perhaps due to the complexity of construction projects (Winch, 1987). Lean emphasizes flow, cooperation and seeing the big picture (Liker, 2004), which is relatively difficult in the construction industry because of the fragmented industry and temporary organizations made up of several actors (Koskela, 1992). According to Gadde & Dubois (2002) the industry is a loosely coupled system that may promote innovation due to its ability to generate variation but where project organizations; a decentralized organization and the lack of long-term relationships make learning and innovations difficult. Another reason why lean construction is lagging behind research in other field is the lack of diffusion of construction innovations from university research (The Swedish Agency for Public Management, 2009). Furthermore, according to the Swedish Agency for Public Management (2009) it is difficult to get a holistic view of construction research in Sweden but there has been noticed a tendency to increased funding, while companies interviewed by the agency stated that they thought there was too little funding. The research undertaken however is more focused on materials, buildings etc. and not on efficient processes.

Lean was not applied to construction until 1992, with Lauri Koskela stating the possibility of using the new production philosophy in construction (Koskela, 1992). Since then the theoretical area of lean construction has grown from a simple idea of using lean manufacturing principles into many elements linked more specifically to construction. The Lean Construction Institute (2007) defines lean construction as "a production management-based approach to project delivery". Another definition is that lean construction is the application of the lean production philosophy, with the current form of production and project management focusing on activities while ignoring flow and value (Koskela, 1992; Koskela & Huovila, 1997).

Eriksson (2010) attempted to investigate the core elements of lean construction by conducting a literature review and dividing the various aspects of lean construction identified into six groups. These six elements were identified as (1) waste reduction, (2) process focus in production planning and control, (3) end customer focus, (4) continuous improvements, (5) cooperative relationships and (6) systems perspective. Due to the complexity and size of the lean approach, the authors of this master's thesis will focus merely on one small part of lean in construction, namely, waste reduction. Waste is everywhere in construction and reduction of this waste will greatly affect process efficiency in construction (Soward, 2008). The thesis will however mention the other parts of lean construction since they ultimately affect waste. One such part is process focus which means trying to achieve flow, and together with other parts such as: customer focuses, continuous improvements, relationships and taking a holistic view are important parts of lean and even though focus is on waste reduction all these aspects of lean and lean construction are intertwined.

Eight types of waste have been identified and these wastes add no value to the final product and hold no value in the eyes of the customer (Liker, 2004; Soward, 2008). Defects, overproduction of goods, unnecessary transportation, waiting, over-processing, unnecessary movement, inventory and unused employee creativity on the other hand, are waste according to the lean philosophy. That waste can be found on construction sites is seconded by Koskela (1992) who states that waste in construction is due to rework along with non-value adding activities such as waiting, moving, inspecting, etc. According to Josephson and Saukkoriipi (2005), a relatively large part of a workers time is spent on material handling, preparation, waiting, rework and motion that add no value.

Lean manufacturing and lean construction have the same goals according to Paez *et al.* (2005): elimination of waste, cycle time reduction, and variability reduction. Koskela (1999) found that manufacturing goals could be adapted to construction. In addition, in his paper, Eriksson (2010) views waste reduction as the most important core element of lean construction while many also emphasize flow as an important aspect in order to reduce waste (Koskela, 1992; Paez *et al.*, 2005). The literature examined by Eriksson (2010) identified as dealing with waste reduction is centered on housekeeping, Just-In-Time (JIT), IT tools and off site manufacturing. Housekeeping is comparable to the lean manufacturing tool 5S in terms of trying to organize the work site and keeping it clean and tidy. Furthermore, JIT deals with efficient transportation and stockholding with inventory regarded as waste (Akintoye, 1995; Salem *et al.*, 2006). The IT aspect has to do with using IT for error detection and correction while also using it for enhancing integration. The fourth aspect, off-site manufacturing makes lean construction more similar to lean manufacturing, decreasing the work having to be done at the more complex construction site (Koskela, 1992).

One of the ways of reaching the goals of lean construction is flow according to Paez *et al.* (2005). When trying to attain flow in construction one need to realize that there are differences between manufacturing and construction, which may make it difficult to attain the same flow between different processes, attained within manufacturing (Koskela, 1992). These differences are certain construction peculiarities such as one-of-a-kind projects, site production, temporary organization and regulatory intervention, aspects more common with construction projects than manufacturing. According to Koskela (1992) however, the same production principles apply and there is room for improvement when it comes to flow in the construction industry. By working with the workflow, waste, in the form of waiting between different work procedures for example, can be decreased. Thomas *et al.* (2003) identified workflow reliability and labor flow as key determinants of construction performance.

There is a connection between lean and increased economical performance. By reducing waste and increasing flow it is possible to achieve better quality, lower cost and shorter delivery time (Liker, 2004). The effect of lean on environmental performance is not as clear. Green (1999) argues that there are dark sides such as congestion, pollution and human costs. Ballard and Howell (1999) refute this, saying that Green's arguments do not hold together and that lean offers workers more autonomy in decision-making and enriched jobs. Qui and Chen (2009) and Gordon (2001) emphasize that a company can be both lean and green and King and Lenox (2001) state that improved environmental performance is a good spillover of lean production. Even though there may be a decrease in environmental performance in some areas and increase in other areas, as a whole, there is a positive effect of implementing lean according to Qui and Chen (2009). In their study, Qui and Chen (2009) found that implementing lean in a production facility meant a reduction in the environmental effect due to time reduction in the production process. This reduction comes from decreased energy usage, material usage, transportation and waste. They show that in their case study, 15% of the environmental impact can be seen as a loss meaning they are not necessary to complete the value added work. Such a production process also exists in construction and shows that there may be a possible to reduce the environmental effect of construction in the same way.

Within the industry there seems to be a few examples of lean construction (Soward, 2008; Elfving, 2010) but there does not seem to be a tool that the industry can use when trying to become lean or to make their operations more effective and efficient. Neither is there any data concerning the environmental impact of implementing lean in construction. In developing such a tool the ends are known, a more efficient process at construction sites. According to Holmström *et al.* (2009) the key is means-end analysis involving problem solving, trying to adapt existing tools and practice in novel ways. The existing tool(s) or practice(s) in this case are lean tools and lean thinking which need to be adapted to the construction industry. As mentioned earlier, lean tools have previously been adapted to other service industries. The end is trying to reduce waste and make resource flows more efficient by combining theoretical and empirical knowledge. Holmström *et al.* (2009) stressed the importance of combing exploration with explanation. While exploration is important in solving the presented problem, the explanatory phase is also important in that the identified artifact needs to be understood in its context in order to be generalized and used in other contexts.

Due to the theoretical and practical gap it would be beneficial to use quantitative data together with lean tools and methods to identify and classify waste at construction sites and point out improvement areas where construction process efficiency can be increased. Hence, this is seen as a source of further research. The quantitative data will be attained by identifying and measuring waste; and is not in itself a part of the theoretical gap meant to be filled. The information attained from measuring will however, be important in analyzing the projected benefits from lean construction and can be used to refine any proposed solution.

1.3 Purpose and Research Questions

By using lean thinking and lean tools and adapting them to the construction industry this master's thesis purpose is to *develop a tool to identify and measure waste, guide in which order waste should be reduced and by this enabling estimations of potential consequences that might occur by implementing a lean approach at a construction site.* This is of interest in order to bridge the research gap between conceptual lean construction and research based on empirical studies.

From the described background and the theoretical and practical problems highlighted in the section 1.2 Problem Area five research questions (RQs) have been structured in order to create a more practical way to approach this master's thesis's purpose. These RQs have the intention to guide both the reader and the researchers throughout the research process. In addition, each RQ is followed by a brief description and motivation.

RQ1: *What types of waste can be identified in construction operations?*
The question aims to reveal what kind of different types of waste that might exist in construction operations. This should be done in order to be aware of what kinds of inefficiencies to look for when examining construction operations.

RQ2*: How can waste be identified?*
The question aims to examine how waste can be detected by a systematic method. By systematically looking for waste, standardization and continuous improvement opportunities of the waste identification process is facilitated.

RQ3*: How can the identified waste be measured?*
The question aims to find ways in how to measure the magnitude of different kinds of waste to understand the impact of these. To determine how different counteractions should be properly prioritized it is desirable to be able to measure construction operations.

RQ4*: How is one to decide in what order to reduce waste at a construction site?*
The question aims to propose a framework for where to start the improvement work if waste is identified since it is not possible to address all problem areas simultaneously.

RQ5*: What potential effects could a lean approach have on a construction site?*
The question aims to display what potential effects (e.g. economical, environmental, work environment, etc.) that might occur if a waste elimination approach from a lean perspective is used within the construction industry. This will be discussed from both a quantitative and a qualitative aspect.

1.4 Delimitations

The focus of this master thesis is on the internal resource flow at construction sites and not on external flows to and from construction sites such as material transports made with trucks. In addition to this, due to the complexity of the industry (many interrelated actors) and the size of the lean construction and lean literature this thesis will merely focus on waste reduction.

2 Research Methodology

The research methodology for this master's thesis is presented in this chapter. The first section will describe what kind of research process that has been used followed by a section on how data collection has been made, covering the literature review and giving a perspective on how interviews have been executed. Finally, the master's thesis reliability, validity and objectivity will be discussed. The aim of the research was to learn more about the subject under study and with an anticipation of generating insight within the field of lean and the construction industry. The chosen research design was the study of construction projects in Gothenburg, Sweden.

2.1 Research Process

The research process adopted for this thesis is explorative (Holmström, Ketokivi, & Hameri, 2009), trying to improve the understanding of waste in construction and trying to adapt lean thinking and methods to the construction industry. In order to fulfill the aim of this master's thesis a general outline concerning how to undertake the research was conducted, with the research following six steps. Furthermore, in Figure 2 the reader can see what kind of factors that came to affect this master's thesis outcome.

1. PROBLEM FORMULATION
   A brief literature review on the construction industry and the field of lean was conducted in order to acquire basic knowledge. This was done in order to structure, shape, and define the master's thesis problem area, purpose, and research question that were presented in Chapter 1.

2. LITERATURE REVIEW
   Literature assumed to be relevant for the subject under study was reviewed and connections between the field of lean and the construction industry were made. Since it is stated to be appropriate to use pre-defined keywords in order to structure the data collection and to picture the reports essence for the reader (Björklund & Paulsson, 2003) this was done. The literature review covered key concepts within the fields of lean, construction, value stream mapping, waste, and other relevant topics. The results of the literature study are presented in Chapter 3 and in the end of this chapter the reader will find a literature summary that clarifies and emphasizes the imperative parts from all the literature resources. For a more thorough literature review the reader is directed to the section 2.2.1 Literature Review.

3. INTERVIEWS
   Sets of interviews were conducted with different stakeholders participating. These stakeholders are actors within the construction business and people who possess knowledge and expertise in the lean or construction field. The findings are presented for the reader in Chapter 5.

4. OBSERVATIONS
   Since observations are seen as a source of relatively objective information (Björklund & Paulsson, 2003) the authors performed several field trips to construction sites. These observations have complemented the collected data from the interviews and the literature review. In addition, to gain lean experience within the construction industry the authors looked into a 5S-project that was being implemented at a construction site. Information gathered through observations is to be seen in Chapter 5.

5. DEVELOPMENT OF TOOL
   Findings from the literature review, interviews and observations were combined and a tool was developed in how to identify and measure waste, guide in how to prioritize eventual

waste reduction activities and by this enabling estimation of potential consequences that might occur if lean is implemented. The result is presented in Chapter 7.

6. VALIDATION
   The tool was discussed with the construction industry in order to get their perspective on it and find improvement areas. The Lean Construction Tool was later on tested and validated in a test case. This is presented in Chapter 7.

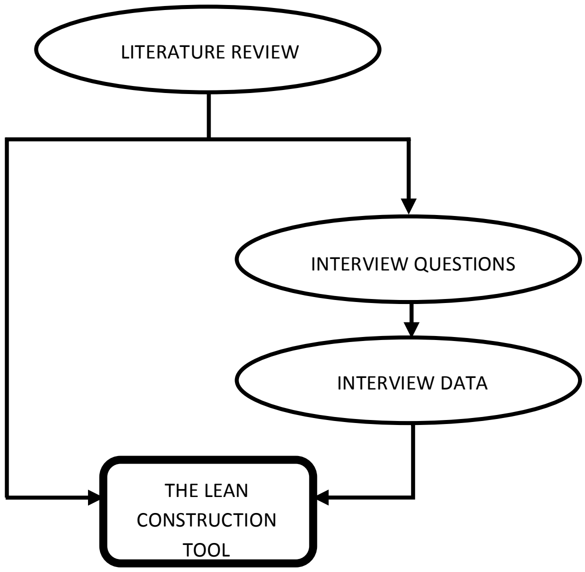


Figure 2 - Factors Affecting the Design of the Master's Thesis' Lean Construction Tool

Furthermore, it was the author's intention to perform this study according to Paulsson's (1999) scientific process. During the time of study the researchers will find themselves moving from different levels of abstractions, the general level (academic theories) and the concrete level (empiric), shaping the path of study to the letter U (see Figure 3). Paulsson (1999) states that it is common to start on a general level and then gradually becoming more concrete, e.g. when collecting data, to finally move back to a general level in the end of the study. Furthermore, it is said that if the researchers do not go up in level of abstraction at the end of the project it will give the path of study the shape of a hook (see Figure 4), which is called the consultant's hook since the study will most likely resemble a consultant's report. The reason behind the name is that consultant reports are more focused on solving individual client's problems, without interest in discussing the more general problem and the solution to this (Paulsson, 1999). The authors of this master's thesis were highly motivated to follow through with the U-model in order to secure an academic product and not merely a consultant's report.

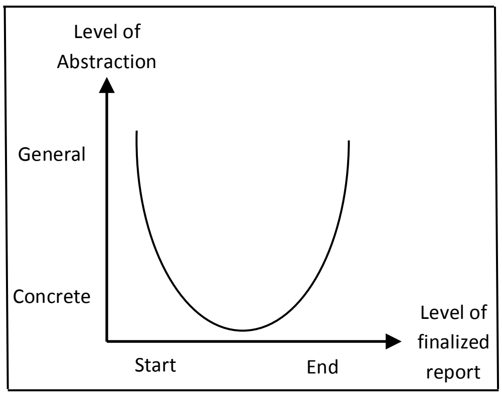


Figure 3 - The U-model (Paulsson, 1999)

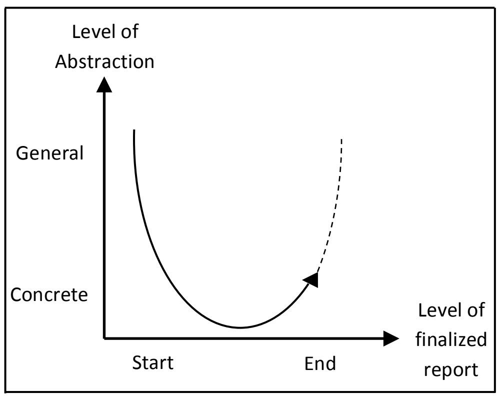


Figure 4 - The Consultant's Hook (Paulsson, 1999)

2.2 Data Collection

Both primary and secondary data has been collected. In line with Björklund and Paulsson (2003), primary data is information that has been gathered explicitly for the study. In that sense the main source for this master's thesis primary data are interviews, observations and information obtained during the execution of the study. Data that has been published or released earlier in some way is defined as secondary data (Björklund & Paulsson, 2003) and is various type of literature from the literature review. For a complete list of literature used in this master's thesis the reader is referred to the reference chapter.

In addition, triangulation is a way to enhance a study's trustworthiness by using several different methods or sources of data in the study of the same phenomenon (Björklund & Paulsson, 2003; Bryman, 2004). By interviewing different people with different perspectives due to their unique experiences of the construction business and the author's own observations through several VSM studies and other field trips it was assumed that triangulation was achieved.

Furthermore, all interviews and observations that have been a vital part of designing the tool have been made with Swedish people and on the Swedish market. However, the intention is that the tool could be used in other areas and markets as well. As the Egan Report (Department of Environment Transportation and the Regions, 1998) and various reports by the Swedish Government (e.g. the Committee on Construction in 2007 and Construction Process Investigation in 2008) show, the construction industries in these two countries face similar problems.

2.2.1 Literature Review

Thorough research can only be conducted in relation to existing knowledge (Kotzab *et al.*, 2005). Therefore a literature review is an essential part of the research process. A plethora of different types of literature and a number of different types of sources have been used and the initial phase of the data collection was to gather these. Both qualitative data and quantitative data were collected in order to establish a well-built foundation for the analysis section and the discussion chapter. The outcome of the literature review can be found in Chapter 3. Besides achieving an understanding for the subject of study and obtaining data, the literature review was further used to design the framework for primary data collection and supporting the analysis. In an attempt to deliver an impartial report it has been the intention of the authors to value journal articles and literature of scientific and unbiased nature over newspapers, web-information, company internal information, and so forth. The latter will only be used when academic literature is not at the authors' disposal.

What kinds of search terms that has been used in the literature search and in what databases the literature has been downloaded from is being displayed in Table 1. The databases used were: Emerald Library (EL), Science Direct (SD), ProQuest (PQ), Informaworld (IW), and ESBCOhost (ESBCO). In addition, a summary of all vital literature has been made and can be viewed in Appendix A – Literature Summary. The Literature Summary shows the different articles and other literature sources divided into the groups: lean literature, construction literature, lean construction literature or other literature depending on from which type of literature the source originated. The summary also shows how the different articles and other literature sources have contributed to this thesis.

Table 1 - Lists of Search Terms and Databases used in the Literature Review

Search Term	Database
Lean Construction	EL, SD, PQ, IW, ESBCO
Lean Service	EL, SD, PQ, IW, ESBCO
Lean Building	EL, SD, PQ, IW, ESBCO
JIT Construction	EL, SD, PQ, IW, ESBCO
Lean Healthcare	EL, SD, PQ, IW, ESBCO
Lean Implementation Construction	EL, SD, PQ, IW, ESBCO
Effective Construction	EL, SD, PQ, IW, ESBCO
Efficient Construction	EL, SD, PQ, IW, ESBCO
Construction Waste	EL, SD, PQ, IW, ESBCO
Construction Material Waste	EL, SD, PQ, IW, ESBCO
Construction Time Waste	EL, SD, PQ, IW, ESBCO
Construction Labor Waste	EL, SD, PQ, IW, ESBCO
Construction Supply Chain	EL, SD, PQ, IW, ESBCO
Construction Logistics	EL, SD, PQ, IW, ESBCO
Green Construction	EL, SD, PQ, IW, ESBCO
Green Construction Logistics	EL, SD, PQ, IW, ESBCO

2.2.2 Interviews

The people interviewed can be divided into three different categories, namely: Construction Industry Practitioner, Lean Experts, and Construction Academics and all the interviews conducted in this master's thesis are listed in Table 2. For interest in how the interview questions were structured the reader is asked to go to the section Appendix B - Case Study Protocol. Furthermore, an overview of the interviews can be found in Appendix C – Overview Interviews.

Table 2 - Interviews Conducted in the Master's Thesis

Name	Company
Construction Industry Practitioner 1	Large Swedish Construction Company
Construction Industry Practitioner 2	Large Swedish Construction Company
Construction Industry Practitioner 3	Large Swedish Construction Company
Lean Expert 1	Lean Researcher at a Swedish University
Lean Expert 2	Lean Research at a Swedish University and CEO of a company that is a specialist in construction efficiency
Lean Expert 3	Lean Practitioner at a Swedish research organization
Construction Academic 1	Professor in Building Economics at a Swedish University
Construction Academic 2	Industry PhD at a large Swedish Construction Company
Construction Academic 3	Consultant at an analytics and technology company and has a PhD from a Swedish University

The reason behind interviewing different persons from different positions is that it is believed by the authors that one single person cannot possibly possess all the necessary insight for giving a good reflection of the situation under study. However, by using respondents with different experience it is assumed by the authors that a holistic view and understanding of the construction business and its processes will be given. The purposes with the interviews are explained below.

PURPOSE OF INTERVIEWING CONSTRUCTION INDUSTRY PRACTITIONERS

The interviews with these people were conducted to give the authors insight into what the construction industry looks like and what kinds of operations that could be anticipated at building sites. Interviewing people who perform construction operations on a daily basis is of great importance in order to cover the practical know-how perspective. Furthermore, another purpose with these interviews was to get an understanding for how change averse the people of the industry might be and how attitudes are towards improvement work.

PURPOSE OF INTERVIEWING LEAN EXPERTS
The purpose of interviewing these people was to gain knowledge in the field of lean and to get a profound understanding of lean implementation in a construction context. It could be argued that such knowledge could only be gained through practical experience. Therefore, it is the authors' belief that lean experts that both have academic merits and real life experience of lean implementation projects (not necessarily within construction projects) are highly valuable as objects for data collection. In addition, the aim with these interviews was to get a perspective of the lean construction covering: what can be done, what should be done, how should it be done, and why should it be done?

PURPOSE OF INTERVIEWING COUNSTRUCTION ACADEMICS
The aim of these interviews was to get the perspective of academics within the construction field. This is of interest to contrast how people with more practical experience are different in their view of change and improvement possibilities in relation to how people with academic experience look at it. Furthermore, these interview objects will serve as a source of knowledge guiding the authors in what kind of data to look for in the making of the master's thesis.

2.2.3 Interview Process

The interviews were designed according to the semi-structured approach, which refers to a context in which the interviewer has a series of questions that are in the general form of an interview guide but is able to vary the sequence of questions (Kotzab *et al.*, 2005). By using this method it gave the authors the ability and flexibility to ask further questions in response to what were seen as interesting replies simultaneously as it gave the respondent enough freedom to elaborate on specific topics chosen by the researchers.

In line with Trost's (1997) recommendations the interviews were, if possible, conducted with the presence of both authors since it is argued that this approach results in greater amount of information obtained and a better understanding for the subject. Furthermore, only one person was interviewed at the time to avoid the risk of group behavior since it is argued by Trost (1997) that a group interview can easily lead to comments and behaviors that really none of the individual respondents sympathize with.

In order to facilitate the interviews for possible execution by other researchers the authors had structured the interview process into five steps making re-creation easy. The following process was used for the interviews and it resulted in the empirical data.

1. PREPARATION
   The authors made sure to have suitable knowledge about the interview theme to be able to ask appropriate questions and control the interview in a good way. Kvale (1996) argues about the importance to have a structured interview guide with clear, simple, easy, and short questions. In addition, Yin's (2003) case study protocol was used as a framework for this master's thesis interview guide. The questions were formulated in a structured way that aimed to help to answer the research questions of this master's thesis. Therefore, the interview guide was structured in five sections of questions, each one corresponding to every one of the research questions of the study (to view this master's thesis' case study protocol see Appendix B - Case Study Protocol). Furthermore, before the interviews were conducted the execution process was discussed in advanced making sure that it was clear about who is doing what during the interview.

2. EXECUTION
   When the interviews were held the case study protocol (see Appendix B - Case Study Protocol) was thoroughly followed in order to facilitate comparison of answers between different interview objects afterwards. During the dialog with the interviewee both of the authors took notes since it was assumed that this would reduce the risk of missing any crucial information. However, those interviews when the respondent agreed to let the dialog be recorded only one of the authors took notes while the other one focused on leading the conversation. This was made for all the interviews but one.

3. PROCESS DATA
   After the interviews the authors transcribed their own notes and then compared the results with each other. Data was structured and updated resulting in a new transcript. In this stage no data was discarded since the authors wanted to validate if the data had been interpreted in an accurate way by sending the transcript to the interviewee. In other words, this was an intentional act for risk avoidance since data might have been interpreted in a wrong way and therefore assumed to be irrelevant even though this was not the case.

4. VALIDATION & APPROVAL OF TRANSCIPTION
   The transcript was sent to seven out of nine of the interviewee to make sure that the authors interpretations were correct and in line with what the respondent had meant to explain. Clarifications and/or corrections could be made in the validation process. The interview object had also to approve the transcripts and was given the opportunity to remove sensitive information. For those interviewees that had the possibility to make corrections or remove data this was practically never done. Therefore it was the authors' perception that the risk of possessing false data from the two interviews where validation was missed was assumed to be minimal.

5. COMPLETION
   Finally, all information was sorted in a systematic way and the data was checked against the purpose and the master's thesis' RQs to avoid the reduction of important data or the keeping of unnecessary data. Data that came to be seen as irrelevant was later discarded and a final transcript was made.

2.2.4 Observation

All the data and information that were gathered during the interviews was complemented with the authors' own observations. The reason for this is that according to Yin (2003) observational evidence is often useful in providing additional information and adds new dimensions for understanding either the context or the phenomenon being studied. To increase the reliability of observational data it was the authors' intention to have more than one observer making the observations since this is in line with Yin's (2003) recommendation. Observations will be made on different construction processes by following different kinds of construction workers such as plumbers, carpenters, electricians, etc.

Observations can be conducted in a passive form or a participated approach where the latter one is an approach where the observer may assume a variety of roles within a study situation and could participate in the events being studied (Yin, 2003). Kotzab *et al.* (2005) further explain that a participated approach will let the researcher attend social settings for an extended period of time, observing behavior, listen to conversations, interact by asking questions and interviewing informants.

There are though both positive and negative consequences of using a participating observation approach as being listed in Table 3. The authors of this master's thesis had, however, the perception that the benefits of using the participated approach instead of being a passive observer overrun the negative aspects. Since the participated approach is chosen the authors will take into account that the Hawthorne effect could possibly affect the results. The Hawthorne effect is the psychological aspect of participating within research and explains how a participant's knowledge about taking part in an experiment affects the outcome (Sapp, 2006). It was further argued by Sapp (2006) that the outcome might be affected in four different ways:

1. Demand Characteristics – researchers can cause participants to produce the desired outcome of a study
2. Evaluation Apprehension – the anxiety of participating in a study affects the outcome
3. Social Desirability – Participants might want to please an experimenter and produce socially desirable results
4. Placebo Effects – Changes in participants' behavior due to expectation effects

For the authors to minimize the Hawthorne effect they tried to distance themselves from the construction workers while they were working and only engaged in small talk before and after the workday. Furthermore, the workers were told that the result was of less importance and that the authors merely wanted to experience what a day at a construction site might look like. It is the authors' perception that this might have reduced the risk of social desirability and placebo effects.

Table 3 - The Pros and Cons of Participant-Observation (Yin, 2003)

Positive Aspects	Negative Aspects
1. The ability to gain access to events or groups that are otherwise inaccessible to scientific investigation	1. Less ability to work as an external observer and may, at times, have to assume positions contrary to the interest of good scientific practice
2. The ability to perceive reality from the viewpoint of someone "inside" the case study rather than external to it	2. Become a supporter of the group or organization being studied, thus losing objectivity
3. The ability to manipulate minor events – such as summoning a meeting of a group of persons in the case study	3. The participant role may require too much attention relative to the observer role
	4. If the organization or social group being studied is physically dispersed it can be difficult for the researcher to be at the right place at the right time.

Furthermore, the authors performed value stream mapping (VSM) of construction processes in order to collect primary data. When performing the VSMs a specific android mobile phone application called *StarBuilder* was used (see Figure 5). It was the authors' intention to only use one technical device when collecting data in order to standardize this process. Hence, variances in measuring due to different measuring techniques could therefore be avoided.

It should be noted that the collection of data through value stream mapping activities has been made at one construction site only. If the construction processes at this site would be outside what is assumed normal for the industry the authors generalization of the result would needed to be revised. However, no reason for believing so has been encountered which gives the authors the possibility to generalize the findings at the construction site and make estimations for the whole industry.

Earlier VSMs have been conducted with a simple watch or a stopwatch and it was the authors' experience that the StarBuilder is superior to the other due to its user friendliness and simplicity. By pushing the button which best match the activity of the construction worker the data is registered and later when the study is over all data is sent over to a Google Document. When downloading the document all data is structured in a good way, easy to overview, and ready for analysis. An explanation concerning what circumstances the different buttons were pressed is given below.

Figure 5 - The StarBuilder Application (www.sternbergconsulting.com/Starbuilder)

CONSTRUCT

When a construction worker performs an activity that is value adding, e.g. welding a gate or putting up a drywall the construct button was pressed. This was also the case for those activities when material was processed in order to be used for the building process, e.g. shaping of metal or cutting pipes to appropriate length.

MATERIAL HANDLING

Whenever material needed to be transported or moved in some way at the construction site it was registered as material handling. Tools were more or less also moved along with material thus tool handling came to be registered as material handling as well. Furthermore, sorting of scrap material and cleaning up a site were also seen as material handling.

DISCUSSION

Every time a conversation was started the discussion button was pushed. However, the sort of discussion varied mainly between two types; (1) problem solving and (2) small talk. One can see the first one as necessary waste since the discussion is needed to be able to precede the construction in a correct way whereas the small talk is pure waste given that it has nothing to do with the construction work. If discussion and walk happened simultaneously the discussion button was used in order to avoid missing out on problem solving conversations.

WALK

The walk button was pressed every time the construction worker walks at the site. The activity can be initiated by the need to pick up material, go looking for tools or that the worker is needed to work at another place at the site. If discussion and walk happened simultaneously the discussion button was used in order to avoid missing out on problem solving conversations.

BREAK

If the construction worker had to make a break from the work tasks this was registered by using this button. Activities that triggered this button could be coffee- and smoke breaks. It was also used to indicate lunch break and when the work day had come to an end.

ADMIN/OTHER
The sixth button was used for administrative handlings and all the activities that did not match with the former described buttons. Other activities could for example be: double checking, and redoing earlier work.

PREPARATION
This button was used for those occasions when material or tools needed to be prepared in some way before the construction worker could use them. Work tasks that had to be done to facilitate value adding activities such as unpacking material, measuring, marking, etc. were registered as preparation.

WAIT
The last button was pushed every time the construction worker had to wait on something. This could be waiting on a machine to heat up, waiting on a colleague to come and help, waiting on other workers to finish their work, etc.

2.3 Reliability, Validity and Objectivity

The following three sections will discuss the master's thesis reliability, validity and objectivity. These are measures used to define a research's credibility (Björklund & Paulsson, 2003).

2.3.1 Reliability

The reliability of a research instrument concerns the level of consistency of the measuring of the concept (Bryman, 2004), put in other words, to what extent does the instruments deliver the same results on repeated trials minimizing the room for errors and biases in the study (Björklund & Paulsson, 2003). Triangulation, which has been mentioned before is according to Björklund and Paulsson (2003), a good method to improve a study's reliability.

In line with Björklund and Paulsson’s (2003) recommendations this master's thesis designed a standardized interview process to ensure high reliability. The interviews were well prepared and thoroughly explained to the interviewees before the questioning started. Furthermore, the interviewees were given sufficient time to ponder their answers without any stress factors affecting the results. Every interview held was written down (or recorded if approved by the interviewee) by both authors. This facilitated an opportunity to compare the authors’ notes against each other in order to see if data was interpreted in the same way. In those situations where the authors interpreted data in different ways the source of data was controlled.

2.3.2 Validity

According to Bryman (2004), validity is a concern with the integrity of the conclusions that are generated from a piece of research and relates to the question of whether a measure is measuring what is supposed to be measured. In addition, validity can be divided into internal validity and external validity. Bryman (2004) explains internal validity to be the concern with the question of whether a conclusion that holds a casual relationship between two or more variables is consistent. When it comes to external validity it is about questioning whether a result of a study can be generalized beyond the specific research context.

In order to ensure internal validity for this master's thesis thorough descriptions were given in how the theory and collected data was linked to the analysis and the RQs. To deal with external validity, Björklund and Paulsson (2003) suggestions such as triangulation and unbiased interview questions with no room for misconceptions were considered.

2.3.3 Objectivity

Objectivity represents an impartial approach of the study where the extent to which values influence the study is considered (Björklund & Paulsson, 2003). The ideal research should not be affected by values, however, according to Paulsson (1999) it is practically impossible to achieve full objectivity, and some researchers believe also that it is not desirable to aim for this. Nevertheless, Paulsson (1999) further states that one should always try to disclose and account for them.

The authors of this master's thesis made an effort to clarify and justify the choices made in the study in order to give the reader the opportunity to consider the study's results. Hence, this will enhance the study's objectivity (Björklund & Paulsson, 2003). It is also argued by Paulsson (1999) that by using observation as a data collection method it will give a high level of objectivity but also a high level of reliability and validity. Nevertheless, this method is used sparingly since it is rather resource-intensive compared to interviews and surveys. Thus, a study's level of its reliability, validity and objectivity must be weighed against its resource consumption (Paulsson, 1999) and this was considered for this master's thesis' study.

Finally, the initiator of a study may want to affect the report's design and have views on how to execute different research processes e.g. how to collect data. However, Paulsson (1999) emphasize the importance that all decisions should be taken by the researchers to keep a high level of objectivity. The authors of this master's thesis were gratefully open to advice, suggestions and comments from the originator of the study but stayed independent and kept in mind that all decisions concerning the study were solely their responsibility.

3 Frame of Reference

This chapter will give the reader an understanding of different concepts and tools that can be used in order to achieve improvements of processes as well as insight into the construction industry. Lean, lean construction as well as the application and adaption of lean tools and methods will also be reviewed. All information gathered in this chapter is the result of the Literature Review.

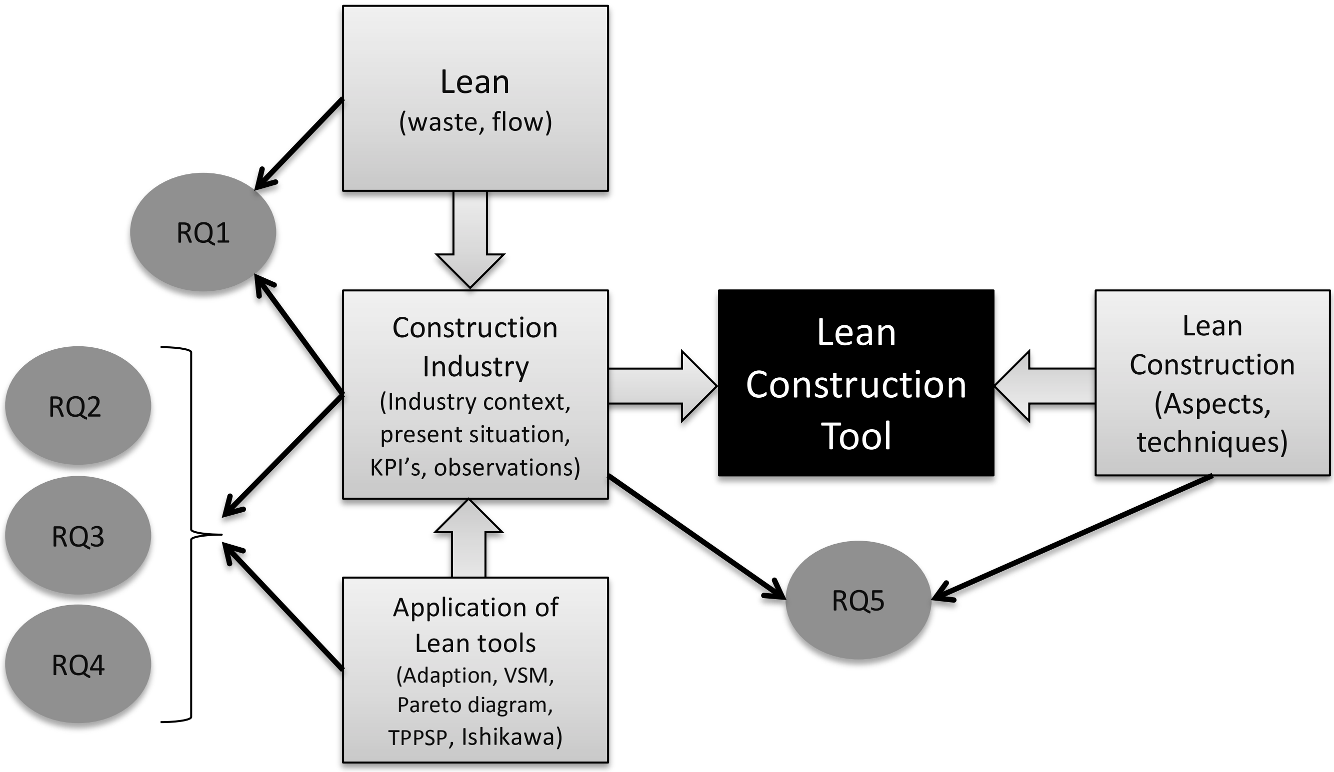


Figure 6 - Frame of Reference Guide

Figure 6 shows, through the thick arrows, how the different subchapters in this chapter affect each other and how they ultimately shape the development of the authors' Lean Construction Tool, e.g. Lean theory is adapted to the construction industry context before being incorporated into the Lean Construction Tool. The thinner arrows show what parts of the literature help answer the different research questions.

3.1 Construction Industry

Many actors in the industry or actors connected to the industry agree that the building costs can be decreased but disagree on which costs should be prioritized (Josephson & Saukkoriippi, 2005). Both Koskela (1992) and Josephson and Saukkoriipi (2005) argue that there has been too little focus on construction processes and trying to make them more efficient by reducing waste. In their study Josephson and Saukkoriipi (2005) show that waste is evident in construction operations and that these affect the industry. For example Love and Li (2000) mention that poor quality in construction activities require costly rework sometimes up to 10% of project cost. To avoid this it is important to understand how these processes relate to the construction industry in a larger context, including their importance for the industry, the environment in which they are in and the actors within that environment.

3.1.1 Present Situation in the Construction Industry

The Swedish construction industry is seeing an increase in competition from international competition, which rose during the latest economic high (The Swedish Agency for Public Management, 2009) along with an increase in building costs greater than the increase in consumer price index (Statistics Sweden, 2011). According to the industry (PEAB, 2011), there is also a lack of qualified personnel as the Swedish economy is doing well and companies have to turn down work due to not having enough staff. This is a problem, which may not become less severe in the future with a large group of the population, those born in the 1940s, retiring in upcoming years.

In their analysis of the current situation as of 1998, the Swedish Agency for Public Management (2009) mentions a decrease in market concentration during the economic high prior to 1998. A similar situation is likely to occur today with larger companies having to turn down job, opening up for smaller business. In their analysis, the agency also mentions increasing incentives to build environmentally friendly and energy efficient. However, at the same time the incentives to improve efficiency; increase competence and for development are low in construction companies regardless of the economic situation. At the same time, the Swedish Agency for Public Management (2009) also says that construction companies are aware of the industries need for rejuvenation.

3.1.2 Construction Industry Context

There are certain peculiarities that set the construction industry apart from traditional manufacturing. These industry specific factors may be used as reasons for not implementing well established production philosophies in construction (Koskela, 1992). They are, however, important in order to understand the industry.

Koskela (1992) identified four construction peculiarities; collected from Warszawski (1990) and Nam and Tatum (1988):

1. One-of-a-kind nature of projects
2. Site production
3. Temporary multi-organization
4. Regulatory intervention

In addition, Koskela (1992) identifies other factors unique for the construction industry such as durability, costliness, complexity and uncertainty. Koskela did not consider the first two of these factors relevant in the context and the second two are not seen as primary peculiarities but rather as resultant process features. Paez *et al.* (2005) take a different view in their paper, considering complexity in the form of a temporary organization and regulatory intervention, together with uncertainty as specific factors of construction. The authors agree with Koskela, seeing complexity as a result of other peculiarities. Below, the factors identified by Koskela will be discussed.

Typical of construction production is that the final product is built at the site it will later stand, site production. Each site with surroundings has its own characteristics meaning that site production leads to one-of-a-kind product (Paez *et al.*, 2005). This one-of-a-kind aspect is also affected by different need and priorities by clients and different views of designers and architects on design solutions (Warszawski, 1990). At the same time, the material, components and skills needed to realize the project are often the same. From a contractors or a designers point of view the processes are many times the same, they see continuity in the processes that clients and other “outsiders” do not see when only looking at a snapshot of the construction industry (Koskela, 1992).

A third peculiarity in construction is due to the fragmented construction industry made up of many different contractors, subcontractors, designers and architects, organizations with different practices (Koskela, 1992). The temporary organization working on a construction project is made up of these different companies and people and there is a good chance that they have not worked together before. They may also be tied to the project through different contractual arrangements. This temporary organization also extends to the workforce where some may only be employed for a particular project and not permanently. This is often due to subassemblies in a construction project, made up of overlapping and interacting activities undertaken by different contractors making it difficult to keep to a set timetable (Paez, Salem, Solomon, & Genaidy, 2005). It is also affected by the practice of using lowest price as criteria for purchasing services for subassemblies (Koskela, 1992). Hatmoko and Scott (2010) on the other hand, state that there are many benefits to subcontracting; e.g. risk sharing together with more specialized, efficient and cost-effective subcontractors

The last peculiarity identified by Koskela (1992) is intervention of regulatory authorities. In construction, due to the complexity of the projects and the risks involved, the site and project are subject to checking and approval. This checking and approval is carried out both by the main contractors but mainly by regulatory authorities to make sure the buildings meet codes and standards.

3.1.3 Logistics in Temporary Organizations

Logistics in temporary organizations at constantly new sites (e.g. construction sites) vary a great deal from that of permanent organizations (Modig, 2004). The organization has the objective to fulfill a need and then leave a project (Nicholas, 2001). This need will in most cases mean different site conditions, which the short-term organization will need to adjust to. These constant adjustments put strain on the organizations logistics but the logistics may however, become more effective and efficient during the duration of the project due to the learning effect (Modig, 2004).

These temporary logistics solutions manage different flows of goods in project-unique environments instead of continuous flows managed in more permanent organizations (Modig, 2004). This demands a great deal of planning and foresight. Modig (2004) denotes planning within a temporary logistics solution as activities that encompass the inclusion and exclusion of possible transportation- and on-site activities as well as sequencing of those activities.

Some characteristics of logistics in a temporary organization are that it is affected by personal preferences and earlier experiences of people involved in the project, are time-critical meaning that goods need to be available at the right time, in the right sequence and where the site locations heavily influences the site design (*ibid*).

Furthermore, other characteristics of these organizations and their logistics are that test events are often run in order to decrease uncertainty. Temporary organizations and their logistics solutions are also greatly affected by their parent organization. If there is no parent organization the temporary organization has a better chance of adapting to a project-unique situation (*ibid*).

3.1.4 Customer and Value

A large part of the lean philosophy is centered on customer value. By asking, "What does the customer want from this process?" value is defined both for the internal customer, e.g. the next step in the process, as well as the external customer (Liker, 2004).

Who to consider the customer may sometimes be difficult though. A contractor working at a construction site may see the main contractor running the site as the customer because that is who gave the contractor his/her job while the reality is a bit more complicated. Another customer to the contractor is also the next contractor, and internal customer, who will be completing the next step in a long process of different smaller jobs. Taking a more holistic view, the customer is the client who is paying for the build. But even that does not complete the picture because in the end the client may not be the one using the building. All in all it is tricky deciding whom you should focus on when focusing on what the customer wants.

When it comes to internal value and logistics, value is created in the logistics systems through the 7R's of logistics (Modig, 2004). The 7R's means the right customer, product, quantity, quality, way, time and at the right price. If the goods for example arrive too early they may be in the way of another crew who needs the space while if they are too late then the worker will not have the goods needed to complete the task at hand.

The construction process is made up of two processes, design and construction, characterized by cost, duration and value according to Koskela (1992). Cost and duration depend on how efficient the value adding activities are and how many non-value adding activities are present. Value on the other hand is made up of two components. The first of these deals with customer requirements, predetermined specifications that the end product must conform to. The other component is product performance. According to Koskela (1992), value is generated by giving the customer what they want, meeting their requirements, and not "an inherent merit of conversion".

3.1.5 Construction Key Performance Indicators

There have been attempts at creating Key Performance Indicators (KPIs) for the construction industry such as the UK best practice program (Kagioglou & Cooper, 2001) but these indicators give little insight into the performance of the individual companies or projects. According to Stewart and Spencer (2006) the industry has few structured frameworks on which to base process improvement initiatives. Therefore, due to this lack of clear guidelines, improvements are often isolated and benefits cannot be coordinated or repeated.

In order to improve the industry a systematic approach could be useful. The purpose of KPIs is to enable measurement of project and organizational performance throughout the construction industry (Department of the Environment, Transport and the Regions, 2000). The information given by KPIs can be used for benchmarking purposes, and will be a key component of any organization's move towards achieving best practice and continuous improvement. However, the concept of project success has remained vaguely defined among construction professionals since project success means different things to different people (Chan & Chan, 2004). Therefore, many project managers still pursue success in a spontaneous and ad hoc fashion as they attempt to manage and allocate resources across various project areas (Freeman & Beale, 1992).

To avoid an unplanned approach, KPIs are means to help companies to identify their strengths and weaknesses, and in addition, it is a way to facilitate comparative assessment of performances against competitors within the industry. Nevertheless, the U.K. Department of the Environment, Transport and the Regions (2000) are concerned that while individual organizations have been measuring their performance for many years, there has been little consistency in the data, and the way it has been published. This might complicate to give an accurate and reliable assessment of a certain project under study. In a study conducted by Lai and Lam (2010) the order of importance of performance criteria in construction projects are: (1) time, (2) profit, (3) environment, (4) quality, (5) safety, (6) effectiveness, (7) no claims or contractual disputes, (8) job satisfaction, and (9) generation of innovative ideas. It was also showed that in the study all of the performance criteria underperform.

However, according to Chan and Chan (2004) the basic factors to analyze project success are time, cost and quality and these criteria have been more or less identified and discussed in almost every article on project success. However, beside this "iron triangle" coined by Atkinson (1999), measures for project success should also include "soft" measures such as psychosocial outcomes which refer to the satisfaction of interpersonal relation with project team members (Pinto & Pinto, 1991). Nevertheless, only a limited, manageable number of KPIs is maintainable for regular use since having too many and/or too complex KPIs can be rather time- and resource consuming (Chan & Chan, 2004). Furthermore, the systematic use of KPIs is essential as the value of these measures is mostly derived from their consistent use over a number of projects.

The British Quality Foundation (2010) recommends that the most effective tool for analyzing all aspects of an organization's operations and enable comparisons with other firms and industries is the

EFQM Excellence Model. However, this model will not be further elaborated since the authors of this master's thesis find themselves inexperienced assessors and users of the model. According to Li and Yang (2003) this is something that has been proven to be a common reason for large scoring variations. Additionally, due to resource constraints there is no time for obtaining the necessary knowledge and skills in order to execute the EFQM model in a successful manner.

Nevertheless, Chan and Chan (2004) proposed that the calculation methods of KPIs are divided into two groups (see Figure 7). The first group containing KPIs such as time, cost, value, safety, and environmental performance uses mathematical formulae to calculate the respective values. The second group that includes KPIs such as quality, functionality of building and the level of satisfaction of various stakeholders uses subjective opinions and personal judgment. With this set of KPIs both quantitative and qualitative measures are used. The Department of the Environment, Transport and the Regions (2000) exemplifies a few KPIs and different levels of these KPIs. These are presented in Appendix F - KPI.

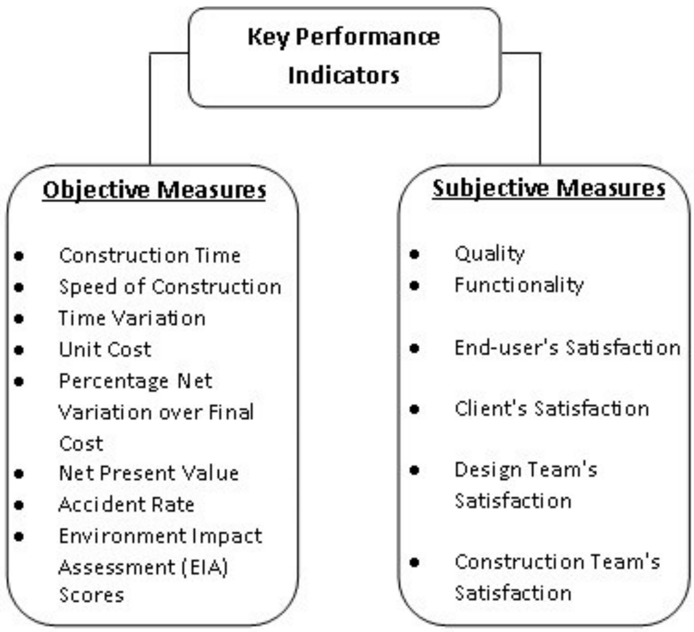


Figure 7 - Quantitative and Qualitative KPIs (Chan & Chan, 2004)

3.2 Lean

The concept lean, originating from the Japanese car manufacture Toyota's production system and often called Lean Production is constantly under development. Since the lean concept was first introduce to the producing industry and the success was significant it has now evolved to other fields than car manufactures. Due to the dynamic business environment the original lean has transformed and is today merely one part of the whole lean concept. This section attempts to present the essence of the lean concept for the reader and this is of importance since it is this philosophy that the authors aim to introduce in the construction industry.

3.2.1 History and Definition

The Lean philosophy was born within the production environment of physical goods and is based on an industrial concept developed in Japan during the 1900s. The automaker Toyota is often ascribed as being the founder of Lean Production through its Toyota Production System (TPS) (Shingo, 1989). In the early 1960s a number of principles had been developed that later become known as the foundation of Lean Production (Womack, Jones, & Roos, 1990). However, it was not until in the 1980s that Toyota first caught the world's attention by designing cars faster, with more reliability and yet at a competitive cost compared to other car manufactures (Liker, 2004). The term Lean Production was coined by the International Motor Vehicle Program researcher Krafcik (1988) and was made popular by Womack, Jones & Roos (1990) in the critically acclaimed book *The Machine That Changed the World*. According to Womack, Jones & Roos (1990) Lean Production is best described as a method which combines the advantages of craft production and mass production, e.g. avoiding the high costs of craft production and avoiding the rigidity of mass production.

After World War I, Henry Ford (Ford) and Alfred Sloan (General Motors) changed the conventional manufacturing from centuries of craft production (led by European companies) into the age of mass production (Womack, Jones, & Roos, 1990). This largely resulted in a global economically domination by the United States. In the post-war period of World War II, Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company in Japan established the concept of Lean Production. The rise of Japan's economic power quickly followed as other Japanese industries copied Toyota's system (*ibid*). Nevertheless, the development of TPS was facilitated through much research of the American mass production industry and the Japanese industry came to borrow and later develop several concepts. The Toyoda family did two long visits and thorough benchmarking of Henry Ford's manufacturing plants in 1929 and in 1950 (*ibid*).

Up to relatively recently Lean Production has traditionally been implemented in businesses with production in high volumes, few product variants, low degree of customer interaction and low fluctuation in demand (Hines, Holwe, & Rich, 2004). However, the lean perception is shifting and lean has been successfully implemented in new settings beyond the traditional manufacturing perspective.

Due to the fact that the term Lean Production is created as an attempt to describe a complete manufacturing philosophy derived from the TPS, there is no single accepted definition. Liker (2004) says that a lean enterprise is the result of applying the TPS to all areas of a business and Womack, Jones & Roos (1990) talk about a five-step process: (1) define customer value, (2) define the value stream, (3) make it flow, pull from the customer, and (5) strive for excellence. Originally, the TPS founder Ohno (1988) explained Lean Production as:

> *"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 case. And we are reducing that time line by removing the non-value added waste"*.

Lean as a concept has evolved beyond Lean Production and it continues to develop. Therefore, the development of lean has led to confusion with regards to what constitutes lean and what does not. Hines, Holwe & Rich (2004) have proposed a model (See Figure 8) covering the whole lean concept where two levels are distinguished: the strategic (Lean Thinking) and the operational (Lean Production). The customer-centered strategic thinking is applicable to every organization that provides customer value, but the shop floor tools are not. The distinction of these two levels is crucial for understanding lean as a whole in order to apply the right tools and strategies to provide customer value. However, Hines, Holwe & Rich (2004) state that much of the academic discussions concerning lean thinking still focuses on the shop-floor which demonstrates a rather limited understanding of what contemporary lean approaches are about. This lack of a holistic view might result in organizations missing the strategic aspect and assuming that quality, cost, and delivery is equal to customer value. This is a common mistake by organizations implementing lean (Liker, 2004) since if only a cost perspective is addressed and the customer-perceived value is overlooked might in the end lead to sub-optimization in the value chain (Hines, Holwe, & Rich, 2004). In other words, lean is about both increasing customer value and reducing waste, and the essence is to understand that these two are not the same. It is possible to increase customer value without reducing waste.

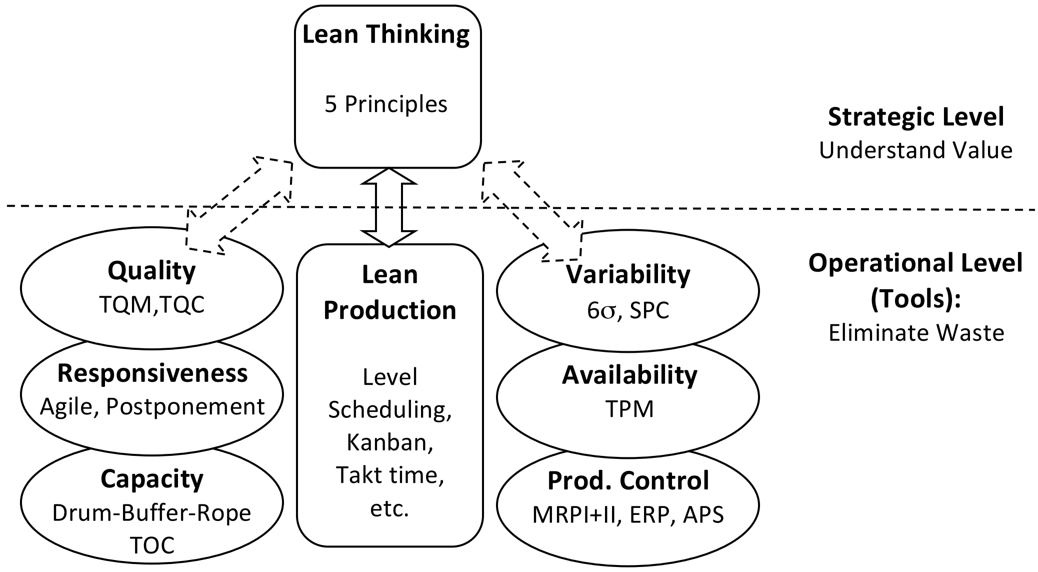


Figure 8 - The Lean Concept and the Levels of Lean (Hines, Holwe, & Rich, 2004)

When Liker (2004) did his research of the TPS he found 14 key principles that drive the techniques and tools of the system and the management of Toyota in general. These principles were divided into four sections (1) Philosophy, (2) Process, (3) People and Partners, and (4) Problem Solving and came to be called the four P's of the TPS. The philosophy aspect is about making management decisions in a long-term perspective even at expenses of short-term financial goals. The Process section is what the authors have come to emphasize on in this master's thesis since it deals with the elimination of waste and creating process flow. The two last sections concern personal and organizational development by applying team work thinking and put effort in continuous improvements and learning.

3.2.2 Waste

Toyota identified seven major types of waste in manufacturing and business processes and Liker (2004) later came to include an additional form of waste, namely *unused employee creativity*. The eight forms of waste, or *muda* as it is called in Japanese is being displayed in Figure 9 and a brief description is giving in Table 4. It might appear that a little waste does not matter but if all these kinds of waste are added up, in the long run, the inefficiency is apparent and could be substantial. It is usually the buzzword waste or *muda* that people identify lean with, however, it should be emphasized that only focusing on eliminating waste could hurt the productivity of people and the production system. Liker (2004) says that two other factors, namely *muri* and *mura* are also necessary to included in the lean work. *Muri* can be translated as the unevenness or lack of balance in the work flow for the workforce e.g. either having too much work or not enough (Lichtig, 2005). Quite often, unevenness results from internal problems that are identified as the reason for creating *muda* (Liker, 2004). *Mura*, in contrast, is overburdening people and/or equipment, creating potential situations for safety or quality failures as people and/or machines are pushed beyond their limits (Lichtig, 2005).

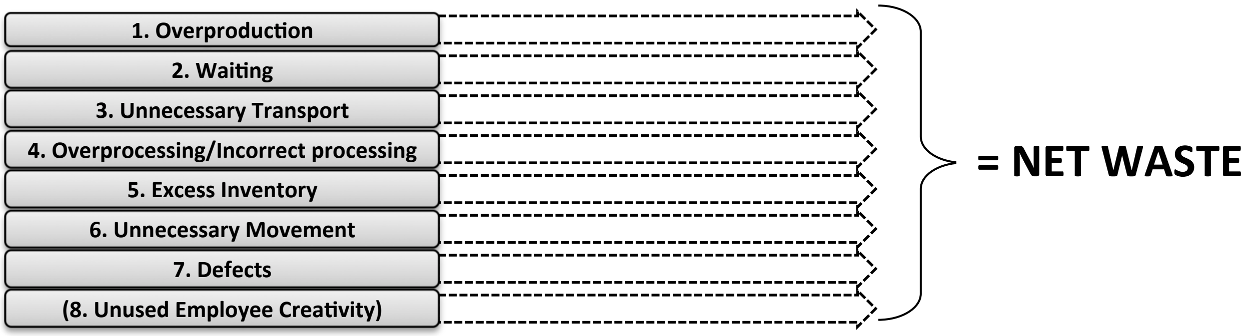


Figure 9 - The Eight Types of Waste (Liker, 2004)

Table 4 - The Eight Types of Waste (Liker, 2004)

	Type of Waste	Description
1	Overproduction	Producing items for which there are no orders, which generates such waste as overstaffing and storage and transportation costs because of excess inventory
2	Waiting	Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, parts, etc., or just plain having no work because of stock outs, lot processing delays, equipment downtime, and capacity bottlenecks
3	Unnecessary transport	Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes
4	Over processing or incorrect processing	Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary
5	Excess inventory	Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
6	Unnecessary movement	Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc. Also, walking is waste
7	Defects	Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort
8	Unused employee creativity	Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees

In addition, when examining a process with the aim to detect waste and eliminate these, activities need to be classified in some way. Monden (1993) identified three different types of operations in an internal manufacturing context. The activities could be:

1. Value Adding (VA)
2. Non-value Adding (NVA)
3. Necessary Waste (NW)

In an article by Hines and Rich (1997) these three classifications were explained where VA operations involve the conversion of processing of raw materials or semi-finished products through the use of manual labor, e.g. sub-assembly of parts, forging raw materials and painting. The second one is clarified as pure waste and involves unnecessary actions that should be eliminated completely, e.g. the eight types of waste such as waiting time and excess inventory. Thirdly and last is the NW-category, which is activities that may be wasteful, but necessary to perform in the operation procedure. In other words, they are necessary but non-value adding activities, e.g. unpacking deliveries.

3.2.3 Flow

Within lean, flow means shortening the elapsed time from raw material to finished goods and that this will lead to the best quality, lowest cost, and shortest delivery time (Liker, 2004). This is true in the sense that improved flow lowers the "water line" hence exposing problems. In order to create flow these problems, or wastes, need to be removed. Here it is common to touch upon process mapping, which is used to identify what is and is not waste (this will be discussed later on in this chapter). In addition, the importance of flow according to Polat and Arditi (2005) is that materials account for a significant proportion of the total cost and duration of a project; hence proper management of these flows may therefore have potential benefits for contractors.

As Liker (2004) points out, continuous flow is not always possible to achieve but it is something to aim for. This goal can be reached or the process can be greatly improved by using small lots, trying to keep processes close together and keeping material moving uninterrupted through the process production. Furthermore, through one-piece-flow, decreasing inventory, increasing takt time and getting rid of waste flow can be achieved. However, two mistakes often made by companies are: (1) they perceive they implement flow but in reality they set up fake flows and (2) if something goes wrong the attempt to implement flow is quickly abandon and they go back to how things used to be done (Liker, 2004).

In his article from 1992 on the new production philosophy, Koskela (1992) goes through what he identified as principles for flow process design and improvement. These steps, eleven in total, outline how decreasing or eliminating waste and making conversion as efficient as possible can achieve flow. They include waste reduction, customer focus, reduced variability, reduced cycle time, increased flexibility, simplification, increased process transparency and continuous improvements. The final step and an important step, is benchmarking. By combining your strengths with those of the best external organizations you can gain superiority (Camp, 1989). Benchmarking can, however, also be to set up goals and milestones for the organization to reach (Eriksson, 2010).

A good way to measure flow is to use the *percentage plan completed* (PPC), it is used to see how much of the work is completed on time, that is, the proportion of completed activities with respect to planned activities, hence measures the workflow reliability (Ballard & Howell, 1998). This is in a sense a measure of flow since a work that has not been completed when it should have been is a disruption of flow and can therefore be used as a benchmark in order to move forward and improve.

3.3 Application and Adaption of Lean Tools

As mentioned earlier the concept of lean can be implemented in almost every industry imaginable. Swank (2003) mentions how the life insurance company Jefferson Pilot Financial (Today Lincoln Financial Group) adapted lean principles to streamline its “service product” through the company. An insurance claim goes through the processes in the company, gaining value at each step and the aim is to minimize the parts of the processes that do not add value, much like the assembly line in a factory. Lean can also be applied to healthcare where it can be used to improve operations. Black and Miller (2008) state that the same improvement methods used for other products or services can be used in healthcare, saying that providing healthcare does not differ from building cars. In their book, lean principles were applied and adapted at Virginia Mason Medical Center with very good results. Spear (2005) is another author who says that hospitals that have tried to work like Toyota have gotten impressive results.

A few of the tools and methods mentioned by Black and Miller (2008) are Value Stream Mapping (VSM), standardized work, Andon, 5S, Heijunka and Kaizen. Some of these tools are also mentioned by other authors such as Graban (2008) who talks about 5S and Kanban whereas Condel *et al*. (2004), mention VSM and 5S. According to Graban (2008), visual management can also be used in healthcare, as a simple way of spreading information among employees in a hospital. Sobek and Jimmerson (2004) mention the A3 reporting system as a way of incorporating problem-solving in the lean approach. The A3 was also developed at Toyota and involves tools such as VSM and root cause analysis (Chakravorty, 2009).

Aspects of lean can also be seen in the retail industry where industry giant Inditex with stores such as Zara use "takt time" in order to optimize their production, making it easier for surrounding processes to adapt to the production process (Ferdows, MacHuca, & Lewis, 2004). Furthermore, Slomp *et al*. (2009) show how certain aspects of lean can be applied to yet another type of production. In their case it was a dual constrained "made-to-order" job shop.

Allway and Corbett (2002) mention how lean can be used for all types of services giving new types of KPIs that Healthcare, Finance & Insurance and Food Service/Hospitality sectors can use. A form of VSM is also described in the article along with the impacts of going lean. These impacts where not only economical but going lean also affected productivity and capacity.

The above mentioned examples point towards how lean can be applied and adapted to different settings and different industries. The underlying philosophy of putting focus on the customer and cutting out operations that do not add value can be applied to the context of any service or product (Allway & Corbett, 2002).

3.3.1 Value Stream Mapping in Construction

VSM at Toyota called ”Material Information Flow Mapping” (Rother & Shook, 2003), was developed to give manufacturing companies lasting improvements and help them identify waste and the root cause of waste. In addition, Winch and Carr (2000) state that a process mapping tool is recognized as an important management tool for understanding how value is delivered for customers. Since it is a functional tool for the manufacturing industry and Swank (2003) mention the possibilities of streamlining a service company by adding value at each step it can be assumed that it is plausible to streamline the construction industry as well. Therefore should the VSM tool be of interest for construction companies which yearning for being leaner.

Viewed as a suitable tool for redesigning production systems, VSM is a way to focus attention on flow and to see the big picture (Lasa, Laburu, & de Casto Vila, 2008). In order to implement lasting improvements incorporating the entire system, one needs to see the flow rather than thinking of production as discrete production processes. By doing so lean systems are implemented rather than isolated process improvements. Furthermore, by defining the value stream with help of a process mapping tool an understanding of what adds value in the process and what waste can be removed will be given.

According to Hines and Rich (1997) there are seven different VSM tools, each with its own strengths and weaknesses. These tools are part of a bigger jigsaw, each incorporating different parts of the value stream and can be applied independently or in combination. Different tools will deal more or less efficiently with certain types of wastes or structures and which one to use should depend on where the focus is put.

The method of removing waste is aimed more at productivity rather than quality, but improved productivity exposes more waste and quality problem in the system leading to further possibilities of improvements. The systematic attack on waste is at the same time an assault on many of the factors that lead to poor quality and other management problems (Bicheno, 1991).

VSM is a simple visualization tool, to be used with paper and pencil, where one registers if the studied activity can be classified as value adding, non-value adding or necessary waste (description of these classifications were made in the earlier section 3.2.2 Waste). By following the resource and information on the floor, on its way through the value stream, insight of the flow of resource and information is gained. VSM is a visual representation of this flow and is the blueprint from which the ideal future state is created. Unless current processes are fully understood, than it is difficult to create a route map from where one is to where one might want to be in the future (Winch & Carr, 2000). From the current-state you try to create a future, improved state as can be seen in Figure 10. The arrows in the figure indicate that the development of the current- and future-state maps overlap.

The goal when implementing VSM should be to implement VSM through different plants and facilities (if the resources take such a route), however, it is best to start at just one facility, so called door-to-door. In order to fully understand the different value streams a company works in, it is necessary to map both inter-company and intra-company value- adding processes in the long run (Rother & Shook, 2003). In a construction industry context this could be to not only focusing on the focal company but to involve external actors and the whole supply chain.

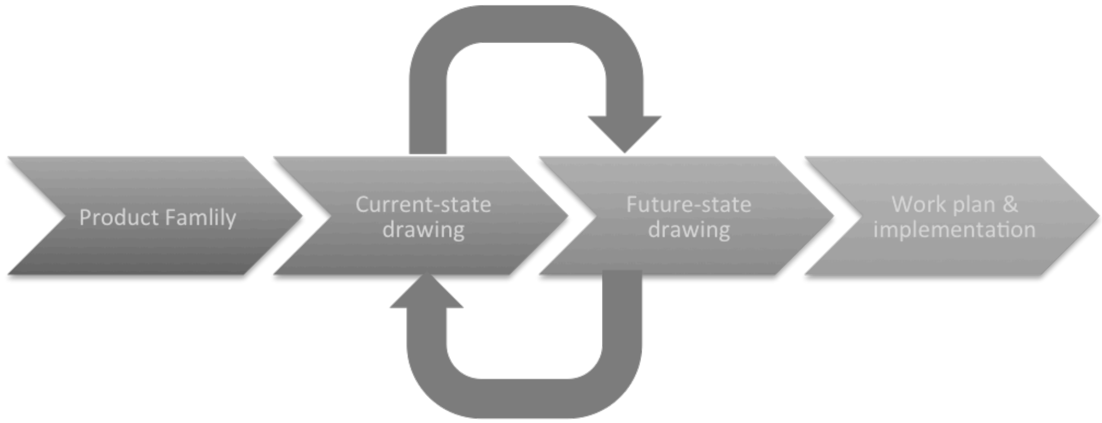


Figure 10 - Initial Value-Stream Mapping Steps. (Rother & Shook, 2003)

In addition, if looking at material, a VSM should be undertaken for a product family, not all products. Drawing a VSM for all products would, in most cases, be too complicated and clutter the map. Following one product family may be complicated enough, often crossing organizational boundaries in the company. It is therefore advised to have a Value Stream Manager (Rother & Shook, 2003), someone who is responsible for the value-stream perspective. Further advised with this is the need for this manager to be in charge of the whole VSM and not to divide the pieces among area managers and then try to tape the pieces back together into a complete VSM.

3.3.2 Toyota Practical Problem-Solving Process

When it comes to solving problems (the ones found in the VSM studies) it might be rather confusing and difficult to know if it is the actual problem that is being solved. Maybe it is just a perceived problem (not enough material ordered) resulting in countermeasures for just a symptom of the real problem (bad handling of material resulting in too much scrap). Therefore, it is suitable to have a structured process when examining problems to avoid costly counteractions. This is in line with Rother's (2010) thoughts; that further states that it is common to think that good problem solving means applying countermeasures.

The 5-Why analysis is a renowned method to pursue the deeper causes of a problem to find correspondingly deeper countermeasures (Liker, 2004). It’s a systematic questionnaire technique where the question "why?" is asked five times (generally sufficient to identify the root cause of a specific problem but the depth of layers of questions and answers is not set in stone). The key is to continue asking and answering the new layer of questions that arise from previous answer until a question is very difficult to answer and this is often where the root cause is found.

However, at Toyota, the 5-Why tool is often used as part of a seven-step process they come to call *practical problem solving.* The emphasis of the Toyota practical problem-solving process (TPPSP) is not to quickly implement countermeasure but first of all to understand the current situation so deeply that the countermeasures become obvious (Rother, 2010). Liker (2004) substantiates this and points out that practical problem solving requires that the problem be clarified and that the situation is fully grasped before recommending any solutions. The reason for this, according to Rother (2010), is that if countermeasures are introduced before understanding the situation, more variables are created, which interferes with identifying root causes and the risk of using the wrong counteractions resulting in sub-optimization is high.

The TPPSP can be depicted as a funnel (See Figure 11) where at the beginning the problem perception is rather vague and unstructured but when examine according to the method the root cause can be found. The following seven steps (Liker, 2004) are phases of the problem solving process and can be used as guidelines in how to encounter problem in a practical way resulting in, hopefully, the right countermeasures.

1. Describe what the **initial problem perception** is.
2. **Clarify the problem**. This is allegedly the most difficult part to learn and it starts with observing the situation with an open mind and comparing the actual situation to the standard.
3. **Locate Area/Point of Cause (POC)**. If there are many problems these should be prioritized with for example a Pareto analysis. The Pareto diagram use bar graphs to sort problems according to severity, frequency, nature, or source and displays them in order of size to show which problems are the most important. At this point set targets for improvement.
4. **Investigation of Root Cause.** Perform a 5-Why analysis to find the actual cause behind the problem.
5. **Countermeasure.** Match the necessary countermeasures to the discovered root cause
6. **Evaluate.** The results of using the particular countermeasure should be evaluated
7. **Standardize.** If the countermeasure is effective it should become part of a new standardized approach to facilitate further improvements

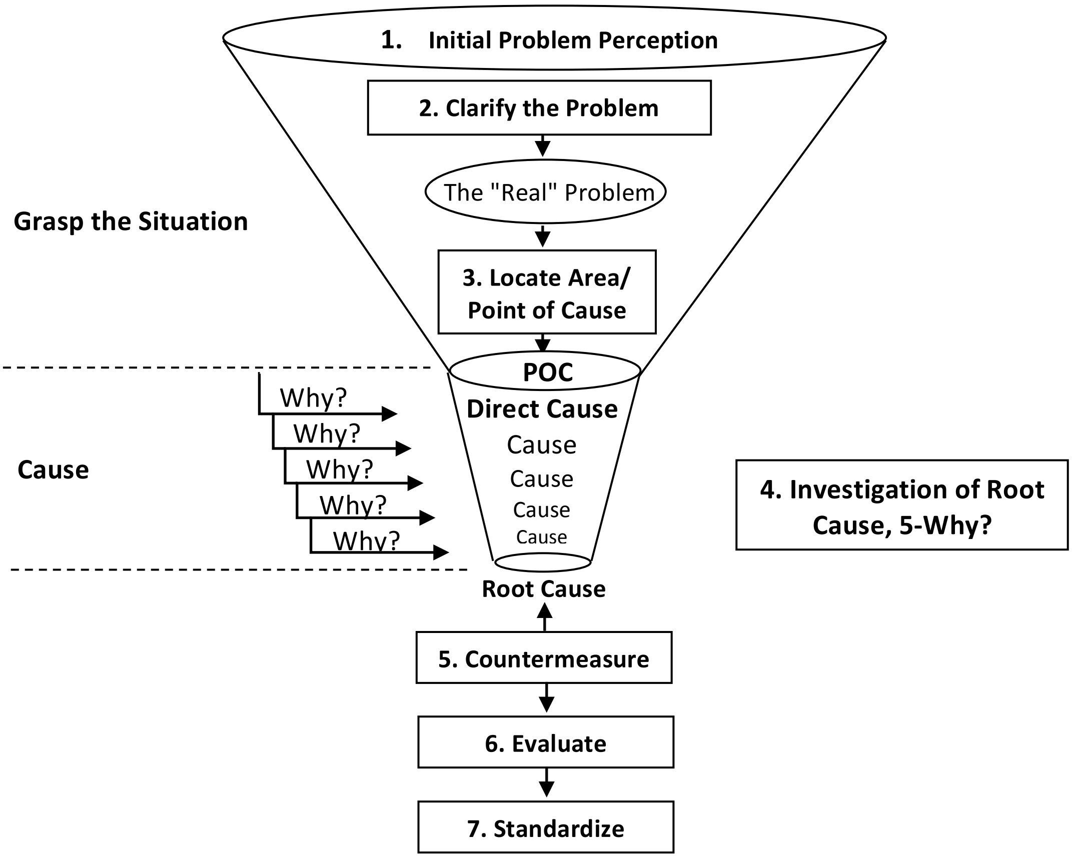


Figure 11 - Toyota's Practical Problem-Solving Process (Liker, 2004)

3.3.3 Ishikawa Diagram

The Ishikawa diagram, also known as cause-and-effect diagram or Fishbone diagram, is a problem-solving tool that is acclaimed to be an efficient tool due to its simplicity and practicality (Clary & Wandersee, 2010). The diagram was originally developed for use in the area of quality management but organizations have found it useful in problem-solving and decision making (Hannagan, 2008). At first it was used in a manufacturing and production context but over time it has shown to be equally valuable in service industries (Capper, 1998; Chakravorty, 2009). The principles behind the tool are alleged to be universal since organizations consist of a web of complex relationships (Capper, 1998) and the Ishikawa diagram provides a framework to identify causes and their relationships (Hannagan, 2008). Furthermore, the tool gives a focused analysis of key factors contributing to the problem and a clear overview which enables prioritizing and seeking solutions (Hannagan, 2008).

In short, the Ishikawa diagram displays casual relationships by stating a quality characteristic or effect at the head of the diagram and then listing possible causes along branch arrows (Capper, 1998). These effects or causes are commonly divided into seven different categories (See Table 5) that Bergman and Klefsjö (2004) denoted as the seven M's of quality issues in the production industry.

Table 5 - The Seven M's of the Ishikawa Diagram (Bergman & Klefsjö, 2004)

Man	Do the employees have enough knowledge to do the job?
Materials	Is the material used for the production processes correct?
Machine	Is the machine used in the operations correct?
Method	Is the method of conducting the job correct?
Measurement	Are the quality assurance test measures correct?
Management	Does the management provide sufficient support and information?
Milieu	Are there any external factors that cause problems?

Capper (1998) recommended a step-by-step approach when using the Ishikawa diagram. This approach is being displayed below and a general picture in how the diagram could look like is showed in Figure 12.

1. Define the quality characteristic or effect that is wished to be analyzed and write it in the head of the diagram. This might be in the form of a desired state or a problem.
2. Decide upon the headings for the branch arrows. The suggested headings are commonly the seven M's of the Ishikawa diagram. Although these may not be appropriate in every situation.
3. Taking each branch arrow in turn, list possible causes or factors and place them against the appropriate branch arrow. Related causes or factors should be grouped together to form sub-arrows.
4. Make sure to exhaust all ideas under each branch arrow before moving on to the next M in line.
5. Tidy up the diagram and look for any missing factors and gaps.
6. The diagram is finished and following steps might be to identify specific areas for further study, collect data about individual factors or to allocate specific actions to people.

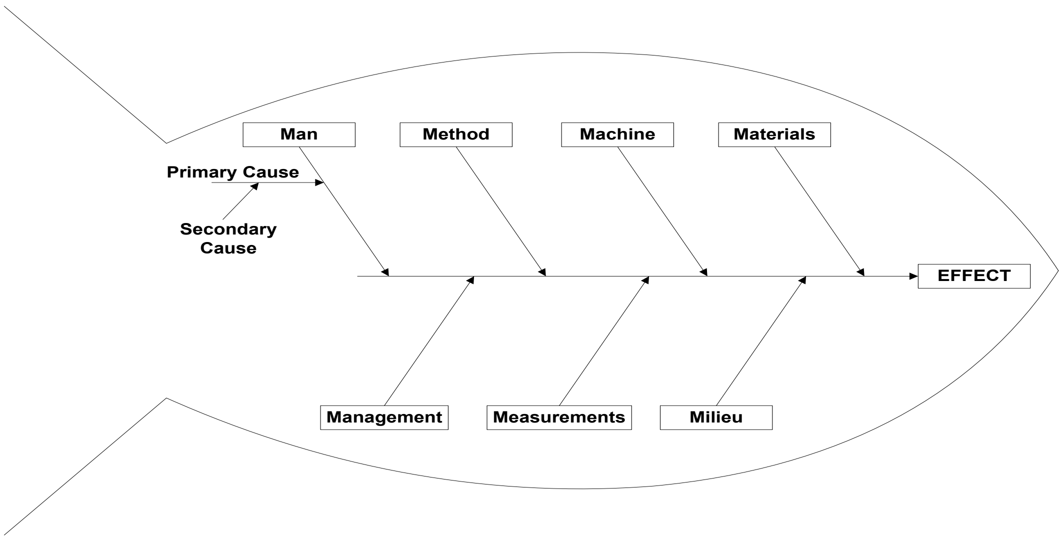


Figure 12 - The Ishikawa Diagram (Bergman & Klefsjö, 2004)

3.3.4 Pareto Diagram – Waste prioritization

When different types of waste have been detected and identified, for example with help of the earlier mentioned tools, it is necessary to prioritize in what order to solve these predicaments. According to Shim and Siegel (1999) along with Bergman and Klevsjö (2004), one can expect to find a few vital sources that primarily contribute to costs and errors rather than the many trivial problems that in truth contribute much less to the large costs and errors. Perhaps break downs of construction tools cause more cost and delays than bad handling of material. However, almost without exception, only a few of the sources account for the bulk of the costs. Hence, it is of interest to find out the largest cost factors and reduce or eliminate these first.

When an organization is facing different problems it can be difficult to decide which problems to tackle first. A practical guideline on how to prioritize problems is given by Liker and Meier (2005), where every problem can be evaluated from three criteria:

1. Importance – in relation to customer satisfaction and/or company goals. Safety issues automatically receive high importance.
2. Urgency – in order to, for example, meet a deadline.

3. Tendency – is the problem getting worse? A problem that is getting worse receives higher priority.

Another way to compare problems and to rank them is to use a Pareto diagram. By conducting a Pareto analysis, it is said by Gaupta (2005) that one can focus on the vital problems instead of working on many minor projects with an insignificant return on investment. Shim and Siegel (1999) explain that during the Pareto analysis a bar chart is constructed (the Pareto Diagram, an example of the diagram is displayed in Figure 13) with bar height representing frequency as a percentage and these bars are later arranged in descending order by weight (importance). By looking at the bars it is possible to deduce that the largest bar with the greater frequency is the problem area where process improvements should begin. The Pareto diagram is valuable in the sense that it provides the following aspects (Gaupta, 2005):

1. Analyze a problem with a new perspective
2. Focus attention on problems in priority order
3. Compare data changes during a different time period

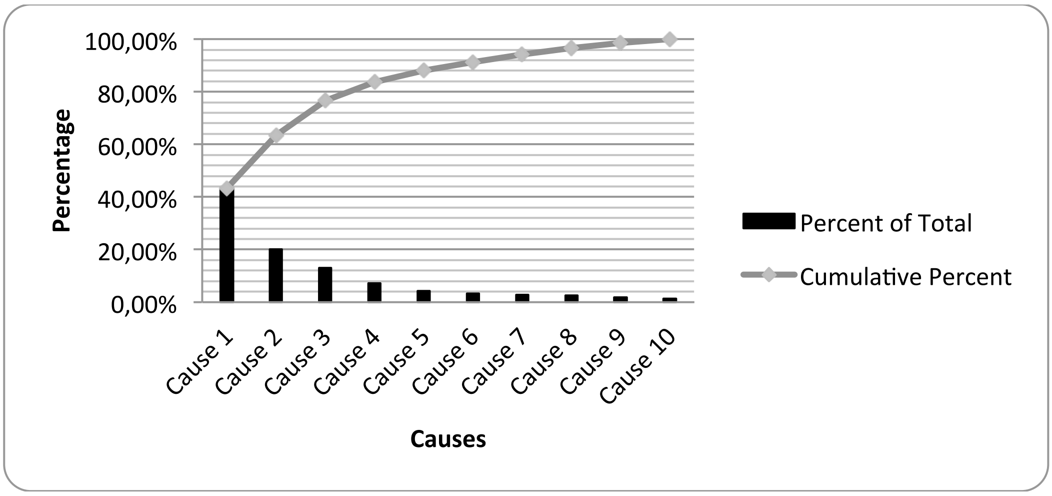


Figure 13 - Example of a Pareto Diagram

3.4 Lean Construction

Eriksson (2010) summed up much of what lean construction is in his article, including the six groups in which he classified the aspects of lean construction. In Paez *et al.* (2005) article they do not summarize the literature available on what lean construction is but rather focus on specific techniques that can be applied in order to reach the goals of lean construction.

3.4.1 Lean Construction Aspects

Lean construction is the application of lean manufacturing principles in the context of the construction industry. While the definition of lean manufacturing is quite clear, there is debate about what lean construction is. Many say they have been lean for a long time, e.g. using JIT delivery, long before the term Lean or Lean Construction was on every ones tongue. Many also associate lean more with partnering than the principles of lean manufacturing (Green & May, 2005). In his article, Koskela (1992) concluded that there was, both in construction and manufacturing, too little focus on processes and value. His work has become the foundation of lean construction and in 1993 the 1st International Workshop on Lean Construction was held. Jørgensen and Emmitt (2008) also identify a few common elements between lean manufacturing and lean construction.

- Focus on the elimination and reduction of waste.
- End customer focus in order to determine what value is and what waste is.
- Pull approach from a customer perspective
- Focus on processes and flows of processes
- System perspective

In order to further try to explain how construction can become lean, a seminar by Koskela (2008) is used. If construction is decomposed into tasks and each task is to be completed within a certain timeframe and budget two decision rules are given. If each task keeps its start and end date *and* if each task is kept within budget then the entire project is completed on schedule and within the set budget. Why is this then so difficult? That is because reality is almost never like it seems on paper. As with lean manufacturing, flow is the goal in order to have the same average output each week or day. In a real project however there are always problems, which will mean large fluctuations in the output each day or period.

Koskela (2008) tries through statistics to explain the problem further. If a task needs all prerequisites in order to start, if it has seven prerequisites and the probability of a task being completed is 95% during one week there is only a 70% chance of having no deviations from the schedule during a week. Trying to be lean within construction is to try to smoothen out the output and increase the chance of completing tasks with as little complication as possible and there are many views on how to come about these results. One way to overcome this fluctuation mentioned by Jørgensen and Emmitt (2008) is to use a flexible workforce. Here we also touch upon a difference in country context. The level of unionization and other workforce related issues between different countries could affect the ability to implement lean and lean techniques in different countries and industries.

Eriksson (2010) goes on by discussing the different aspects of lean construction, which he divides into six core elements (see Figure 14). The six core elements are waste reduction, process focus in production planning and control, end customer focus, continuous improvements, cooperative relationships and systems perspective.

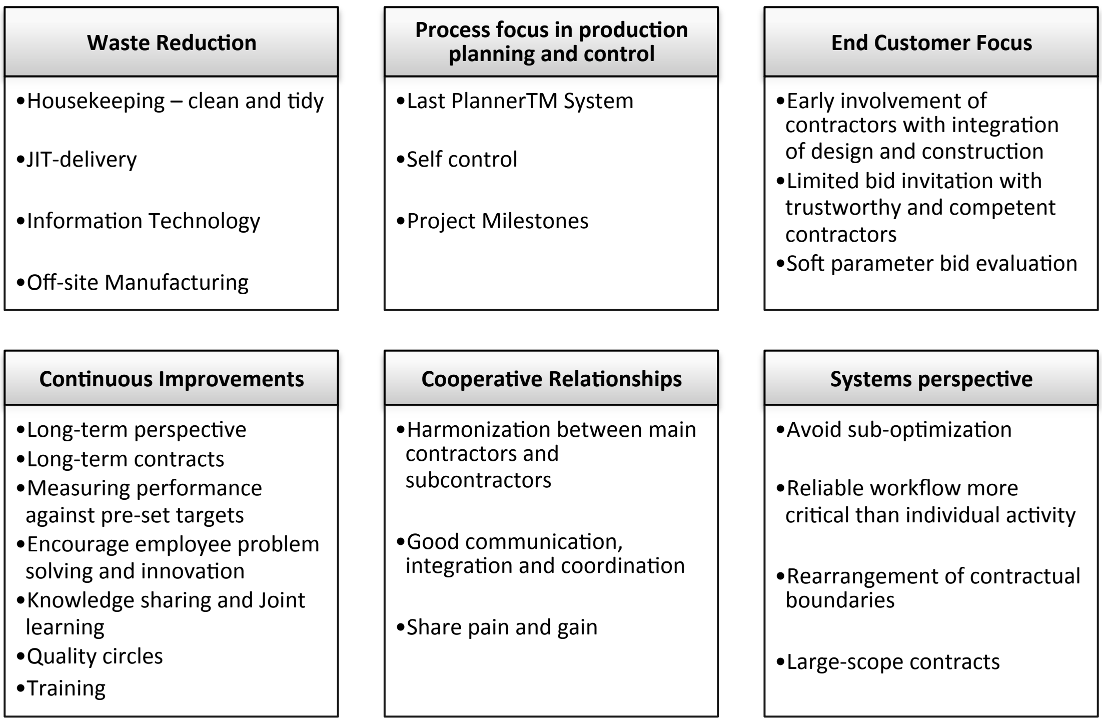


Figure 14 - The Six Core Elements of Lean Construction (Eriksson, 2010)

The first of the six core elements is waste reduction where housekeeping, keeping the construction site nice and tidy, is an essential aspect. Other aspects of waste reduction mentioned by Eriksson (2010) are JIT-delivery, information technology and finally, off-site fabrication of components and units. JIT means contractors get the material they need when they actually need it, decreasing stockholding and double handling of material. IT-tools can be used to better synchronize the actors in the supply chain in order to make things flow better. The fourth aspect of waste reduction, off-site fabrication, will minimize the work at the actual building site increasing construction flow and decreasing waste material.

Process focus is the second core element and deals with aspects such as last planners. Last planer is a concept where a last planner is responsible for the completion of individual tasks; each week preparing work plans for the task. If the task is not completed on time, the last planner must then find the root cause in order to prevent the problem from occurring in the future. According to Dolio (2008), research suggests that pre-planning and programming are the most critical factors in trying to increase labor productivity at construction sites suggesting that last planner can be an important tool. Another aspect of process focus is empowerment; contractors perform self-control on their work, making project participants feel more involved in their work.

Customer focus is a large part of lean. Understanding what the customers want helps to determine what adds value. Eriksson (2010) mentions the need for contractors to understand the needs of the end customer and not what they ask for. The UK Construction Task Force wrote that in their experience the industry tends to focus more on the next contractor rather than the client or customer, the industry has no processes to better understand what the actual end-user actually wants (Department of Environment Transportation and the Regions, 1998). Eriksson (2010) also mentions early involvement of contractors as well as the integration of design and construction in concurrent engineering as being important in lean construction. Soft parameters should also be used when selecting contractors in order to find contractors that can satisfy customer needs.

Continuous improvement is as important in lean construction as it is in lean manufacturing and the TPS according to Eriksson (*ibid*). The important aspects of continuous improvement are long-term contracts to promote lasting improvements and take focus away from cost reduction, worker participation in problem-solving and measuring performance against pre-set targets. Eriksson (*ibid*) also mentions quality circles as a method of furthering the improvement process.

Eriksson (*ibid*) also identifies cooperative relationships as an important part of lean construction. The main aspect of this core element is harmonization between contractors and subcontractors and also the need for all parties involved to benefit from the improved performance. This will increase the will for all parties involved to commit to the improvement measures. Packham *et al.* (2003) write about partnering from a subcontractor's view and they mention how the benefits are not shared with the subcontractors gradually decreasing their will to undertake any such initiatives to increase performance.

The last core element described by Eriksson (2010) is to have a systems perspective. In order to avoid sub-optimization a holistic view needs to be taken. This demands cooperation between the parties involved and is simplified by large scope contracts instead of dividing the project into small pieces.

A weakness of the frame of reference developed by Eriksson (2010) is mentioned by the author himself and that is that the different aspects are not exclusively linked to one single core element. The case study in the article pointed to how an aspect such as long-term contracts help both continuous improvements as well as customer focus but according to Eriksson (2010) the frame of reference can serve as an illustration of different aspects of lean construction.

Eriksson (*ibid*) also describes three stages of lean construction, taken from Green and May (2005). The first stage is mostly focused on operational aspects using housekeeping, JIT and sharing pain and gain. The second stage goes more into relationships, focusing on enhancing cooperation between parties involved. The third stage is described as the most ”sophisticated” going even further utilizing aspects such as information technology, pre-fabrication, last planner, empowerment, rethinking design and construction, training, long-term contracts and systems perspective among others. The first stage is seen simply as aspects of an efficient construction project while stage two is viewed more as partnering, which will be discussed later on. Stage three is closest to what can be viewed as true lean construction and where the maximum benefits can be achieved.

There are those however, who see the limitations of simply moving the frame of what is lean from manufacturing and placing it on the construction industry. Even though there are similarities in the industries they are of course also vastly different. According to Koskela (2008) there are two views on if TPS can be applied in construction. One is that there are no hindrances in transferring TPS, its methods and practices from manufacturing to construction. The Egan Report (Department of Environment Transportation and the Regions, 1998) is an example of this view. The Egan report states that Lean thinking describes the core principles underlying this system that can also be applied to every other business activity. The other view is that construction is fundamentally different and that the methods and practices need to be reinterpreted to fit the construction industry. The construction peculiarities mentioned by Koskela (2008) are one-of-a-kind production, site production and temporary project organization. Two alternatives for tackling these obstacles is either to eliminate them by standardizing products, using off-site production and long-term alliances or to accept them and develop new methods to overcome them. According to Koskela (2008) the ends for lean construction are the elimination of making-do and lead time reduction. The means for getting there is using the Last Planner system of production control and using practices and methods from lean production and lean product development when applicable.

3.4.2 Lean Construction Techniques

In their study, Paez *et al*. (2005) presented seven techniques within lean construction used to create flow and reach lean construction goals:

- **Concurrent Engineering:** The execution of parallel development tasks in multi-disciplinary teams in order to obtain an optimal product keeping functionality, quality and productivity in mind.
- **Last Planner**: Introduced by Ballard (2000) as a planning technique to deal with project variability in construction.
- **Daily Huddle Meetings**: Last Planner manages operations while Daily Huddle Meetings is a way to follow-up the highly variable events that affect assignments.
- **Kanban system**: Used to organize the flow of certain materials (consumables, personal protective equipment, hand tools, power tools, and consumables for power tools. This was shown to work by Arbulu, Ballard and Harper (2003).
- **Plan Condition and Work Environment in the Construction Industry (PCMAT)**: It is proposed by Saurin *et al.* (2002) as way of introducing health and safety into the project execution. Here safety practices are integrated into short-term planning.
- **Quality Management Tools**: Integration of quality tools into lean construction. Marosszeky *et al.* (2002) propose a shift from conformance-based quality to quality at the source. This means a checklist, which is to be enforced by the workforce.
- **Visual Inspection**: Increased speed of operation and reduction of the risk of choosing the wrong material through easy material identification. Schedules, milestones, or progress charts to enforce commitment to assignment completion. Increased communication between decision makers and executers.

3.5 Literature Summary

The traditional lean literature helps us understand the basics of the lean concept such as the importance of flow, continuous improvement and waste reduction and elimination. It also helps us grasp the tools of lean that can be used. This literature together with other literature concerning lean construction and lean in other industries will help the authors find the pieces of lean that can be used in a tool for the construction industry.

In lean construction literature, a large part focuses on flow, waste or aspects that affect flow and waste. The literature may not specifically state that flow is the goal but characteristics that affect flow and waste often have their root in the peculiarities of the construction industry which the provided solutions in lean construction are trying to solve. These peculiarities need to be overcome or handled in order to obtain better flow and decrease waste.

Other aspects that can be important when implementing lean in construction in order to get better flow is to see how lean has been implemented in other industries. From the identified literature that concerns lean in other industries VSM was one of the tools identified as important in lean implementation along with the standardized work and the A3 problem-solving method. The A3 problem-solving method includes tools such as VSM and root-cause analysis such as 5-Why, techniques identified as important for constructing a lean tool for the construction industry in order to understand the situation and to treat the problem and not the symptoms.

The TPPSP and Ishikawa diagrams were also discussed in the literature. These are other tools which can be used to find the root cause of the problem. A Pareto diagram can then be used to help prioritize what needs to be done. Everything will be done however, if there is anything that the lean philosophy teaches us it is continuous improvement, to continually strive to become a little bit better.

The ability to measure before and after when making changes is also an important aspect not only in lean but also in running a business as a whole. Therefore KPIs are seen as an important part of implementing lean and working with continuous improvements. The need for these KPIs to be used consistently over several projects in order to be usable was also identified.

4 PEAB

In this chapter a company presentation will be given in order for the reader to understand what kind of company that has been studied. The company structure, concept and environmental policy will be briefly explained. PEAB's purpose of participating in this master's thesis is also described.

PEAB is a Swedish construction and civil engineering company that was founded in 1959 and has its' headquarter in Förslöv, Sweden. With its main market in Sweden PEAB has also business abroad through its subsidiaries in Norway and Finland. They employ approximately 14.000 people within their three business areas (1) construction, (2) civil engineering, and (3) industry, and have a net sale above 38 billion SEK (PEAB, 2010). Table 6 displays PEAB's net sales divided among the Nordic countries for the years 2010 and 2005 whereas Figure 15 is showing how much each business area generates in annual turnover compared to each other. Needless to say, the construction business in Sweden is PEAB's largest business segment.

Table 6 – Operative Net Sales per Geographic Area (PEAB, 2011), (PEAB, 2010)

	2010	2005
Sweden	85 %	86 %
Norway	8 %	7 %
Finland	7%	7 %

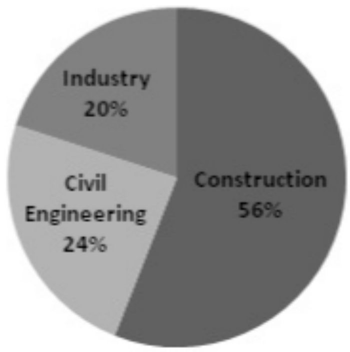


Figure 15 - Operative Net Sales 2010 per Business Area (PEAB, 2010)

The business area "Construction" works with all aspects of house building and development, construction maintenance and project development. Furthermore, this business area is divided into five existing construction divisions, namely (1) Southern, (2) Western, (3) Housing, (4) Stockholm Commercial and (5) North Eastern (PEAB, 2009). This master's thesis was performed at Western Division in Gothenburg.

PEAB's business concept states that the guiding principle for the enterprise is to incorporate total quality at all stages of the construction process and that the aim is to transfer the clients' interest to their own, hence, facilitating willingness, responsibility and a sustainable approach to build at all times for the future. The PEAB group accommodates the whole chain of production resources required to manage the construction process (PEAB, 2011), e.g. the industry business sector provides access to raw material and services for the construction and civil engineering business.

PEAB's environmental policy is an important part of the company policy and satisfies the requirements of ISO 14001:2004 (PEAB, 2009). In order to work for sustainable development and environmental friendly processes PEAB are taking responsibility by using several different methods and techniques (PEAB, 2011). The aim with environmental objectives established by management in the business plan is to achieve a reduction of the company's negative impact on the environment and to fulfill their business concept; building for the future.

It is PEAB's intention to strengthen their understanding in how to generate more value for customers, improve their operations from an economic perspective and how to improve their environmental approach, by initiating this master's thesis.

PEAB's processes at a construction site look different depending on the role PEAB has. At Clarion Hotel Post, the project followed by the authors, PEAB has more of an administrative role meaning that PEAB staff makes up roughly 5-10% of the total staff. During other projects, PEAB may have an all-in contract which means they take care of almost 100% of the work. The type of contract or role PEAB has during a project affects the number of workers and types of processes that are PEAB's compared to the number of workers and types of processes undertaken by subcontractors.

The contract for the project followed by the authors, Clarion Hotel Post, is worth 600 million SEK. It consists of a conversion and extension of the historic Central Post Office at Drottningtorget in central Gothenburg. Work has begun and completion is expected in January 2012. PEAB is the main contractor accounting for planning, site management and overall management of the project. Different subcontractors handle the building itself.

5 Empirical Study

In this section the reader will find all the information gathered during several interviews and visits at construction sites. The empirical data is presented in seven sections and the first five sections corresponding to each of the five RQs. The sixth section presents the authors' observations of a 5S project at a construction site whereas the seventh section presents the authors' observations that were made during the VSM studies. The interviewees are divided into three different groups; Construction Industry Practitioners (Practitioner), Lean Experts (Expert), and Construction Academics (Academic).

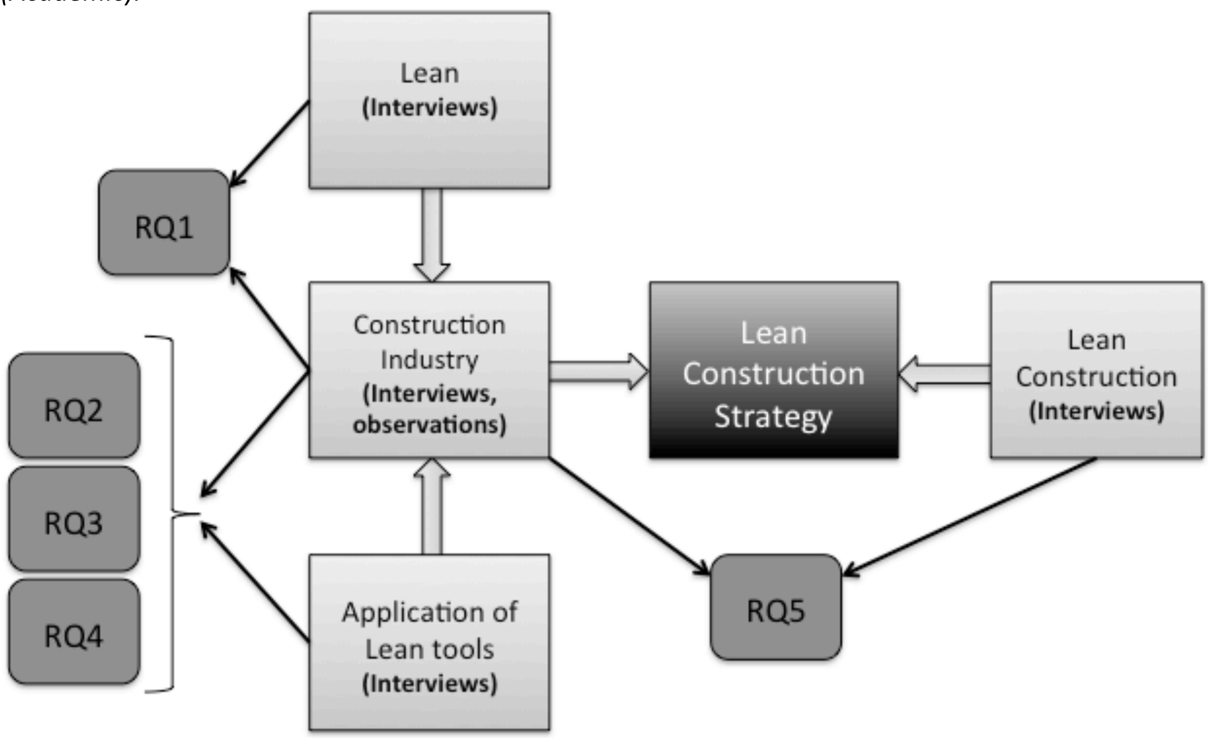


Figure 16 - Empirical Study Guide

In Figure 16 the reader can see how the observations and interviews have affected the different subjects; lean, lean construction, construction industry and application of lean tools as well as how these subjects affect the Lean Construction Tool. The figure also shows how the interviews and observations affecting each subject help in answering the different research questions.

5.1 Waste in Construction

This section will summarize all the answers that were given by the nine interviewees concerning what potential waste that can be found at construction sites (RQ1). In the end of the section the reader will find Table 7 which summarizes and facilitates easy comparison of the answers between the three different interview groups.

All the Practitioners agree that many times it is quite easy to see what operations are wasteful, e.g. searching for materials and tools, too much material being ordered, material not arriving on time, extra material handling and material being ruined due to improper protection and/or handling. In addition, Expert 2 says that the costs for damages, losses and theft can be quite substantial. Academic 2 adds that it may be easy to find waste but it is not common to go and look for them in an active or pro-active way.

In contrast, according to Academic 3 there is also waste which is much more difficult to see. The different ways to work and the fact that some workers are on piece-work contracts makes the associated waste difficult to see. However, as mentioned by Expert 1 it is not always easy to know what is value adding. Transportation is one of those aspects where it is not always easy to see if it is value adding or not, some form of transportation is always needed. Expert 2 and 3 say that it is all in the eye of the beholder, for a trained person it is easy to point out wasteful activities but not for others. This was exemplified by Expert 2 by saying that a person who works amidst construction processes might not see inventories as a waste if the goods are intact but if the goods are defects or damaged in some way they are seen as waste.

Furthermore, Practitioner 2 and 3 talked about the protection of material and the waste that can be traced back to weather, stressing the importance to protect material and workers. Academic 2 said that downtime and too much inventory are waste as well but it was also said that in many situations waste is accepted in order to move the project forward. This was seconded by Expert 3 who said that the perimeter of the construction site should intentionally be shrunk in order to force the projects to work more efficiently.

There is also a great deal of focus on price within the industry according to Academic 1, a view shared by all of the Practitioners. It is said to be very easy to forget the cost of logistics hence the total costs is rarely addressed. As Academic 1 pointed out, the cost of dealing with the material on site may be just as great as the cost of the goods itself. Expert 3 therefore emphasized a cost focus instead of a price focus. A waste here, according to Academic 1 are the large purchasing organizations that have been built up in many companies focusing solely on purchasing costs. According to Practitioner 1 there are coordination problems as well as logistics problems in terms of time and economic waste due to not considering the logistics.

The Practitioners together with Academic 2 and 3 emphasize coordination as a vital factor in construction projects. A great deal of waste according to Academic 3 occurs due to the lack of coordination. When deliveries of material occur there is not always someone around who knows who has ordered the material, who it is for and where to put it. The material therefore may get placed in the wrong place all while the person who ordered the material does not know that it has arrived.

Another issue raised by Practitioner 1 is the lack of trust in other companies/subcontractors in the industry and the risks associated with each part of the build not being completed on time. It is customary to always ask for a fixed price since there is a risk, often high, that the subcontractor will not complete the task on time. A great deal of waste in a construction project comes from a subcontractor having to wait for another to finish with another task. According to Practitioner 1 this lack of trust also has to do with only using fixed price and piece-work contracts due to the impression that that contractor will not otherwise get the job done.

For the Practitioners, and for Academic 2 and 3, the end user of the product is in their view, the customer whom they are building for. Nevertheless, they also state that this may not be the case for everyone since many subcontractors see only the one who commissioned the job as the customer. According to Practitioner 1, when the project is a partnering project the focus is not always on cost but focused more on what is best for the project. Academic 3 said that in many cases there is also self-interest from the builder's side, which may or may not coincide with the interest of the client.

Table 7 – Types of Waste in Construction Operations

Construction Industry Practitioners	Lean Experts	Construction Academics
Unnecessary Transports	-	Unnecessary transports
Searching for tools and material	-	Searching for tools and materials. (Downtime due to changing tools)
Too much material	Too much inventory	Too much inventory
Damages, losses and defects	Damages, losses, defects and theft	Damages, losses and defects
Waiting on material	Waiting on material	-
-	Material Waste (Redo work due to incorrect processing)	Material Waste
-	Unnecessary handling of material due to coordination problems	Unnecessary handling of material due to coordination problems

5.2 Identifying Waste

This section will summarize all the answers that were given by the nine interviewees concerning how potential waste can be identified at construction sites (RQ2). In the end of the section the reader will find Table 8 which summarizes and facilitates easy comparison of the answers between the three different interview groups.

The interviewees share different views on how to identify potential waste in resource flows at construction sites. Specific tools such as Material Flow Mapping, Value Stream Mapping, Spaghetti Diagrams and Work Sampling are mentioned; hence, the focus is on analyzing flows. However, the focus differs between the tools where Expert 1 emphasizes that Material Flow Mapping analyzes what is between value-adding activities and on a more specific level than the Value Stream Mapping technique. Practitioner 1 states that another tool that could help in avoiding wasteful activities by identifying critical areas is IT planning tools in 3D, 4D (3D + time) or 5D (4D + material/cost). 3D is up-and-coming and a relatively new tool today whereas 4D and 5D is a desirable future IT support. However, these tools' primary function is not to identify waste but to facilitate efficient planning, which in the end leads to waste avoidance. Academic 3 said that while these tools may be useful in the planning stage of the building process they are not useful for the actual builders on site who for the most part of their workday never see a computer.

Academic 3 also stated that using time studies and comparing costs between different alternatives are ways to identify possible waste or wasteful behavior. Comparing costs may be difficult in some situations because different projects declare their logistics costs differently, sometimes the costs will be baked in with other cost items such as purchasing, external transportation cost, building costs etc. However, according to Expert 2 total cost analysis which analyzes direct costs and overhead costs is a good way to get a profound understanding about how the costs occur and where waste might exist.

Besides the earlier mentioned tools for waste identification, the Academic 1 and 2 highlighted different methodologies that are suitable for the pursuit of waste reduction. Visual Planning is one such method, argued by Practitioner 1 quiet similar to the Last Planner method but according to Academic 2 there is a difference. The Last Planner is good at coordination says Academic 1 and Practitioner 1 adds that the method is functional for highly complex projects where all the information needed is not always at hand. When it comes to the Visual Planning tool it is argued by Academic 2 that it is more functional at visualizing a process than coordinating it. However, all interviewees who have mentioned Visual Planning say that over the last years it has gained a lot of attention due to positive feedback from practical cases.

All of the Practitioners and Academic 2 state that when it comes to identifying waste all that is needed is common sense and rather simple methods and tools. The Practitioners also emphasize that a prerequisite to see waste is that the construction crew structures the construction site and keeps it clean and tidy by using 5S. In addition, Practitioner 1 says that educating employees in how to identify waste and avoid unnecessary operations is one way to improve the efficiency at the construction sites. Expert 1 complements this view by arguing that having quality circles with small groups are imperative for developing a thinking organization that has the possibility to identify waste, a practice used by Practitioner 2 and 3 at their construction site. In line with earlier arguments, Expert 2 states that there is a lot to gain if waste can be reduced and by starting up discussions about waste and total cost people will notice the problems and a need for solutions will appear. Furthermore, according to Practitioner 3 it is important not to trust too much in different tools and IT solutions. There are many great technical aids but it is important to remember that the simplest methods are sometimes the best, for example to identify waste just go out and really look for them.

Finally, Expert 2 is troubled that the industry always looks forward and never look back at earlier experiences and failures. This was explained with a metaphor that a doctor would never give drugs to a patient before finding out what kind of drugs the patient has had before. The problem is that the construction industry does not have a "medical journal". Another aspect that needs to be considered according to Expert 2 and 3 is that in order to identify waste and become a lean organization it is not enough with employing one lean expert, in contrast, at Toyota they have 314.000 employees looking for waste every day. Therefore, it is vital to educate the people working with the construction processes in what waste is and how to detect it. People use to say that this is not an easy task but Expert 2 has the perception that many have not even tried. This was exemplified by following quote: "O.K, so you are not a world champion in high jumping, but what the hell you have not even tried"

Table 8 - Tools and Methods to Identify Waste

Construction Industry Practitioners	Lean Experts	Construction Academics
Process Mapping (Spaghetti Diagrams)	Process Mapping (VSM, Material Flow Mapping)	Process Mapping (VSM, Frequency Analysis – Work Sampling)
Planning Methods (Visual Planning, Last Planner, IT support such as 3D, 4D and 5D)	-	Planning Methods (Visual Planning, Last Planner, Linear Planning)
Meetings (Team/Planning meetings, quality circles, education and teaching)	-	Meetings (Team/Planning meetings, quality circles, education and teaching)
Common Sense	-	Common Sense
Structure and clean up the construction site	-	-
Be out on the construction site and see for yourself	-	-
Check lists	-	-
-	Look at past experience and especially past failures	-
-	Total Cost Analysis, look at direct costs and overhead costs	-

5.3 Measuring Waste

This section will summarize all the answers that were given by the nine interviewees concerning how potential waste that has been found at construction sites can be measured (RQ3). In the end of the section the reader will find Table 9 which summarizes and facilitates easy comparison of the answers between the three different interview groups.

All the Practitioners and Academic 2 say that there are little or no KPIs of waste or performance at a typical construction site other than some economical key figures and time data. The construction sites visited measured delivery accuracy, waste management (garbage/recycling) and PPC. In recent years the use of KPIs concerning material waste, environmental waste (CO_2) and waste management (recycling) has risen according to Academic 1. In contrast, Expert 2, Academic 1, and Academic 3 say that the construction companies measures a lot but how this data is used after it has been collected is the critical part. They say that it is common to collect data but not to make use of it. Expert 2 adds that economical measures are common but measuring of logistics and resource flows is more or less absent. According to Academic 2 it is difficult to find a universal metric to use at every single construction site since the projects always differ in their context. Expert 2 partly substantiated this view by arguing that it is necessary to have standardized processes to be able to measure and compare data. To achieve standardizations in this industry is rather difficult and therefore they do not exist to a large extent.

Furthermore, Academic 3 says that waste can be measured in costs or rather by comparing costs for different logistics alternatives. By seeing the difference in resources used for different alternatives the amount of waste before and after can be identified and measured. Academic 3 also said that the industry needs more KPIs but at the right level. In order for the KPIs to be understood they need to be used high up in the project organization. The workers on the ground, e.g. carpenters or electricians do not have the need for the KPIs, their interest lies in doing a good job within their field. In line with the cost perspective, Expert 2 says one way to find waste and measure it could be by doing a Total Cost Analysis. In this way direct costs (e.g. purchase cost) and overhead costs (e.g. administration, handling of material) are compared and segmented which make it easier to locate waste and measure it and have it thoroughly analyzed.

Beside cost items, Expert 2 argues that time is worth measuring and that this could be done with VSM since it is a rather general tool and could therefore handle many kinds of resource flows. Additionally, it is said that the company should start by measuring common resources and analyze past and present states of these. According to Expert 1, delivery accuracy may be an important measure to look into due to the interdependencies in construction. Practitioner 2 also states that unnecessary transports and the number of express transports would be possible to measure. What Academic 2 would like to see is figures displaying costs for moving around material at construction sites compared to the delivery cost or inventory turnover rates at the construction sites. Nevertheless, Academic 2 also said that what is measured, if anything at all, depends greatly on the site manager. Inventory turnover rate was something that Expert 3 also wanted to measure, seeing it as a way measure how effectively they are using their resources.

One problem highlighted by Expert 1 and Academic 1 is that construction companies often measures what is easy to measure, which may not always be what is relevant to measure. In that sense there is always the risk of sub-optimization. According to Expert 1, sup-optimizations can be avoided by using assessment tools which pinpoints what needs to be done at a company. One of these tools is Lean Navigator where 35 different areas are plotted. In addition, Expert 2 argues that technology can also help out to measure resource flows. For example, Radio Frequency Identification (RFID) can help to keep track on arriving deliveries or how resources flow at the construction site.

It was also mentioned by Practitioner 2 that there is not always an understanding of what waste is, and this was experienced during the time when the Practitioner 2 wrote a thesis within the field. During the thesis it was experienced that workers did not think going back for nails was waste because the worker needed the nails and did not reflect over the waste compared to remembering the nails the first time.

Table 9 – Different Ways in how to Measure Identified Waste

Construction Industry Practitioners	Lean Experts	Construction Academics
Measure Time (Measure delivery rate)	Measure Time (VSM)	Measure Time
KPIs (delivery accuracy)	KPIs (for example delivery precision, quality, etc.)	KPIs (Measure economic, environmental or waste metrics)
-	Measuring Cost (Total Cost Analysis)	Measuring Cost (compare costs between different logistic alternatives)
Measure coordination and flow (keep count on unnecessary transports and express deliveries)	Measure coordination and flow (do an situation analysis and compare this to the new situation after changes have been implemented)	Measure coordination and flow
-	Technical Tools (Lean Navigator, RFID)	-
-	-	Percentage of planned activities completed (PPC)
-	-	What to measure differ between projects (depends often on the site manager, no universal metric)

5.4 Waste Prioritization

This section will summarize all the answers that were given by the nine interviewees concerning how one is to decide in what order to reduce waste at construction sites (RQ4). In the end of the section the reader will find Table 10 which summarizes and facilitates easy comparison of the answers between the three different interview groups.

Academic 1 said it is important to think about the root cause when prioritizing waste reduction activities. In order to do this Expert 1 and Academic 2 said that a Pareto analysis can be used to deal with the most troublesome waste in a sufficient way and Expert 1 also mentioned the Ishikawa diagram. Furthermore, both Expert 1 and Expert 2 also pointed out that many lean projects often start with something simple such as 5S, in order to get a first success since this tool is rather user-friendly and displays results relatively direct. Expert 2 also said that by using a VSM the construction companies will more easily see what to prioritize and with help of a Pareto diagram it is possible to structure this task.

The Practitioners said that to prioritize what waste to deal with first one have to look at the most important materials and the parts of the construction project. The Practitioner 2, 3 and Academic 2 also said that a good way to decide how to structure waste elimination could be to sit down together, blue and white collars, and discuss what can be done better and how to do it since the people who work with it daily have most experience. The Expert 2's view on the matter is that the construction company should begin with those areas that they have most control and power over.

Another aspect considered by Academic 3 is that the construction companies should look at costs and work environment. But the organization should first learn how to eliminate waste in small scale before taking on large change projects; hence the simple problems should be prioritized in the beginning. Important to keep in mind is that the project leader is important in prioritizing what to do, their focus on where to reduce waste or even to reduce waste is what goes. Instead of the project leader Academic 2 said that it is up to the site manager to decide what to prioritize. Some site managers often prioritize money while some prioritize time. What is critical to each build is said to differ from project to project. However, according to Academic 1 the industry is getting better and better at dealing with these kinds of problems. Nevertheless, it was further said that new technology and ways to work are sometimes implemented a bit too fast without thinking about the big picture, hence it could cause more waste than reducing it. The importance of thinking about the whole picture, the flow and total cost is substantiated by Expert 1 and Academic 3.

Academic 2 believes there is a high risk of sub-optimization when waste is eliminated since the problems solved are presumably not the root cause but merely a symptom. The mindset at construction sites towards problem solving is that small problems are not probed; only large problems are thoroughly analyzed in order to solve the root cause. Academic 3 also said that it is important to try to consider all the variables and eventual consequences, but it is difficult to see everything and something that may look good on paper does not always work in practice. Expert 2 agrees with Academic 3 by stating that to avoid sub-optimization it is necessary to consider all actors involved, e.g. suppliers. Furthermore, it was the Expert 2's perception that it might look like a costly initiative from the beginning but in the long run it will pay back generously.

Table 10 - Methods and Tools in how to Prioritize what Waste to Reduce

Construction Industry Practitioners	Lean Experts	Construction Academics
Prioritize what is most critical at the moment (types of material)	-	Prioritize what is most critical at the moment (time, money) varies between projects
Discuss (discuss in small mixed groups how to prioritize)	-	Discuss (Listen to construction workers, they have a lot of experience)
-	Identify the root cause (Ishikawa Diagram)	Identify the root cause
-	Tools (VSM, Pareto Analysis)	-
-	Take on easy problems first to show success stories	-
-	Have a holistic perspective (look at the total cost)	Have a holistic perspective (look at the total cost)
-	Start with processes where one have the most control and power over	-
-	-	Larger problems are analyzed whereas small problems are not

5.5 Potential Effects of a Lean Approach

This section will summarize all the answers that were given by the nine interviewees concerning what potential effects a lean approach would have on construction sites (RQ5). In the end of the section the reader will find Table 11 which summarizes and facilitates easy comparison of the answers between the three different interview groups.

Everyone agrees that there would be economic benefits from reducing waste but as Practitioner 2 pointed out, there is little regard for the amount of waste as long as the project are on or below budget. In Academic 3's work at one of Sweden's largest construction companies, it was shown that it was possible to decrease cost with alternative logistical setups and that the monetary gain could be five to ten percent, mainly in city projects and where there is a lack of space. Furthermore, Expert 2 declares that by reducing waste, process uncertainties are eliminated which leads to stability and possibilities for more accurate forecasts. With these improved forecasts fewer problems will occur resulting in shorter lead times and less tied up capital.

According to Practitioner 2 and 3 along with the Academics, waste reduction may also lead to improvements in the work environment through a decrease in psychological and physical stress. This decrease in stress is facilitated by getting rid of unnecessary hassles and frustration which stem from having to redo work or wait for material. Expert 1 and 3 stated that the positive effects would be better flow, improved coordination and handling which are factors that can influence the production rate, something that Practitioner 1 along with Academic 3 assumed to be a possible effect of waste reduction. The possible increase in production rate may also bring about an increase in salary for the construction workers working on piece-work contracts.

Another point of view is that Academic 2 thinks that the environmental effects would be marginal, that there would not be a big difference in the amount of material used. However, Expert 2 believes that the environmental impact will be affected in a positive way but it is difficult to say how much. Furthermore, Academic 3 also contradicted Academic 2 by saying that there are environmental effects both in terms of decreased vehicle emissions made possible through transshipment outside the cities (if external logistics are considered) and even reducing material spill. Academic 2 also pointed out that there might be an increase in quality. Practitioner 2 and 3 mentioned this as well, saying that the workers learn that it is better to do the work properly the first time.

Practitioner 2, Practitioner 3 and Academic 3 said that they think that the lean philosophy is applicable for the industry. However, the Practitioner 3 does not think that every lean tool or methodology is suitable or will necessarily work in a construction context. According to Practitioner 1 and Academic 1 it is important to motivate the changes being made and help workers see the benefits in order to help people understand the importance of working with these issues. Another important consequence mentioned by Academic 3 is the possibility to get ahead of the competition and becoming the industry leader.

But in order to do well, Expert 1 argues that when implementing lean or waste reduction initiatives it is important to realize that there may be resistance if not implemented correctly. It is also extremely important to have support from management. Expert 2 agrees with this statement and adds that without a committed top management it will be difficult to permeate the lean approach throughout the whole organizations. It was emphasized several times that this is the most vital factor in order to succeed.

Table 11 – Potential Effects of a Lean Approach at Construction Sites

Construction Industry Practitioners	Lean Experts	Construction Academics
Improved work environment (decreased psychological and physical stress)	Improved work environment (safer construction site)	Improved work situation (less hassle and frustration)
Improved efficiency and effectiveness (increased production rate, more money to the construction workers)	Improved efficiency and effectiveness (increased production rate, better flow, coordination, handling of material)	Improved efficiency and effectiveness
Increased commitment (positive attitude and understanding for change projects)	Increased commitment (if successful)	-
-	Economical savings	Economical savings (cheaper product or increased profit)
-	Environmental savings	Environmental savings (decreased emission, less material waste and energy consumption)
-	Process stability (reduction of risks and uncertainties which leads to improved forecasts)	-
-	-	Improved quality

5.6 Observation of a 5S Project at a Construction Site

When conducting the interviews with the Practitioners, visits were made at different construction sites. From these visits many observations were made, for example the authors got the unique possibility to experience a start-up lean construction program where the lean tool 5S was in the process of being implemented. As can be seen in Figure 17 and Figure 18 the differences are significant and the construction workers at the construction site were very positive towards this start-up.

When talking to people at the construction site the positive comments were many even though they had been rather skeptic towards the idea from the beginning. In their point of view it was the result of an enthusiastic and inspiring speaker from a nearby university who made them decide to give the lean approach a chance. Although their lean program has not been active for a very long time they said that they have noticed some significant changes. To start with, the work environment had improved and workers did not get frustrated when looking for tools as much as before. This had contributed to a lower level of stress at the construction site. In addition to this less time was spent on non-value adding activities such as finding the right kinds of screws, tools, etc. It was argued by the people on site that in the long run this might reduce the lead time of certain activities, processes and thus the whole construction project. The authors could easily see a correlation between structure and tidiness. In the tool shed where the 5S was under process of being implemented the tools were cleaned and placed in position in a way that they could not fall to the ground or be broken by stepping on them. In the tool shed that had not been exposed for the 5S it was rather easy to accidentally step on and break a tool or material. The people on site confirmed this observation. This was not only a matter of increased costs for the project but a safety issue as well.

It was apparent that the 5S implementation had resulted in a willingness to improve and develop the work conditions at the construction site and the people at this particular site were keen on learning more about lean.

Figure 17 - Tool Shed before 5S

Figure 18 - Tool Shed during Implementation of 5S

5.7 Observations made during VSM Studies

In addition, other site visits have been made where VSMs have been conducted resulting in a number of observations. Several different construction workers have been followed during a whole day or a half day. In total, thirteen VSMS have been conducted. The construction workers that have been followed have been working with plumbing (three VSMs were made: Pipe1, Pipe2 and Pipe3), ventilation (one VSM was made: Vent1), drywalls (three VSMs were made: Wall1, Wall2 and Wall3), plastering of pillars (two VSMs were made: Brick1 and Brick2), welding (three VSMs were made: Weld1, Weld2 and Weld3), and electricity (one VSM was made: Elec1). The reason why some construction processes where followed more than others was due to the construction workers willingness and/or ability to let the authors join them for a whole or a half days work. The VSMs were conducted by using the android mobile phone application StarBuilder.

The major observations that were made during these VSMs are being displayed in Table 12 and the reader can see in what kind of construction process these findings were observed.

Table 12 - Observations made during VSM Studies

No.	Observations
1	It was rather common that when a construction worker needed a specific tool it was nowhere to be found, especially not where it was suppose to be such as in the tool shed or where the construction worker left it. In that sense the worker had no idea of where the tool might be or who might have taken it. This resulted in a lot of unnecessary walking around at the construction site searching for the tools and starting up conversations with random colleagues which lead to time being wasted on small talk. (Pipe1, Pipe2, Pipe3)
2	It happened from time to time that when a construction worker needed material that was not at hand the worker had to walk relatively long distances to pick it up. It was common that the worker had to take this walk to the same place several times during the same day. Furthermore, it happened that material was not where it was suppose to be since it was processed by a colleagues at another location at the site, forcing the worker to start looking for the colleague. All of this resulted in a lot of unnecessary walking at the construction site and sometimes conversations with random colleagues were initiated which lead to time being wasted on small talk. (Pipe1, Pipe2,)
3	Some material could not be processed at the place where it was later needed due to the size of the material, safety circumstances, etc. Therefore this material was forced to be processed at another location. The consequences of this were unnecessary walking at the construction and starting up conversations with random colleagues which lead to time being wasted on small talk. Furthermore, if material was not shaped perfectly the workers had to go back for tools in order to correct their mistakes. At many times the moving of material at the construction site was time consuming and difficult. (Pipe1, Pipe2, Weld2, Weld3)
4	The authors observed how construction workers sometimes had to stop performing their activities in order to help out colleagues in looking for material, tools or solving a problem. At other times workers had to wait on colleagues to finish their work first before the worker could carry on with the activity that was under process. It was in those cases common for the waiting construction worker to take a break and sit down, looking at the colleagues and waiting for them to finish. This resulted in time being spent on nothing at all. (Weld2, Weld3)
5	If mistakes had been made in earlier construction processes this was not identified until much later on in the project. This could sabotage a whole working day and lead to a lot more extra processing of material, use of machines and time. Furthermore, sometimes mistakes were tried to be solved with muscle strength (e.g. lifting heavy materials) which increased the risk of injuries. (Pipe1, Vent1, Weld1)
6	Some processes are less complicated than others and do not require the same level of problem solving as other processes do. More ad hoc problem solving is more time consuming. Additionally, some processes take more time than others resulting in that other construction workers have to wait on others. It was also observed that the faster construction processes could cause problems for the slower ones i.e. if a wall was set up before pipes had been installed. (Pipe1, Pipe2, Vent1)
7	In line with the earlier described Hawthorn effect it is the authors' belief that their presence at the construction site might have slightly affected the outcome of the individual VSMs. Some workers were keener on socializing during their work tasks than others resulting in more sessions with small talk at these occasions. However, the authors have the perception that they might have observed construction workers who tried to work faster and more efficient than usual. This gives higher value on VA and lower value on NVA for some VSMs but the opposite on other VSMs. (Vent1, Wall1, Wall2, Wall3)
8	For a few construction processes material was deployed by external worker who ensures that the needed material was in place for the construction worker when they arrived in the morning. The result of this is that time was mostly spent on value adding activities since there was no need for walking around at the site to pick up material in different locations or looking for lost material. With everything in place the workers could achieve a good work pace. (Wall1, Wall2, Wall3)
9	For those construction workers who kept good track of their tools and material they hardly had to going around looking for these. It was the authors' perception that these workers also took better care of their tools. (Wall1, Wall2, Wall3, Brick1, Brick2, Elec1)
10	It was obvious that good communication and focus on problem solving instead of long sessions of small talk resulted in fast moving construction processes with a good work pace and with few interruptions. (Wall1, Wall2, Wall3, Brick1, Brick2, Elec1)

In addition, the data collected during the VSMs has been extremely valuable to estimate the general efficiency rate at a construction site. Once all the VSMs had been made the results could be aggregated and a value of the projects efficiency was given. An example of a filled in data protocol is seen in Table 13. All activities that were observed during the VSMs have been classified by the authors according to Monden (1993) grouping of operations, namely: Value Adding activities (VA), Non-Value Adding activities (NVA) and Necessary Waste (NW). This data collection process was made for all VSMs and the data from this is for the reader to be found in Appendix H – Value Stream Mapping Data Collection. However, the results of the VSMs are presented in Table 14 and the results differ quiet a lot between the different construction processes. The percentage of value adding activities was anywhere between 23% and 67% whereas non-value adding activities have been between 17% and 61% and necessary waste were found to be between 7% and 35%.

Table 13 - Example of VSM Data

Company: Construction Ltd	Date: 201X-XX-XX
Construction Site: Project Alfa	Observer: Last Name, First Name
Value Flow: Construction Worker A	Pages: X

Activity	Description	Classification	Start	End	Duration
…	…	…	…	…	…
Break	Waiting on colleague	NVA	10:14:57	10:18:35	00:03:38
Construct	Processing material	VA	10:18:35	10:21:53	00:03:18
Material	Handling tools	NW	10:21:53	10:28:21	00:06:28
Discussion	Small talk	NVA	10:28:21	10:30:05	00:01:44
Walk	Walking away with tools	NVA	10:30:05	10:34:44	00:04:39
Material	Looking for material	NVA	10:34:44	10:39:00	00:04:16
Discussion	Problem solving	NW	10:39:00	10:43:28	00:04:28
Break	Waiting on colleague	NVA	10:43:28	10:45:20	00:01:52
Construct	Assembling material parts	VA	10:45:20	10:48:31	00:03:11
Discussion	Problem solving	NW	10:48:31	10:50:04	00:01:33
Walk	Going for tools	NVA	10:50:04	10:53:11	00:03:07
Material	Picking up tools	NW	10:53:11	10:54:45	00:01:34
Walk	Going back with tools	NVA	10:54:45	10:58:04	00:03:19
Discussion	Problem solving	NW	10:58:04	11:04:52	00:06:48
Construct	Processing material	VA	11:04:52	11:09:41	00:04:49
Discussion	Small talk	NVA	11:09:41	11:12:22	00:02:41
Construct	Screwing	VA	11:12:22	11:15:14	00:02:52
Material	Handling material	NW	11:15:14	11:17:00	00:01:46
Discussion	Problem solving	NW	11:17:00	11:18:57	00:01:57
…	…	…	…	…	…

Table 14 - Data gathered from the VSM

		VA		NVA		NW		TOTAL	
		Time	%	Time	%	Time	%	Time	%
½ Day	Pipe1	01:04:36	30,91%	01:41:00	48,33%	00:43:24	20,77%	03:29:00	100%
	Vent1	00:18:59	23,45%	00:49:42	61,40%	00:12:16	15,15%	01:20:57	100%
	Brick1	00:58:47	52,52%	00:19:17	17,23%	00:33:51	30,25%	01:51:55	100%
	Wall1	01:26:59	54,46%	00:43:27	27,20%	00:29:17	18,33%	02:39:43	100%
1 Day	Pipe2	01:38:18	28,22%	02:15:16	38,84%	01:54:43	32,94%	05:48:17	100%
	Pipe3	02:50:01	47,88%	02:06:16	35,56%	00:58:50	16,57%	05:55:07	100%
	Brick2	02:57:13	52,62%	01:28:51	26,38%	01:10:45	21,01%	05:36:49	100%
	Wall2	02:23:25	49,37%	01:35:10	32,76%	00:51:54	17,87%	04:50:29	100%
	Wall3	03:00:10	60,17%	01:23:40	27,94%	00:35:37	11,89%	04:59:27	100%
	Weld1	00:47:15	24,27%	01:17:21	39,73%	01:10:04	35,99%	03:14:40	100%
	Weld2	01:24:03	29,90%	02:41:40	57,51%	00:35:24	12,59%	04:41:07	100%
	Weld3	01:17:16	27,19%	02:04:49	43,92%	01:22:06	28,89%	04:44:11	100%
	Elec1	04:09:26	67,54%	01:33:58	25,44%	00:25:54	7,01%	06:09:18	100%

6 Analysis

The analysis is structured and divided into six sections, of which the first five correspond to the five RQs. Additionally, in the first section covering the RQ1 every single VSM that were made is analyzed and a number of interesting findings have been pinpointed. In the same section the aggregated result is displayed, analyzed and, finally, estimations of financial implications were evaluated in order to state if the construction industry is in need of improving process efficiency. This result is vital for stating if there is a need of a Lean Construction Tool. The sixth and last section analyzes how the environmental impact of a construction project might be affected if a lean approach is implemented at a construction site.

6.1 RQ1 - Waste in Construction

According to the theory there are eight types of waste, seven originating from Toyota and the last one originating from Liker (2004). These eight types of waste from lean theory help categorize waste identified in the interviews and observations. Later on in this subchapter waste will however be categorized after construction waste rather than being categorized after waste categories from manufacturing.

During the observations the three most observed types of waste where over processing, waiting and unnecessary movement. Over processing was identified in interviews as material waste; a great deal of material is thrown away during production because material needs to be adapted to the building itself. Due to this, it is difficult to get rid of this type of waste (especially when renovating old constructions) but through creative planning and design, adapting the design to the material available this spill can be decreased (especially for new constructions). During the observations it was seen how the complexity of the building greatly affected the amount of work, something that will become clear when using the Lean Construction Tool where finding the root-cause is a part. In addition, it was observed quiet often that the workers disregard for the little things like screw, nuts and bolts. During a build a great deal of these items are dropped at a construction site and rarely picked up. Even though the economic cost of this material is not great there is the matter of how this material affects other parts of the building. Screws and nails can damage soft parts of the building like insulation and get lodged in many different places where they should not be, creating future costly predicaments. The workers need to be made aware of waste in construction and how their actions affect their work environment, cost, time and ultimately, customer satisfaction.

Waiting and unnecessary movements were also identified both in the interview and observations. Waiting could be for material but for tools and colleagues as well. Unnecessary movement was a type of waste that was very visible during the observations. A great deal of time was spent searching for tools, material, colleagues or walking back and forth for different reasons. Often the material needed for a job was located in one place while the job was performed in another part of the construction site. Workers' miscalculating how much material was needed and having to go back accounted for some of the unnecessary movement too. It was the authors' feeling that people with less care for structure and control were those causing most non-value adding activities in form of unnecessary movement.

Unused employee creativity and unnecessary transport are types of waste identified in theory and interviews but not in observations. Unnecessary transports where not seen in the observations due to observations being focused on workers and not specifically on material movement. Unnecessary transports where however identified in the interviews and mainly transports to and from the construction site. These transports can possibly be decreased through transshipment and by not ordering more material than necessary for the build. When categorize waste "unnecessary transports" have been omitted since focus was on internal resource flows at construction sites.

Excess inventory is the last waste identified. Interviewees stated that often more material than needed is ordered simply to be on the safe side and during the observation stage there was a lot of material on site. It is believed that better planning would make it possible to decrease the amount of material brought to the construction sites. Having a lot of material on site leaves it more susceptible to damage and loss because often the material is not kept orderly or stored correctly but haphazardly kept in cardboard boxes stuffed in a corner or stacked on top of each other, also making material more difficult to find. This was also true for the storing of tools, where improper storage might cause breakdowns at a too early stage of the tool's lifetime.

It must be said that many of the workers worked very well keeping a good pace but it was evident everywhere that there was a great deal of waste during the observations. This corroborated the theory and interviews.

Theory gives us a base to stand on when it comes to waste, complemented by examples of waste identified both in the interviews and observations. The waste from theory is categorized based on waste in manufacturing but these categories are also applicable in other industries like construction. As can be seen in Figure 19, there are many different types of waste at a construction site affecting all aspects of work and all of them need to be identified in order to get the full picture of a construction site and the processes that take place there. These identified examples of waste in construction help future users of the Lean Construction Tool to get an idea of what types can be expected in construction and makes it easier to identify waste by knowing what to look for.

However, the authors collected quantitative data by making VSM studies during a two weeks period at a construction site. In total thirteen VSM were conducted and the result varied quiet substantial between different types of construction workers. By following a mixture of workers the authors assumed that it would give a relatively general and fair picture of the efficiency level at a construction site when aggregating the result from all the VSM studies.

From the VSMs and the interviews the authors have tried to group the most common wastes that a construction worker might encounter on a day at work. The authors have come to refer to these as construction site wastes. These classifications and examples of activities are being displayed in Figure 19. This grouping is focused more on trying to classify waste after what happens at a construction site rather than trying to group the waste in construction into the predetermined categories that are based on the manufacturing industry (Liker, 2004). "Unnecessary transports" is an example of a waste category taken from Liker (2004) that the authors have chosen to leave out and that was not seen in the empirical study since only internal resource flows at construction sites have been analyzed. On the contrary "Breaks" is a category that has been added because it was one of the types of waste that stood out and that needed highlighting. This new classification will make it easier to see where much of the construction waste can be found. Three categories have also been left out of the construction waste model since they were not reported in the empirical study. That is not to say they do not exist but it could not be substantiated. One of these wastes however, unnecessary transports, was reported by Modig (2004) in her research as well as by Josephson and Saukkoriippi (2005) but lies outside the scope of this thesis.

The construction waste identified is consistent with many types of waste identified by Josephson and Saukkoriippi (2005). In their report they identify both preparation and waiting as substantial waste, the two types of waste that have been added to construction waste from manufacturing waste. Other types of waste identified by Josephson and Saukkoriippi (2005) that corroborate this thesis' findings are defects, unnecessary movement, unnecessary transports, material spill, problem solving, over processing and problem solving. Unnecessary movement due to not considering logistics was also mentioned by Vrijhoef and Koskela (2000).

RQ1 SUMMARY

A few of the categories stay the same, albeit some of the waste in that category may be a bit different compared to the manufacturing industry. The three types of wastes that stood out during the observations were "Breaks", "Waiting" and "Unnecessary movement". As construction workers are freer to plan their own work and time compared to workers on a production line, it gives them a greater chance for small talk and smaller breaks compared to production line workers. They also have a greater opportunity to plan their work to avoid unnecessary movement, an opportunity not often taken. Another identified category is "Preparation"; work done preparing for the actual construction. An example is when beams and drywall need to be measured prior to being cut to fit the building. This can be avoided by building according to the height of the drywall or beams, a kind of standard. This is however, difficult when renovating a building where everything has to be adapted to the building, something that can be made easier in the future if building according to a standard.

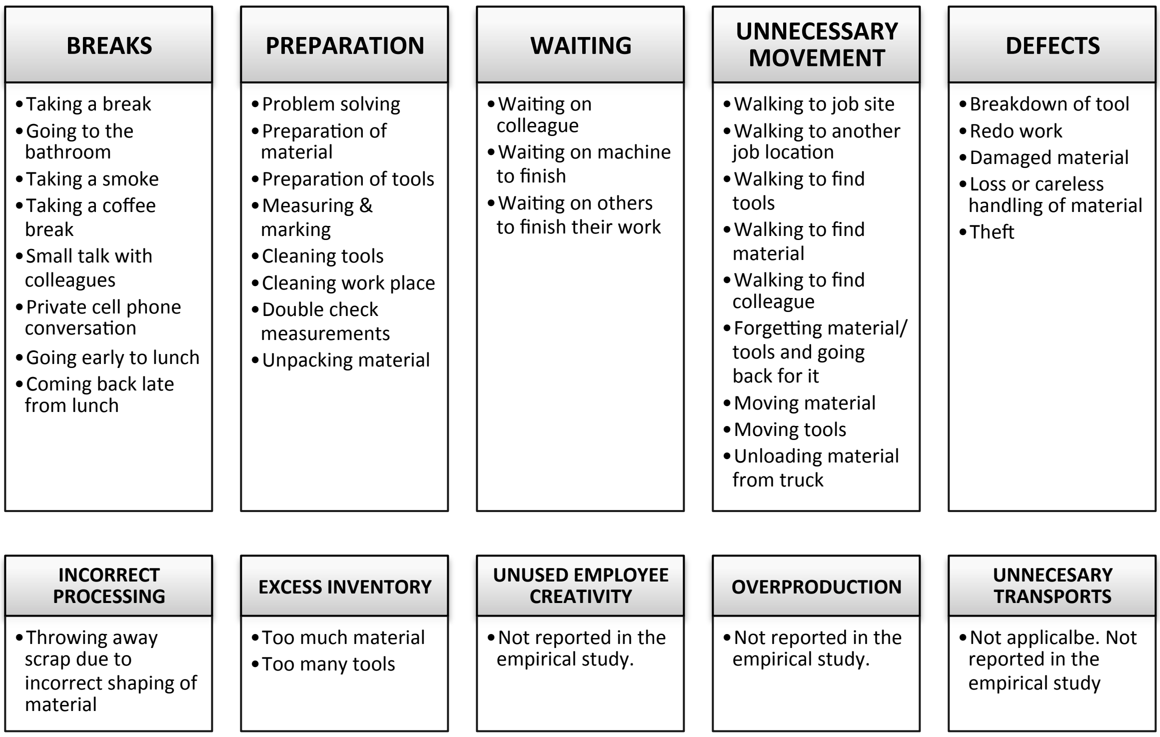
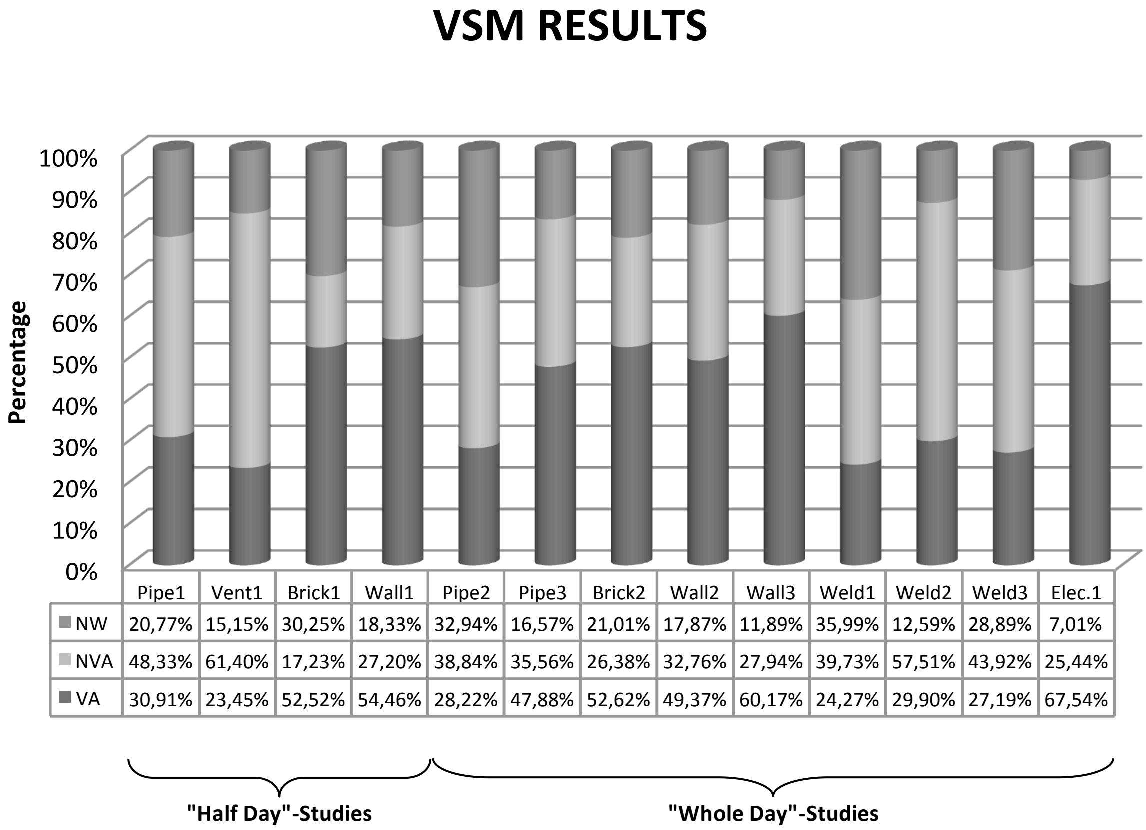


Figure 19 - Construction Site Waste

6.1.1 Results of Individual VSM Studies

The aim with the VSMs was to structure what kind of problems that might occur on a construction site and show that waste exists to a great extent within construction activities. Data was collected during a two week period resulting in four "half day"-studies and nine "whole day"-studies. The result (see Figure 20) is relatively scattered between the different construction processes and it was found that one type of construction worker could perform value adding activities around 20% of their time whereas another type of constructor delivered value close to 70% of their time. These differences depend both on system issues as well as the individual workers.



	Pipe1	Vent1	Brick1	Wall1	Pipe2	Pipe3	Brick2	Wall2	Wall3	Weld1	Weld2	Weld3	Elec.1
NW	20,77%	15,15%	30,25%	18,33%	32,94%	16,57%	21,01%	17,87%	11,89%	35,99%	12,59%	28,89%	7,01%
NVA	48,33%	61,40%	17,23%	27,20%	38,84%	35,56%	26,38%	32,76%	27,94%	39,73%	57,51%	43,92%	25,44%
VA	30,91%	23,45%	52,52%	54,46%	28,22%	47,88%	52,62%	49,37%	60,17%	24,27%	29,90%	27,19%	67,54%

Figure 20 - VSM Results

The observations made during the VSMs that were earlier presented in chapter 0 are being analyzed for the reader in Table 15. The idea is to try to explain why these situations occurred and how they might have affected the outcome of the VSMs. However, when the construction workers that had been studied were asked if it had been a typical day at work they all said it to be a normal workday. Nevertheless, Vent1 and Weld1 uttered that there had been slightly more trouble than usual but situations like these happened from time to time according to them. In that sense the data from Vent1 and Weld1 are valuable for this study to give a fair picture of the construction industry.

Table 15 - Analysis of VSM Observations

No.	Observations	Analysis
1	It was rather common that when a construction worker needed a specific tool it was nowhere to be found, especially not where it was suppose to be such as in the tool shed or where the construction worker left it. In that sense the worker had no idea of where the tool might be or who might have taken it. This resulted in a lot of unnecessary walking around at the construction site searching for the tools and starting up conversations with random colleagues which lead to time being wasted on small talk. (Pipe1, Pipe2, Pipe3)	For some workers there seem to be no willingness to keep track of tools or keep the tool shed tidy. Since this do not goes for all workers it can be assumed to be an individual issue such as lacking a structural mind. However, since it was mainly plumbers who had these problems it could be lack of training or structural thinking within the firm performing the plumbing activities. Nevertheless, looking for tools turned out to be rather time consuming thus costly.
2	It happened from time to time that when a construction worker needed material that was not at hand the worker had to walk relatively long	The authors got the impression that planning of the next day's activities was rather uncommon. Often it was planned that something was suppose

	distances to pick it up. It was common that the worker had to take this walk to the same place several times during the same day. Furthermore, it happened that material was not where it was suppose to be since it was processed by a colleagues at another location at the site, forcing the worker to start looking for the colleague. All of this resulted in a lot of unnecessary walking at the construction site and sometimes conversations with random colleagues were initiated which lead to time being wasted on small talk. (Pipe1, Pipe2,)	to be done but not what kind of materials that were needed or how much of it. This point towards the lack of structuring a work day or a problem. That material cannot be found due to other workers processing it on another location show that the communication between workers should be improved. The lack of communication can also explain the problems with planning ahead since these often correlate. Nevertheless, the material issue resulted in a lot of time being spent on walking around at the construction site.
3	Some material could not be processed at the place where it was later needed due to the size of the material, safety circumstances, etc. Therefore this material was forced to be processed at another location. The consequences of this were unnecessary walking at the construction and starting up conversations with random colleagues which lead to time being wasted on small talk. Furthermore, if material was not shaped perfectly the workers had to go back for tools in order to correct their mistakes. At many times the moving of material at the construction site was time consuming and difficult. (Pipe1, Pipe2, Weld2, Weld3)	That some material is unwieldy to handle is difficult to change but to go back and forth will result in long lead times of the construction process. First of all, the material should be located as close to the place where it is needed since this reduces the distance to walk. It can also be argued that through more thorough measuring the workers will not have to go back with the material and process it again or go back for the tools. The aim should be to do it right on the first try. Rather time consuming and several workers said: "it is a lot of walking in my job". However, this should not be the case.
4	The authors observed how construction workers sometimes had to stop performing their activities in order to help out colleagues in looking for material, tools or solving a problem. At other times workers had to wait on colleagues to finish their work first before the worker could carry on with the activity that was under process. It was in those cases common for the waiting construction worker to take a break and sit down, looking at the colleagues and waiting for them to finish. This resulted in time being spent on nothing at all. (Weld2, Weld3)	In this case it was obvious to be a planning mistake by the manager who had assigned too many workers for the job. However, it is partly the workers fault as well due to their unwillingness to inform the manager of the over capacity. Some people prefer to find ways to work as little as possible where others have a better work ethic. Another explanation to the scenario could be that specific tools which requires special license were needed for the work task and perhaps only a few people possess these. This could therefore justify the over capacity of human resources.
5	If mistakes had been made in earlier construction processes this was not identified until much later on in the project. This could sabotage a whole working day and lead to a lot more extra processing of material, use of machines and time. Furthermore, sometimes mistakes were tried to be solved with muscle strength (e.g. lifting heavy materials) which increased the risk of injuries. (Pipe1, Vent1, Weld1)	The underlying factor to this problem might be poor communication between different kinds of construction workers (e.g. the plumber do not talk to the carpenter). Therefore it could be argued that all the actors within a construction project have to be better at team work and help each other. It is also problematic to not have any systematic procedure to make follow ups if quality is deficient. This results in that more mistakes will be made in the future without any possibility to avoid them or find the source of the problem.
6	Some processes are less complicated than others and do not require the same level of problem solving as other processes do. More ad hoc problem solving is more time consuming. Additionally, some processes take more time than others resulting in that other construction workers have to wait on others. It was also observed that the faster construction processes could cause	The more complicated construction processes requires better planning, however, the extra planning was not present. From time to time the work day was all about ad hoc problem solving which could be rather time consuming. With better planning the lead time could be reduced and reducing the time that worker is waiting on other workers. The issue with the finished wall and the

	problems for the slower ones i.e. if a wall was set up before pipes had been installed. (Pipe1, Pipe2, Vent1)	not yet installed pipes shows the lack of communication between construction workers and managers.
7	In line with the earlier described Hawthorne effect it is the authors' belief that their presence at the construction site might have slightly affected the outcome of the individual VSMs. Some workers were keener on socializing during their work tasks than others resulting in more sessions with small talk at these occasions. However, the authors have the perception that they might have observed construction workers who tried to work faster and more efficient than usual. This gives higher value on VA and lower value on NVA for some VSMs but the opposite on other VSMs. (Vent1, Wall1, Wall2, Wall3)	The authors are well aware that they might have affected the outcome of some of the VSMs by their presence and their participative observation approach. However, since some studies may have given a higher level of VA activities and other lower level of VA activities the authors have made the assumption that it will level out. Therefore, the aggregated result should be valid.
8	For a few construction processes material was deployed by external worker who ensures that the needed material was in place for the construction worker when they arrived in the morning. The result of this is that time was mostly spent on value adding activities since there was no need for walking around at the site to pick up material in different locations or looking for lost material. With everything in place the workers could achieve a good work pace. (Wall1, Wall2, Wall3)	What is common for the VSMs conducted on workers handling drywalls is that they had among the highest efficiency level. Sometimes double or triple the VA activities than other workers. Therefore it could be argued that having material at hand when it is needed give substantial benefits in terms of good work pace and shorter lead times. The management should consider paying the extra money to have the material transported and placed on the right spot for more construction processes. There might be some serious money and time to be saved.
9	For those construction workers who kept good track of their tools and material they hardly had to going around looking for these. It was the authors' perception that these workers also took better care of their tools. (Wall1, Wall2, Wall3, Brick1, Brick2, Elec1)	By keeping track of all tools/material and taking care of these in a systematic way they facilitated a high work pace with very few interruptions. Since some construction firms where better at this than others it is plausible that the management of these firms are taking more responsibility and informing the workers about the importance of good structure and tidiness.
10	It was obvious that good communication and focus on problem solving instead of long sessions of small talk resulted in fast moving construction processes with a good work pace and with few interruptions. (Wall1, Wall2, Wall3, Brick1, Brick2, Elec1)	The reason that some workers focused more on doing a great job than finding ways to take a break is a matter of the individuals' work ethic. This is something that managers can affect and change by teaching the importance of problem solving communication, work ethic and how more efficient work can improve the workers own financial situation.

6.1.2 The Aggregated Result of the VSMs

If all the VSM studies are summarized an aggregated result will be given. This result is shown in Appendix H – Value Stream Mapping Data Collection and Figure 21 shows that roughly 44% of the workers' time at the construction site is spent on value adding activities that need to be optimized while 36% of the time is non-value adding activities which need to be eliminated. There is also necessary waste accounting for 20%, which needs to be minimized. These results may vary compared to other studies. Josephson and Saukkoriipi (2005) did their own study which gave results that were fairly similar in terms of non-value adding activities. However, in their study, 17.5% was recognized as value adding, roughly 45% as necessary waste and approximately 33% as non-value adding activities. The discrepancy in results concerning necessary waste and value adding activities stems from different views on what actually is value-adding and what is necessary. What is identified as value adding differed between interviewees and as the results show the authors took a wider view of what is value adding when making observations.

However, the 36% that is pure waste makes it fair to say that the construction industry is struggling with efficiency problems. There is a great deal that can be done, not only to eliminate the non-value adding activities and minimize the necessary waste but also to optimize the value adding. During the observations it was observed that clever building design has the possibility of greatly affecting the amount of work needed for completion. By taking the problems and difficulties faced by the different construction workers on a daily basis into account when designing a lot of extra work can be avoided.

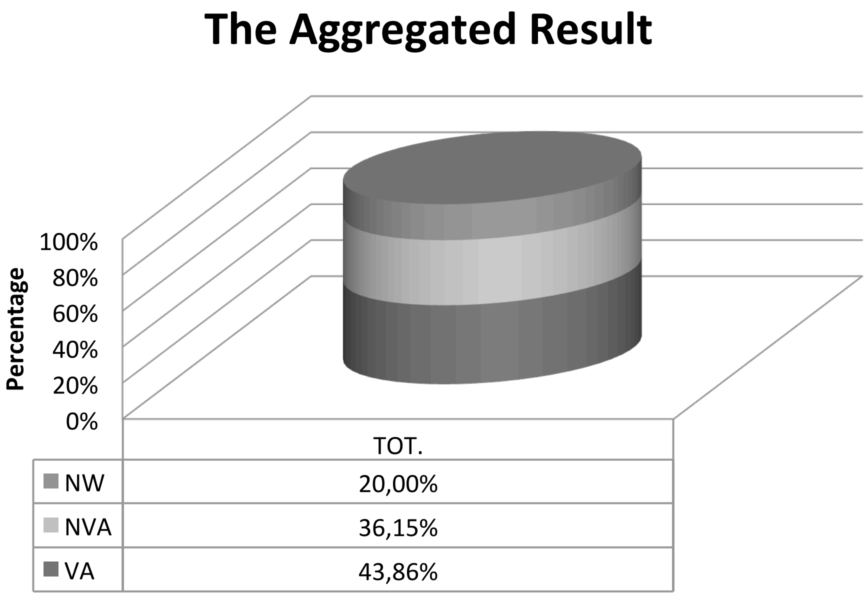


Figure 21 – The Aggregated VSM Results

6.1.3 Financial Implications

The construction industry (construction of new buildings and maintenance) in Sweden has steadily contributed roughly 10% to the GDP between 1967 and 1991 except for a few peaks (Lutz & Gabrielsson, 2002). If one includes operations and management the contribution jumps to nearly 20% (Lutz & Gabrielsson, 2002). In its "widest sense" the contribution to national GDP is similar for the UK, with the construction industry in its contributing 10% to the GDP and employing 1.4 million people and construction is the third largest contributor to the GDP in Brunei (Department of Environment Transportation and the Regions, 1998; Sumardi & Anaman, 2004). The actual percentage or what is included in the definition 'construction industry' does not matter. Considering how much time is spent on non-value adding activities the data shows how important the construction industry is for many countries and that even a few percent increase in efficiency level can result in tremendous savings.

If 40% of the construction workers time is adding value for the customer(s) a total of 60% is not giving anything to the end product. However, it is not possible to say that 60% of the cost of a construction project can be eliminated. The material that is needed for moving the construction process forward is a large part of this cost. Furthermore, the authors have been following construction workers and through time studies made several VSM which emphasize that approximately 60% of their time is wasted on other things that do not add value for the customer. Therefore, in order to analyze potential savings that can be made by making employees work more efficient and smarter; one has to contrast the cost of labor and the total cost. Hence, net sale of construction projects minus the profit margin will give the total cost to construct the building. As mentioned earlier in this report the profit margin for projects within this kind of industry is approximately around two percent (Olsson, 2000; Andersson & Ohlsson, 2007). However, in the latest annual report from PEAB (2010) the profit margin was four percent thus this will be used in the estimations.

In Table 16 the total cost of all construction projects that were under process in Sweden during the period 2006 – 2009 is presented. Moreover, as were mentioned by Statistic Sweden (2004) close to 25% of a construction project's cost is linked to cost of labors. In addition, as the VSMs have pointed out, 60% of the time does not add value for the customer. This would mean that:

$$25\% \ of \ the \ project \ cost \ (the \ labor \ cost) \times$$
$$60\% \ of \ workers \ time \ (activities \ that \ do \ not \ add \ value \ for \ the \ customer) =$$
$$15\% \ of \ the \ project \ cost \ is \ money \ being \ wasted$$

This would mean that an immense amount of money is being spent on nothing at all in the construction industry every year (see Table 16). Radio Sweden made an interview with Sweden's minister of finance Anders Borg who stated that the Swedish GDP for the year 2008-2009 was around 3100 billion SEK (Radio Sweden, 2010). This would mean that the wasted money within the Swedish construction industry stand for approximately 2% of the GDP.

Table 16 – Total Cost and Wasted Money (SEK million) in Swedish Construction Projects from year 2006 – 2009 (Statistics Sweden, 2010)

	2006	2007	2008	2009
Building Contractors	149 071	175 424	185 931	191 074
Construction Contractors	21 692	24 666	26 732	30 699
Specialized Building and Construction Contractors	187 733	216 069	238 640	231 225
Total Net Sale	358 496	416 159	451 303	452 998
Total Cost (Total net sale minus 4% profit margin)	344 156	399 513	433 251	434 878
Wasted money (≈15% of Total Cost)	51 623	59 927	64 988	65 232
Wasted money in % of the Swedish GDP			2.09%	2.10%

To clarify: If a construction project net sale is 800 million SEK and the value adding activities account for 40% of the construction workers' time it is possible to estimate the money being wasted due to inefficiencies as follows.

$$800 \ million \ SEK \times 96\% \times 25\% \times 60\% \approx 115 \ million \ SEK$$

$$(115 \ million \ SEK \ \div (800 \ million \ SEK \times 96\%)) \times 100\% \approx 15\%$$

However, if the people around the construction project can improve the construction processes by optimizing value adding activities, eliminating non-value adding activities and minimizing necessary waste the savings can be quiet substantial. For example, if non-value adding activities and necessary waste are cut down to 55% instead of the earlier 60% the construction project will save approximately 10 million SEK, or 1.25% of the construction cost. This saving might have a potential effect on the profit margin and lead time. In Appendix I – Potential Savings the reader can see how much the construction company PEAB (in 2010 in Sweden) as well as the entire Swedish construction industry (in 2009) might have been able to reduce its construction cost if non-value adding activities had been eliminated and necessary waste minimized to a certain extent.

In that sense, there is a lot to gain by working with increasing the efficiency at construction sites. Therefore it would be valuable for construction companies to start looking for improvement areas and understand the whole concept of lean. A user-friendly Lean Construction Tool that helps these companies to manage the waste issue has therefore been developed and can be found in chapter 7.

6.2 RQ2 - Identifying Waste

Theory points towards VSM as a good process-mapping tool for identifying waste and studying the flow, which the reader might have already noticed in the previous section when the RQ1 was analyzed. The reason why this is covered in both sections is that the RQ1 and RQ2 are interrelated.

However, both Toyota (Liker, 2004) as well as companies in other industries (Allway & Corbett, 2002; Condel, Sharbaugh, & Raab, 2004; Black & Miller, 2008) have used VSM to identify waste in their processes. The tool focuses on the value stream, helping companies understand the delivery of value to customers. By identifying a current state and constructing a future state there is a game plan for change. The interviews corroborated the view that VSM is a qualified tool for identifying waste in construction as well. Finally VSM was used when conducting observations at construction sites, mapping the value adding activities, the non-value adding work and the necessary waste. VSM was also chosen as a part of the Lean Construction Tool because it was recommended both in the theory and interviews as well as being a simple, paper and pencil tool.

When looking at the parts of lean construction identified by Eriksson (2010) there were other tools and methods that can be used to identify waste, where some were identified in the interviews while some where not. Planning tools, meeting and education were identified in both, yet with slight variations. Planning tools can be used to optimize planning and identifying waste by finding a better way to complete a task or project. Meetings are tools for identifying waste by utilizing the workers intimate knowledge of their work. Together with meetings, education and learning from past experiences were identified as facilitators of waste identification by giving workers the tools and knowledge to identifying waste and making the meetings more efficient. These where not chosen to be part of the Lean Construction Tool but hold a central place if lean is to be fully implemented within a construction company.

Keeping the work place organized was seen as important in theory (Liker, 2004; Eriksson, 2010), interviews and observations. During the observations a great deal of the workers time was spent looking for material pointing to the need to be organized and planned. During the interviews it was said that the easiest way to find waste was to go and see for yourself; something which is a vital part of lean according to Liker (2004). Going and seeing for yourself was chosen as a part of the authors' Lean Construction Tool because as the authors themselves found out, it is the best way to understand the problems faced by construction workers on a daily basis and the waste than can be found. Other ways of identifying waste that were found are total cost analysis and checklists Maroszeky *et al*. (2002). Checklists can be used to identify waste by using it for planning and seeing waste by comparing to how work use to be done and using it as a way to focus on the process. Theory also mentioned benchmarking (Camp, 1989; Chan & Chan, 2004). By benchmarking with the best in your industry as well as other industries it is possible to see where improvements can be made and need to be made. If lean is to be implemented and the industry is serious about becoming more efficient all of these ways of identifying waste should be considered.

RQ2 SUMMARY

Theory identifies many tools from lean manufacturing that can also be used in construction. The interviews and observations state possible tools that can be used to identify waste (see Table 17). The tool chosen by the authors' in their observations was VSM due to its simplicity where one goes out and looks at the process being studied. The VSM is complemented with interviews and observations at the construction site under study in order to gain further in depth knowledge of the waste. The data from the VSM together with information from interview and observations shape the base of the Lean Construction Tool. Understanding the processes is necessary when trying to change the processes.

Table 17 - Summary of Identifying Waste

Theory	Interviews	Observations
Process mapping tools (VSM)	Process mapping (VSM, Material Flow Mapping, Frequency Analysis, spaghetti diagram)	Process mapping (VSMs by using StarBuilder)
Planning methods (Last Planner, IT-tools)	Planning methods (Visual planning, Last Planner, Linear Planning, 3D/4D/5D	-
Meetings (Quality Circles)	Meetings (Team/Planning meetings, quality circles, education and teaching)	-
Education (Training, knowledge sharing, encourage employees	Education (Look at past experiences and especially past failures)	-
Structure (5S, clean and tidy work place, go and see for yourself)	Structure (clean up the construction site, common sense, go out and see for yourself)	Structure (Missing material and tools are not noticed due to unstructured workers or to disorder in tool shed/box)
Checklists	Checklists	-
Benchmarking	-	-
-	Total Cost Analysis	-

6.3 RQ3 - Measuring Waste

How to measure waste is important when trying to calculate the economical, environmental and time implications of lean initiatives as well as when trying to prioritize. The most common measure of waste is time and cost. This is because time and cost are the most critical performance factors in construction (Lai & Lam, 2010). A client and the contractor as well, want the project to be completed on time and on budget.

The above ways of measuring waste were together with other KPIs identified in the theory too. A list of nine KPIs where identified in order to measure process efficiency (Lai & Lam, 2010). A few of them are quantitative while others are qualitative. Time, profit and perhaps quality are those mainly used to measure waste in the processes while the others can be used for example to measure waste in areas that affect the workplace. One of these aspects was the environment; environmental performance was identified in the interviews as an important measure of waste. Figure 22, which is merely a suggestion from the authors, shows a number of different KPIs linked to different types of waste that affect the KPIs. It is the authors' belief that this may be helpful in designing a measurement system and deciding on what types of KPIs are interesting and important to measure.

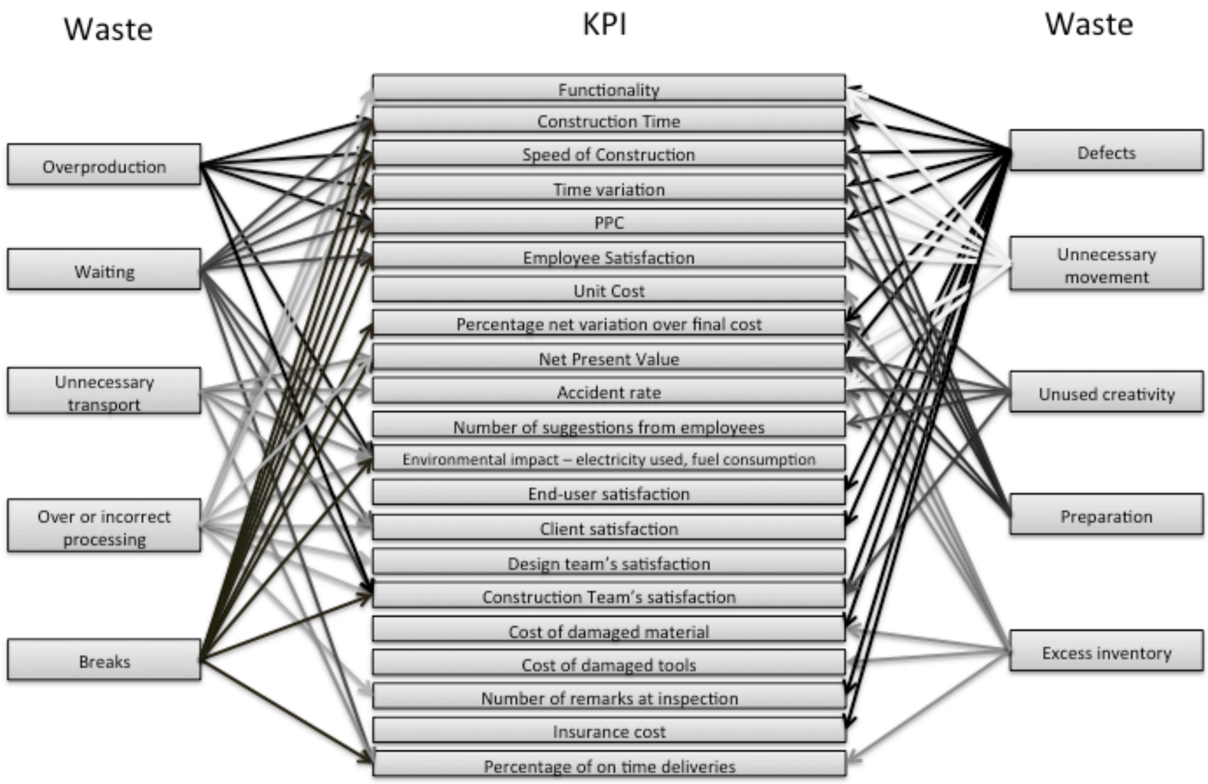


Figure 22 – Suggested Schematic Connection of Construction KPIs and Waste

As the interviewees have pointed to, the cost aspect, or rather price, is often the way waste is measured. As one interviewee pointed out, cost and not price should be used in order to measure waste. Here total cost alternatives or comparing different logistics alternatives can be used to measuring waste. The interviews also pointed to the use of time and situation analysis to analyze waste. Time is an extremely crucial factor in the construction process in order to keep the timetable; hence this makes time an important way of measuring waste. Situation analysis means comparing the current state to a possible future state to see how the operations can be improved. How to do this in a good way has been discussed during this master's thesis and theory and interviews have emphasized some sort of process mapping as a functional tool to do this. VSM is mentioned several times and argued to be a rather simple tool to handle. This was the authors' perception as well when collecting data by using the application StarBuilder.

Both theory and interviews identified an interesting metric which was PPC (Ballard & Howell, 1998). It is of interest in sense it deals with time since a planned activity not completed on time needs to be completed later on, behind schedule. It is used as a part of the last planner and the authors see it as a very interesting metric to use.

How technical solutions can help to measure waste was not mentioned in the academic literature but it was only during the interviews that this was pinpointed. In the literature methods where discussed, e.g. VSM, but if these can be performed with technical aids were never stated. By possessing the application StarBuilder the authors had the possibility to try out how easy a VSM can be conducted.

RQ3 SUMMARY

As can be seen in Table 18, theory, interviews and observations together identified several ways to measure waste. The most common and easily used measurements are common metrics including time, cost, quality etc. What is most important when choosing how to measure waste is to choose simple measurement that can be applied to different projects and different types of projects in order to facilitate comparison and benchmarking. It is also important to think about the Lean Construction Tool when choosing metrics because the tool is to be used over and over again in order to continuously improve. Therefore the way waste is measured needs to be made able to follow and measured over time.

Table 18 - Summary of Measuring Waste

Theory	Interviews	Observations
Measure Time (process mapping)	Measure Time (process mapping, VSM, delivery rate)	Measure Time (VSM by using StarBuilder)
KPIs (time, profit, environment, quality, safety, effectiveness, no claims or contractual disputes, job satisfaction, generation of innovative ideas	KPIs (for example delivery precision, quality, economic, environmental or waste, etc.)	-
Measuring Cost	Measuring Cost (Total Cost Analysis, compare costs between different logistic alternatives)	-
Measure coordination and flow (do an Situation Analysis)	Measure coordination and flow (do an situation analysis and compare this to the new situation after changes have been implemented)	-
Percentage of planned activities completed (PPC)	Percentage of planned activities completed (PPC)	Percentage of planned activities completed (PPC)
-	Technical Tools (Lean Navigator, RFID)	Technical Tools (StarBuilder)
-	What to measure differ between projects (depends often on the site manager) – no universal metric	-

6.4 RQ4 - Waste Prioritization

Theory pointed to how prioritization can be made, by using the criteria: (1) Importance, (2) Urgency and (3) Tendency (Liker & Meier, 2005). Time and cost have been identified as important aspects for construction, and theory also points to certain industry specific peculiarities mentioned by Koskela (1992) as well as issues and aspects that are important for the success of the project which help in deciding how to prioritize (Lai & Lam, 2010). The industry specific peculiarities lead to a great deal of complexity and uncertainty within projects according to Koskela (1992). A way to prioritize could be to mitigate the effects of these peculiarities.

Time and cost are two aspects important for the success of a project and are the most important factors when prioritizing. When the VSMs have been conducted and the waste has been categorized it is possible to use the authors' suggestions on links between waste and KPIs (Figure 22) to see whether the waste affects time or cost more. Information from the interviews also pointed to time and cost, which one often being decided by the project leader. The criteria mentioned in the theory can help to separate the two; if one of the factors is getting worse faster than the other then that one can be prioritized. When focusing on cost it was important to take a holistic view, thinking about total cost. It was also noticed by the authors during their time spent at a construction site that re-prioritizing of work tasks and start with other more time sensitive activities happened from time to time. Below, other aspects will be discussed but in the end most of them affect these two aspects.

Moreover, theory focuses around flow and value (Koskela, 1992; Liker, 2004). Value should focus on the customer meaning that what is most important for the customer is where to prioritize. That can be either time or cost but can be other factors like environmental issues, quality or end-user satisfaction as well. Flow focuses more on time, putting more effort into planning and doing things right the first time. Interviewees said to prioritize the most important or crucial material first with one interviewee mentioning cement, used for the frame of a building, as crucial both from a time as well as a cost perspective. This was later observed by the authors when more workers were assigned to process floating cement when it arrived to the construction site and the workers gave up the activities they had at their hands at the moment. If flow is prioritized it is likely to have positive implications both on cost and time.

Other interviewees mentioned focusing on the larger problems, which will have the greatest effect on overall project performance whereas another recommended starting with small and easy problems first to show on success stories. Another wanted to focus on areas where the company had control or power to make changes to start with. A third reminded us to take a holistic view which is similar to taking a total cost perspective or listening to the customer; what is best for the project. The authors' point of view in the subject matter is that it would probably be best to take on small and easy problems first to get a hold of the improvement process and in time take on more complex issues.

Something that has been stated both in theory (Liker, 2004) and by interviews is that the root cause behind waste is of great importance to understand and find. In order to do this it was argued by interviewees that by using an Ishikawa diagram a problem can be broken down and the real reason behind the problem is found. Furthermore, using a VSM combined with a Pareto analysis was another idea mentioned several times by different interviewees. The Pareto diagram was said to be a good way of visualizing the most frequently problems and structure the prioritizing process. These tools are simple and powerful and have therefore been incorporated in the Lean Construction Tool in order to facilitate prioritization.

RQ4 SUMMARY

Waste affects the construction work in many different ways, some having a greater impact than others. The theory gave a practical guideline on how to prioritize while the theory, interviews and observations together gave input on which aspects and factors affecting construction that are important. As can be seen in Table 19, the theory gave a few ideas on what to prioritize when trying to reduce waste. The interviewees also had their own, often different, opinions on what can and should be prioritized. There is no right or wrong in choosing which aspect to prioritize, it may depend on what project leader or the client thinks is most important; the important thing is that waste is being reduced and that the process are continually being improved. However, it has been said, both in theory and interviews, that in order to first gain acceptance for working with lean a noticeable change is useful to achieve. By using the 5S tool the workers can easily see what a difference it makes when tools and material are where they are supposed to be and easy to find.

Table 19 - Summary of Waste Prioritization

Theory	Interviews	Observations
Prioritize what is most critical at the moment (mitigate effects of construction peculiarities)	Prioritize what is most critical at the moment (types of material, money, time)	Prioritize what is most critical at the moment (Preparation of concrete floor, Re-prioritizing of work tasks to get started with other time sensitive activities)
Time	Time	-
Cost	Cost (Have a holistic perspective, look at the Total Cost)	-
Identify the root cause	Identify the root cause (Ishikawa Diagram)	-
Tools (5S etc. Noticeable change)	Tools (VSM and Pareto Analysis)	-
Customer Value	-	-
Flow	-	-
-	Discuss (Listen to workers, they have a lot of experience, discuss in small mixed groups)	-
-	Start with processes where one have the most control/power over	-
-	Take on easy problems first to show success stories	-
-	Larger problems are analyzed whereas small problems are not	-

6.5 RQ5 - Potential Effects of a Lean Approach

As with the answers to many of the other RQs, time and money play a pivotal role in the possible consequences of waste reduction. Both theory (Allway & Corbett, 2002; Spear, 2005; Black & Miller, 2008) and interview corroborate the monetary gain and the shorter lead times, with theory as well mentioning increased productivity and capacity (Allway & Corbett, 2002). Time and cost are the two main issues affecting construction processes and a great deal of effort is put in to minimize these.

After these two aspects comes quality which both theory (Liker, 2004) and interviews point out as possible consequences too. Stable processes and as an interviewee said, that workers learn to do right the first time, may help improve build quality. Increased process stability was actually another consequence mentioned by both theory, by Liker (2004) and interviews. Increased process stability or less muri as lean theory states comes from a more even production, which ultimately leads to better flow and brings other problems and issues to the surface. The last consequence mentioned by both theory and interview is improved work environment. Liker (2004) specifies it as not overburdening workers or equipment and in the interviews it was mentioned that a reducing waste could decrease the physical and psychological stress in the work place. There may also be negative aspects of lean; Green (1999) mentions the possibility of increased transports as well as increased strain on workers. There are also many difficulties in implementing lean such as overcoming the construction peculiarities, knowledge transfer, industry mindset, etc that can be it difficult to achieve the possible positive consequences mentioned.

A closely related consequence to the improved work environment mentioned in the interviews is the possible positive environmental effects. It was mentioned that by handling transportation more efficiently, decreasing the amount of unused or damaged material and by transshipping the total amount of transports could be decreased. This would mean a less emissions as well as decreased complexity at the work site. Furthermore, it can be argued that by eliminating waste less material will be scrapped since better planning will lower the inventory levels which are exposed to the risk of being damaged. In addition, keeping track and taking care of material and tools by implementing a 5S program may reduce unnecessary break down of tools and loss of material, giving the possibility to improve the project's environmental impact. It could also be stated that through efficient planning and coordination less use of machines will be necessary; hence energy consumption can be reduced.

Increased customer value is another consequence identified in the theory (Liker, 2004). It is actually a consequence of delivering a building at lower cost, faster and with increased quality to the customer but a consequence nonetheless. Other consequences, identified through the interview, were resistance, sub-optimization and getting ahead of the competition. Resistance was identified if implementation was not done properly (hence the importance of start off with small success projects). A key issue mentioned here was top management support, absolutely necessary for the success of implementing lean. Without mentioning them, there are however other aspect that affect implementation, since in the end it is not top management but the workers themselves that must make the transition to lean (remember how 314.000 employees at Toyota looking for waste every day). Another possible negative consequence is sub-optimization which can happen if a holistic view, as has been mentioned earlier in the report, is not taken (Hines, Holwe, & Rich, 2004).

Getting ahead of the competition is a consequence that takes time. By showing possible clients and other stakeholders that the construction company can deliver a project with reduced cost, increased quality, increased customer value, better work environment, faster than any competitor then that company will be in a extremely good position.

RQ5 SUMMARY

The potential effect of a lean approach and the affects of getting rid of certain types of waste are important both in order to prioritize but also to justify the effort put into reducing waste. The effort of reducing waste and trying to become lean must yield a positive net effect. As Table 20 shows, there are effects on time, cost, and process stability as well as positive effect on the environment. As mentioned in the empirical study the environmental improvements are synergy effects of becoming lean. By reducing waste it is possible to reduce material waste, energy for machines, heating and lighting and extra transports ultimately having a positive environmental effect. There will also be a positive effect on the work environment since less time will be spent trying to find tools and getting stressed about not finishing on time.

Table 20 - Summary of Potential Effects of a Lean Approach on Construction Sites

Theory	Interviews	Observations
Improved work environment (less mura)	Improved work environment (decreased psychological and physical stress, improved safety)	-
Increased efficiency & effectiveness (better flow, shorter lead times, increased productivity and capacity)	Increased efficiency & effectiveness (better flow, coordination and material handling, hence reduced lead times and increased production rate)	-
Economical savings (reduced costs)	Economical savings (cheaper product or increased profit)	-
Environmental savings	Environmental savings (decreased emission, less material waste and energy consumption)	-
Process stability (less muri)	Process stability (Reduction of risks and uncertainties which leads to improved forecasts)	-
Improved quality (improved	Improved quality	-

reliability and customer value)		
-	Increased commitment (positive attitude for change projects)	-

6.5.1 Environmental Effects

Every operation at a construction site entails a certain amount of environmental impact. If goods are being damaged more material has to be order which increases production emissions and since the new order has to be delivered the transport emissions increase. In this way it is easy to see that wasteful activities at construction sites could cause negative contribution to the environmental impact. However, if one can increase the negative impact there should be ways to reduce it as well.

By reducing waste not only can money be saved, but it is also possible to get a synergy effect out of it since the construction companies' environmental impact is reduced. Operations that are non-value adding are pure waste and they should therefore be eliminated and the same goes for the negative environmental impact of these operations. However, the impact from the value adding activities should be reduced if it is possible but sometimes the goal is not to since they might be seen as necessary environmental damages. The logic behind this is that a holistic perspective is needed to reduce the environmental consequences since single efforts may result in sub-optimization, hence increasing the environmental damages even more.

During the interviews a number of wastes were identified and these can be found in section 5.1 Waste in Construction. In addition, several environmental consequences could be linked to these wastes were extra transports, damaged material and extra work to fix defects, to mention a few, all contribute to increased emissions and energy use.

During the interviews and observations operational waste was identified and observed. Together with information concerning the environmental impact from the operations a figure of the environmental impact from the different types of waste was compiled, shown in Figure 23. The figure shows the different environmental impacts from different types of construction waste.

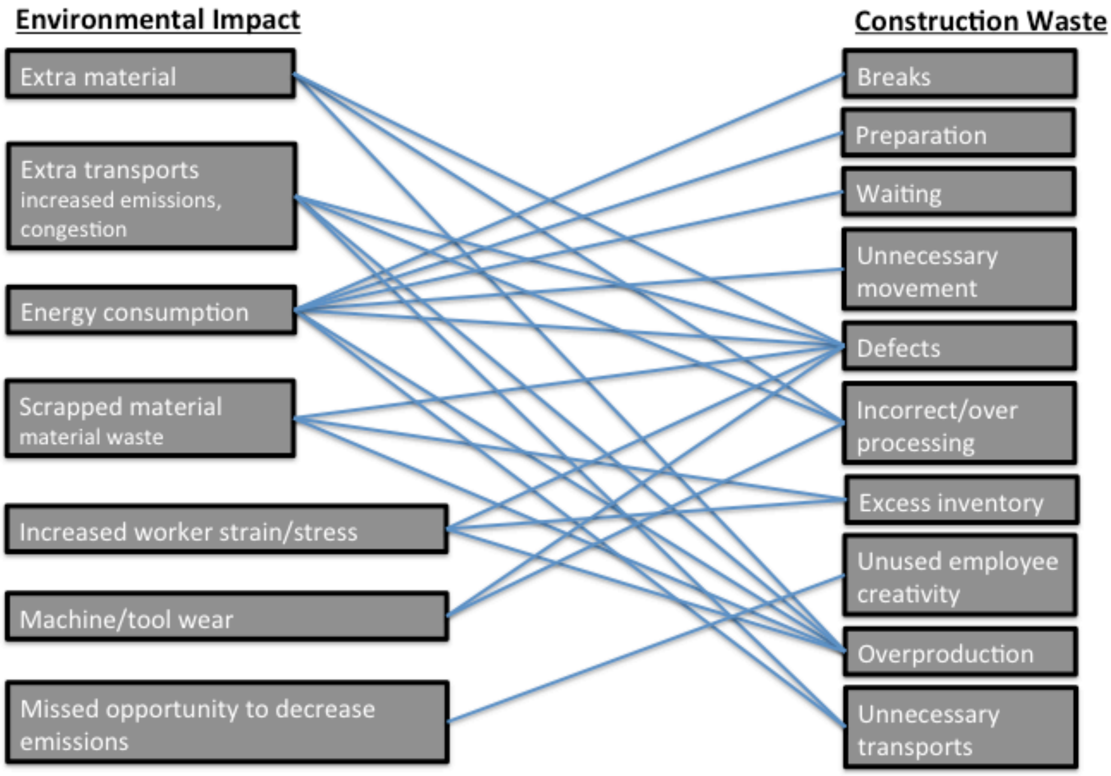


Figure 23 - Schematic Picture of how Construction Waste is Linked to Environmental Impacts

7 Results

In this chapter the authors will present a Lean Construction Tool. This tool has been designed along the findings in literature, academic theories, interviews and the authors' own observations that have been made during this master's thesis project. The tool is designed to answer the five research questions and it aims to be as user friendly as possible for future practitioners of the lean tool. The chapter is concluded by a validation case to test the tool, conducted on a painting process at a construction site.

7.1 The Lean Construction Tool

The lean tool that has been constructed, seen in Figure 24, is built upon many different aspects collected from the theory, interviews and observations gathered during the master's thesis. The different steps of the lean tool are presented below.

STEP ONE
Through lean theory it has been taught that a situation analysis is a prerequisite and needs to be done, a snap shot of the current situations in order to understand the situation at hand. Through theory, interviews and the authors' own experiences VSM was identified as an important tool for this task. Others tools were also identified as possible candidates for the task but since the VSM tool is seen as a rather general and simple tool to use that can handle many different resource flows and situations it was decided to reject the other process mapping tools. When it comes to practicing VSMs the important thing is not to focus too narrow or too wide but have a holistic view of the situation without increasing the complexity too much. In other words, there is a need to find a functional balance. It is also important to decide where the situation analysis should be focused, should it be on cost, time or other factors. If the focus is on time the authors highly recommend the mobile phone application Starbuilder. In addition to what just have been mentioned the practitioners' own observations are valuable for the research. This together with interviewing people working with the construction processes will give a strong foundation for evaluation of the situation. This is highlighted several times in theory, for example, lean literature from Toyota points to the importance of going and seeing for yourself, only then can one truly understand how the system or process being studied works.

STEP TWO
After the situation is understood it needs to be studied and analyzed. Using TPPSP and Ishikawa diagrams the root cause of the problem can be found. It is important not to treat the symptoms but find what is actually causing the problem. A problem may indicate that it is the workers fault but may in fact be due to poor design of the building and/or poor planning by the main contractor.

STEP THREE
The third step is to prioritize which problems to deal with first, which are most important. During the interviews different areas were identified by different people. It was said that often it is up to the project leader, whether he/she is more focused on cost or time. Other interviewees said that one should focus on the problems that had the most effect or the materials that were most important for the projects. It is also important to keep sub-optimization in mind so that fixing one problem does not cause even more problems somewhere else. Both theory and interviews emphasized that Pareto diagrams and/or together with KPIs can be used to prioritize what is most crucial. By understanding which factors are most important for a certain project or a company the right prioritizations can be made. KPIs can be used to see progress over time or project where improvements are necessary. A company can also benchmark, compare value on their KPIs with other companies to see where improvement is needed in order to keep up with or exceed the competition.

STEP FOUR

The fourth step in this Lean Construction Tool aims to close the loop of this master's thesis. Everything that has been done in the earlier steps is now evaluated and one should ask questions like "what is the improvement potential in making certain changes?" and "how will our economicl and/or environmental performance be affected?" For example, in this master's thesis it has been showed that by working with construction efficiency rather large costs can be avoided (see Appendix I – Potential Savings) and in addition improved work environment and environmental savings might occur.

THE LAST STEPS

However, just stating that waste exists within the construction industry and what kind of money that can be saved will not automatically decrease these costs. For that reason the authors have added the two last steps in the Lean Construction Tool even though these fall outside the master's thesis' purpose and scope. However, these two steps deal with taking action based on the information gathered and assessed during the previous four steps. When proposing specific solutions in step five tools, techniques and methods are put forth in order to reduce waste and later on in step six these are implemented and the reaction is evaluated. It is the authors' intention to hand over this master's thesis' project to someone who can complete the Lean Construction Tool's last two steps. This is discussed further in chapter 8 Discussion, Recommendations, and Continued Research.

Finally, once the last step has been processed it is possible for the operator of the Lean Construction Tool to start all over again and find new improvement areas. In this way continuous improvements of the construction industry can be secured.

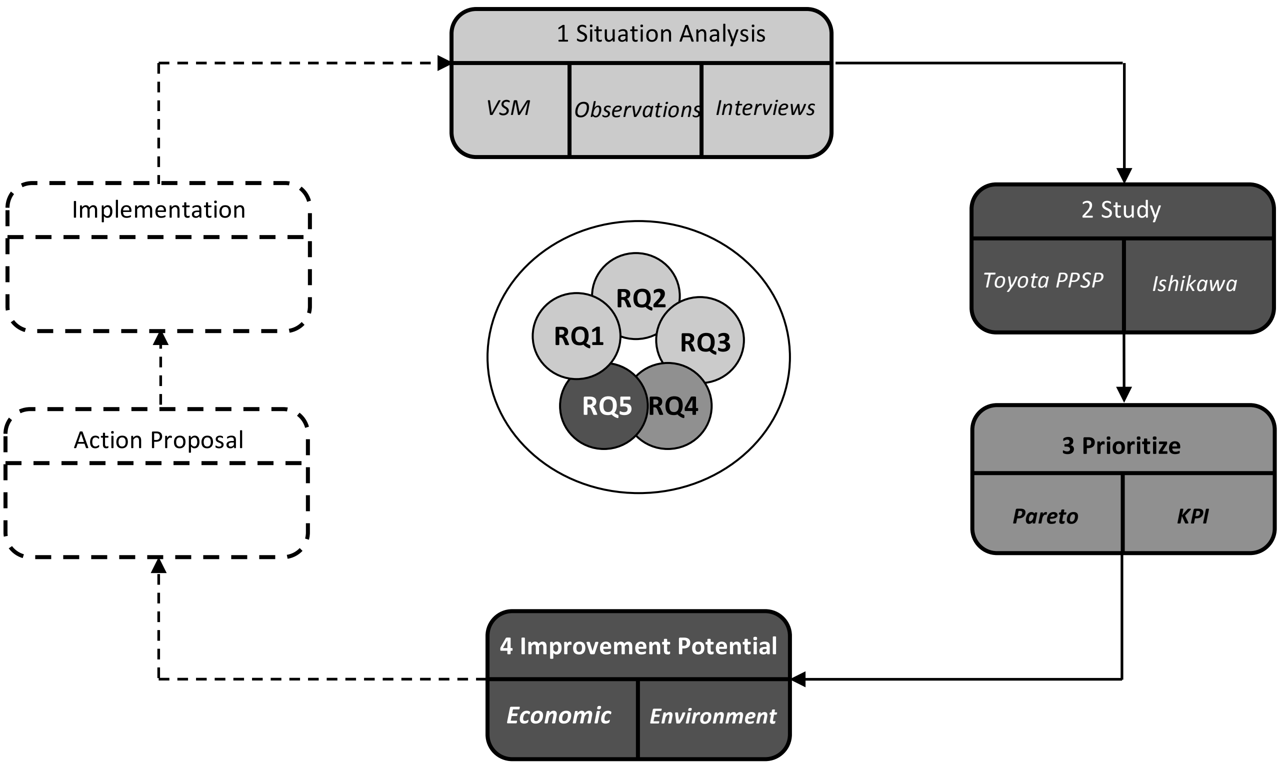


Figure 24 - The Lean Construction Tool

7.2 Validation Case

To validate the lean tool that has just been presented it was tried out on a construction process at a large size construction company based in Sweden. The first four steps of the Lean Construction Tool were carried out after the authors had followed a construction worker performing a painting process. The findings from this validation case are presented in the following sections.

7.2.1 Situation Analysis

A VSM was conducted with the mobile phone application StarBuilder and the result is being presented in Table 21. A dialogue was held with the construction worker about the different activities to give the authors better understanding about the construction process. The data that was collected showed that approximately 69% of the activities were value adding, 17% were non-value adding and 14% were necessary waste. This is being displayed in Figure 25.

Table 21 - VSM Data from the Validation Case

Company: Målericentralen	Date: 2011-05-24
Construction Site: Clarion Hotel Post	Observer: Arleroth & Kristensson
Value Flow: Construction Worker – Painter	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Picking up material	NVA	09:35:12	09:43:21	00:08:09
Material	Handling material	NVA	09:45:45	09:46:55	00:01:10
Construct	Filling the wall	VA	09:46:55	09:48:30	00:01:35
Other	Moving the lift	NW	09:48:30	09:48:59	00:00:29
Construct	Filling the wall	VA	09:48:59	09:52:03	00:03:04
Other	Moving the lift	NW	09:52:03	09:54:05	00:02:02
Construct	Filling the wall	VA	09:54:05	09:58:50	00:04:45
Other	Moving the lift	NW	09:58:50	09:59:13	00:00:23
Material	Moving buckets filled with putty	NVA	09:59:13	09:59:47	00:00:34
Construct	Filling the wall	VA	09:59:47	10:03:40	00:03:53
Other	Moving the lift	NW	10:03:40	10:04:08	00:00:28
Construct	Filling the wall	VA	10:04:08	10:07:27	00:03:19
Break	Taking of a sweater	NVA	10:07:27	10:07:50	00:00:23
Preparation	Mask the door molding with tape	NW	10:07:50	10:08:34	00:00:44
Construct	Filling the wall	VA	10:08:34	10:09:17	00:00:43
Other	Moving the lift	NW	10:09:17	10:09:42	00:00:25
Discussion	Problem solving	NW	10:09:42	10:10:44	00:01:02
Walk	Looking for buckets	NVA	10:10:44	10:12:40	00:01:56
Discussion	Calling boss cause the buckets cannot be found	NVA	10:12:40	10:13:28	00:00:48
Walk	Going back with two buckets	NVA	10:13:28	10:16:17	00:02:49
Other	Transporting the lift to a new room	NW	10:16:17	10:19:39	00:03:22
Construct	Filling the wall	VA	10:19:39	10:38:18	00:18:39
Other	Moving the lift	NW	10:38:18	10:40:03	00:01:45
Construct	Filling the wall	VA	10:40:03	10:45:11	00:05:08
Other	Moving the lift	NW	10:45:11	10:46:19	00:01:08
Construct	Filling the wall	VA	10:46:19	10:56:46	00:10:27
Other	Moving the lift	NW	10:56:46	10:57:46	00:01:00
Construct	Filling the wall	VA	10:57:46	11:01:05	00:03:19
Other	Moving the lift	NW	11:01:05	11:01:49	00:00:44
Construct	Filling the wall	VA	11:01:49	11:03:21	00:01:32
Discussion	Small talk	NVA	11:03:21	11:04:40	00:01:19
Construct	Filling the wall	VA	11:04:40	11:09:17	00:04:37

Other	Moving the lift	NW	11:09:17	11:10:05	00:00:48
Construct	Filling the wall	VA	11:10:05	11:16:21	00:06:16
Preparation	Scrape off excess material on the wall	NVA	11:16:21	11:16:56	00:00:35
Construct	Filling the wall	VA	11:16:56	11:19:13	00:02:17
Other	Moving the lift	NW	11:19:13	11:20:25	00:01:12
Construct	Filling the wall	VA	11:20:25	11:24:44	00:04:19
Material	Unpacking material	NW	11:24:44	11:25:18	00:00:34
Construct	Filling the wall	VA	11:25:18	11:27:21	00:02:03
Preparation	Scrape off excess material on the wall	NVA	11:27:21	11:28:22	00:01:01
Construct	Filling the wall	VA	11:28:22	11:36:36	00:08:14
Preparation	Moving material	NW	11:36:36	11:36:58	00:00:22
Construct	Filling the wall	VA	11:36:58	11:43:53	00:06:55
Other	Moving the lift	NW	11:43:53	11:46:00	00:02:07
Walk	Going for more material	NVA	11:46:00	11:46:58	00:00:58
Other	Moving the lift	NW	11:46:58	11:49:21	00:02:23
Construct	Filling the wall	VA	11:49:21	11:58:32	00:09:11
Other	Moving the lift	NW	11:58:32	11:59:57	00:01:25
Construct	Filling the wall	VA	11:59:57	12:03:26	00:03:29
Discussion	Problem solving	NW	12:03:26	12:04:01	00:00:35
Construct	Filling the wall	VA	12:04:01	12:14:35	00:10:34
Other	Moving the lift	NW	12:14:35	12:16:17	00:01:42
Construct	Filling the wall	VA	12:16:17	12:22:58	00:06:41
Other	Moving the lift	NW	12:22:58	12:23:45	00:00:47
Construct	Filling the wall	VA	12:23:45	12:26:17	00:02:32
Material	Gathering material and tools	NVA	12:26:17	12:28:15	00:01:58
Discuss	Small talk	NVA	12:28:15	12:33:01	00:04:46
Walk	Going on lunch	NVA	12:33:01	12:33:59	00:00:58
Wait	Waiting on elevator	NVA	12:33:59	12:34:06	00:00:07
Walk	Going on lunch	NVA	12:34:06	12:37:54	00:03:48
TOTAL					3:00:18

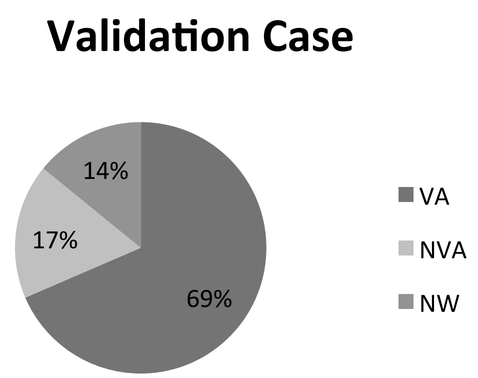


Figure 25 - Result of Validation Case

To finalize the first step of the Lean Construction Tool the different forms of waste that have been identified in the VSM are grouped according to the earlier mentioned construction site wastes. This can be seen in Figure 26.

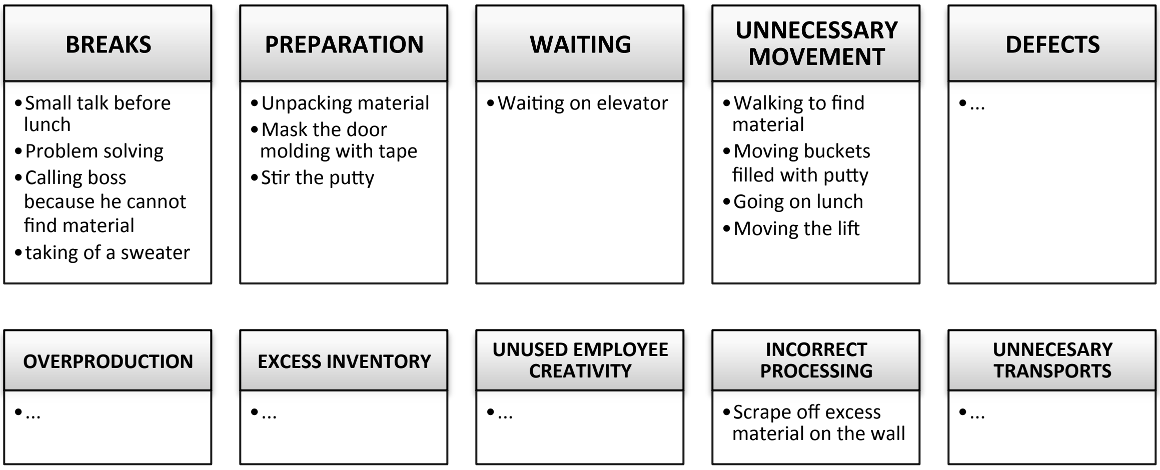


Figure 26 - Identification of NVA and NW in Validation Case

7.2.2 Study

The NVA and NW from the validation case should be analyzed in order to fully understand the situation; this is the second step of the Lean Construction Tool. The authors will exemplify this by doing a TPPSP for one of the identified problems from Figure 26 just to validate the functionality of the Lean Construction Tool.

8. **Initial problem perception**
    a. The construction worker cannot find the needed material
9. **Clarify the problem**
    a. The construction worker need more buckets filled with putty to precede his work. The manager informs the worker that the all buckets are located on another floor in a specific room and the worker goes to the right floor but cannot find the right room. The problem might be the manager's bad explanation, the workers inability to listen at instructions or that he is unfamiliar to the construction site. However, the real problem is that material is not located where it is needed.
10. **Locate Area/Point of Cause (POC)**.
    a. Material is not located where it is needed
11. **Investigation of Root Cause.**
    a. **Why** are the buckets not located where they are needed? – *They are; one pallet of buckets is located on every floor.*
    b. **Why** where there no buckets left on the floor they were working on? – *They were all used; it appears that too few had been ordered.*
    c. **Why** had too few buckets been ordered? – *The same amount of buckets per room had been ordered as usual.*
    d. **Why** was this amount of buckets not enough? – *More putty than usual had been used.*
    e. **Why** had they used more of the putty? – *Because they had been forced to redo some of their work since other construction workers had not communicated that they were not finished in some of the rooms causing damages on the already processed walls.* (In this sense it is "defects" that are causing the unnecessary walking around and moving material.)

12. **Countermeasure.**
    a. Suggestion: Improve the information sharing and communication between different types of construction workers, i.e. with morning meetings, checklists saying which rooms that are completely finished by other workers, etc.
13. **Evaluate.**
    a. This step has not been carried out for this situation since the countermeasure has not been implemented.
14. **Standardize.**
    a. This step has not been carried out for this situation since the countermeasure has not been implemented.

7.2.3 Prioritize

In order to prioritize, information about what factors affecting the project the most should be attained. In the validation case time was chosen as the most important factor since the customer is keen on having the project finished for the inauguration. A Pareto diagram was made to visualize which types of waste that have the greatest affect on time sensitive KPIs (See Figure 27). The types of waste identified were breaks, preparation, waiting, unnecessary movement and incorrect processing and these wastes all affects time in some way, making them all possible candidates. The figure can then be checked to see how the different types of waste affect KPIs other than those based on time, which may help in choosing.

After understanding how the different types of waste affect different KPIs it is recommended to analyze other factors that may affect the possible decision. How easy or difficult the waste is to reduce may influence, which depends on the root cause of the problem or how much value can be gained by making the change (value in this case being time). Breaks, waiting and unnecessary movement stood out since they are easier to remedy than preparation and incorrect processing which are more complex and dependent on the material and processes. Because the workers have not done any waste reduction previously it was assumed that attacking the three former types of waste would show greater effect compared to the effort put into reducing them.

In order to choose between the three remaining waste types two separate Pareto diagrams where constructed (see Figure 27 and Figure 28)They show that unnecessary movement is the waste that stands out, both in terms of time and frequency. Tackling unnecessary movement is therefore recommended as the number one waste to prioritize.

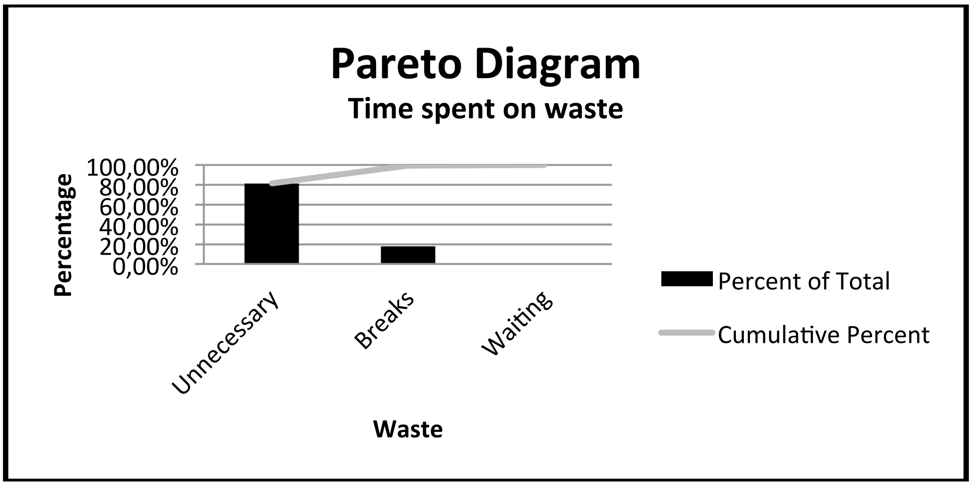


Figure 27 - Pareto Diagram Validation Case (time)

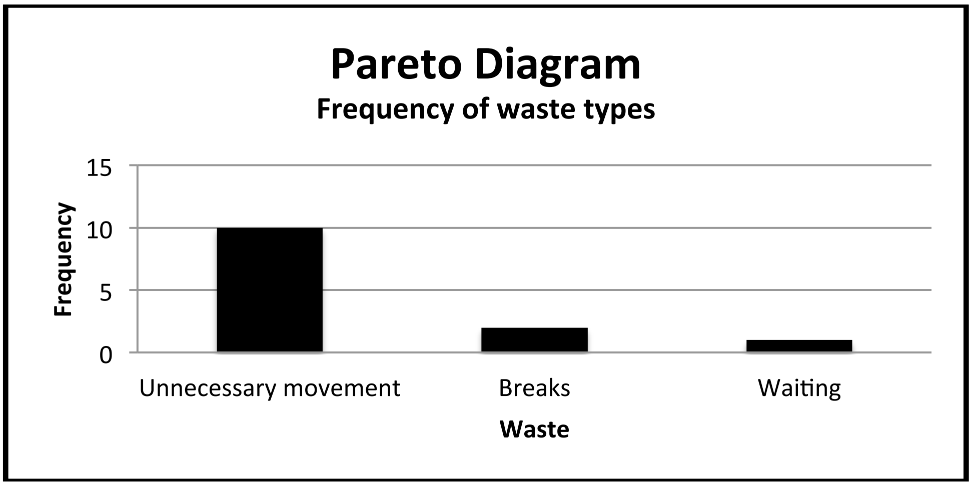


Figure 28 - Pareto Diagram Validation Case (frequency)

7.2.4 Improvement Potential

By considering the information that has been collected and processed through VSM, TPPSP, KPIs and Pareto diagrams qualified estimations and assumptions regarding the financial, the work environment and the environmental implications of an eventual waste reduction can be made. The estimations for this validation case are being presented in Table 22.

Since unnecessary movement stands for 23 minutes of the non-value added time and by reducing this waste by 25%, 5.75 minutes is saved. This time is 3.2% of the total time of work which was 180 minutes, meaning that 3.2% of the total time and therefore 3.2% of the labor cost can be saved. While 5.75 minutes may not seem like a great deal of time saved, 3.2% of the total project time can mean days or weeks.

Since the root cause of large part of this unnecessary movement was due to defects as was discovered in the TPPSP analysis. Those defects need to be reduced in order to decrease the unnecessary movement. This underlines the need to get to the root cause of the problem so that the right problem can be remedied. However, when focusing on unnecessary transports the possible economic and environment effects are shown in Table 22.

Table 22 - Economic and Environment Effects in the Validation Case

Economic	Environment
Time (PPC) – reducing unnecessary movement by 25% saves 5,75 minutes	Increased energy consumption from lift. Increases wear of lift battery
Cost – Reducing unnecessary movement by 25%(5,75 min) would decrease the cost of labor by 3,2%	Increased commitment (positive attitude and understanding for change projects)
Customer Satisfaction	Improved work environment (less mura, decreased psychological and physical stress, improved safety).

7.2.5 Key Learning from the Validation Case

The validation case showed that the Lean Construction Tool worked very well and could detect and visualize different kinds of waste within a construction process. The tools and methods that are incorporated in the Lean Construction Tool have therefore, after this validation case, been assumed to be highly functional for the purpose of the Lean Construction Tool.

All of the tools and methods in the Lean Construction Tool are not used during this validation case. It is not necessary for the user of the Lean Construction Tool to use all of the methods or tools either, but to use those that allow the user to obtain the information necessary to move to the next step and make necessary decisions. In the validation case the Ishikawa diagram was not used because it was assumed by the authors that the necessary information was obtained without using the method. With this opportunity to choose the most appropriate tool or method depending on the specific situation make the Lean Construction Tool rather flexible and user friendly.

Getting to the root cause was also found to be of great importance since one type of waste easily causes other problem. As in this validation case where the root cause of most parts of the unnecessary movement turned out to have been caused by defects.

8 Discussion, Recommendations, and Continued Research

This chapter includes a short discussion, recommendations and the authors' proposal for future research within the subject.

8.1 Discussion

It has been the authors' intention to keep the Lean Construction Tool, which is the final result of this thesis, as simple and understandable as possible in order to make it easier to use. The tool should in addition be seen as a first step in trying to find a suitable way for the implementation of lean construction and the lean philosophy in the construction industry.

Construction is a traditional industry and during the time studies and observations there were some negative comments towards the overall effort to try to make the workers work more efficient, "the material does not move itself". Some of the comments pointed toward their belief that there is just as much if not more to be done in the offices as there was out on site. That is true and when and if lean is implemented focus should be on the entire company not just the carpenters, electricians etc. Getting everyone aboard and having everyone approve of the implementation of lean will be a difficult task. During the time studies however, focus was on the workers who added direct value to the building.

When conducting time studies at a construction site there is the possibility of a discrepancy between the different researchers view on what is value adding, necessary waste or non-value adding. During the time studies questions arose concerning which category an action performed by a workers belonged to. This was however discussed prior to, during and after the times studies in order to ensure a unified view and minimize discrepancies and faults in the data between researchers. The same could be said for the researchers view compared to other researchers who have done time studies at construction sites. In comparison with another researcher who made a more comprehensive study, the amount non-value adding activity was very similar but there was a difference in value adding and necessary waste with the authors study showing much more value adding compared to the other survey. This shows that there may be more potential for increased efficiency than shown in this thesis.

When potential savings where shown, focus was on the cost of worker salary excluding material and machines. When and if workers jobs are done more efficiently there is a possibility that this may lead to an increase in the efficient use of material and machines too. This means that there may be, yet again, more potential for savings. For example, less material and less unnecessary use of machines will give environmental savings and if tools and machines could be handle with more care less break downs would occur which otherwise causing costly delays of the work. There are however difficulties in achieving these savings. Overcoming, or mitigating the effects of the construction peculiarities can be difficult. The industries ability to transfer knowledge, to change its mindset along with its willingness to change will greatly affect lean implementation and potential saving of such an implementation.

However, a more thorough validation and testing of the developed tool would perhaps improve and refine the tool further. If it had not been for resource constraints the authors would like to have tested the tool together with construction practitioners and managers at PEAB. Nevertheless, the tool has been explained and presented to this master's thesis supervisor at PEAB and her colleagues in order for them to communicate and pass it on within the organization.

Whether or not lean is suitable is something that has been discussed both in literature, among the authors themselves and during the interviews. The unanimous answer is yes, there is potential for savings and increased efficiency through the implementation of lean. There were however, both in the literature as well as in the interviews, different views on what parts of lean can be used within construction as well as literature discussing a few negative aspects of lean such as increased transports, frustrated workers and increased strain on workers.

8.2 Recommendations

The construction companies should open their eyes to the possibility for savings and increased efficiency in their operations. Companywide initiatives to introduce the lean perspective should be taken; it is not enough to send a few managers or crews to lean seminars. It needs to be a philosophy and way of working that eventually permeates the entire company. Otherwise the old way of working will continue to dominate and workers at sites will continue to put out fires rather than concentrating on planning and efficiently executing what they were all put there to do. The lean perspective also needs to affect company suppliers and subcontractors. A start is to stop focusing solely on price and start focusing on the total cost of different alternatives and working with different suppliers/subcontractors.

Additionally, the construction industry should realize the possibilities with logistics. Even though studies have mentioned potential monetary savings and that the construction companies themselves have noticed positive effects of having logistic managers at construction sites this is unusual to find. This is for the most of the time true unless the project is one of the largest and prestigious construction projects for the company. Therefore it would be recommended to start pondering if logistic managers should be used at smaller projects as well and not only at the largest ones.

Another recommendation is to start working more closely with subcontractors and suppliers in order to redefine and refine processes. This can only be done if one works with the same supplier again and again and again. If the same people work in a group, on a number of projects together, they will eventually get better and continuously improve their team work. A better dialogue and team work should also be held between different kinds of construction workers and firms in order to avoid situations such as tearing down walls because pipes have not yet been installed.

It is highly recommended that all actors involved in construction projects put extra effort in keeping track of tools and material. Structure the tool shed, clean up the inventory and sustain a clean and tidy work place since this will reduce the time being spent on walking around searching for things and initiating unnecessary small talk with colleagues. In addition, the management should consider paying the extra money for having material put in place for the construction workers so they do not have to transport and move the material themselves. The return on this investment would probably be much greater than the money spent from the beginning since the likelihood of keeping the time schedule would increase and perhaps a reduction of lead time might be achieved.

The proposed Lean Construction Tool is supposed to act as an eye opener and a first step towards more efficient processes and continuous improvements. It is about getting a more in-depth understanding of the processes and interactions between these processes that cause the complexity and uncertainty that plague the construction industry. Ultimately this could lead to increased profitability, quality and environmental performance both in terms of emissions and work environment. In that sense it is recommended that construction workers should be informed about the costly construction site wastes that were earlier described. If the people at the sites start to realize that a lot of their time is wasted on walking and searching for tools/material/colleagues they might come with suggestions on how to avoid wasting time on these kinds of things. Let the construction workers take part of the improvement work.

Furthermore, it is recommended that KPIs of some sort are developed in order to facilitate performance evaluation and to visualize performance affects of changes to the work processes. What these KPIs should measure is something that the organizations themselves need to find out by examines what is most important for them to improve in terms of customer value. If a construction company wants to profile themselves as an environmental friendly company they should probably put in extra effort on KPIs measuring just their environmental impact. Measuring is a key aspect in lean and continuous improvement. Starting off, these KPIs can be used for internal benchmarking but eventually they can be used for benchmarking with external organizations too.

When the lean transformation is under way knowledge management becomes increasingly important. A system to catch and utilize best practice and the good ideas developed at different construction sites is necessary to continue improving. Meetings between different actors from the whole industry (involving both management and workers) to share experience, ideas and knowledge is a great way to make people aware of the existence of waste. It is first when problems are exposed as the need for countermeasures will come thus improvement can be made. Therefore, what the authors would like to see in a not too distant future is a willingness to change and attempts to permeate the lean thinking in the whole organization and industry. Start with small steps and it will suddenly be apparent that with many small steps a long distance can be overcome.

8.3 Future Research

The developed tool is not complete; two steps still need to be developed in order to close the loop, which then needs to be validated as a whole. More research is needed to understand the effects of the by literature proposed lean construction aspects on the industry and if they need to be adapted to the Swedish construction industry. There could perhaps be other parts of lean manufacturing and the lean philosophy that may be able help the industry develop as well.

A more in-depth VSM of the processes at a construction site as well as in other parts of the organization could shed even more light on the mechanism behind the inefficient construction industry. Furthermore, other resource flows but construction workers can be followed, for example material such as pipes or drywalls.

Further research is also needed to specify what types of KPIs can be effective to use in the construction industry as well as how these KPIs can best be used. This needs to be pondered upon if the industry would like to continuously improve and develop. Without KPIs as guidelines it will be difficult for a company to head for the right direction and know what to expect of the future.

9 Conclusion

The industry struggles with inefficient processes leaving much to be desired. In order to meet this challenge the construction industry must become more efficient by using fewer resources. Small changes in the operational costs by reducing waste, which improves the efficiency, can make substantially changes in profit.

Previous researchers have identified the problems of how the industry works today and pointed to possible solutions by using the lean philosophy and tools along with solutions that are part of what is known as lean construction. There has however, been relatively little research on case studies, research based on quantitative data or research making categorization of the types of waste that exist in construction. In order to help bridge this cap, this thesis' academic contribution is to categorize waste in construction according to classifications more adapted to the construction industry rather than the generic waste categories originally developed from manufacturing. The new categorization of waste is called construction waste, where two new categories of waste, "Preparation" and "Breaks", were added. In the VSM studies these two categories contributed a great deal to non-value adding work and necessary waste. This new categorization helps understand the main drivers of waste in the construction industry.

In addition, this thesis practical contribution aimed to be, by posing five research questions, to design a Lean Construction Tool by using a lean thinking approach and applying and adapting lean tools to the construction industry. This Lean Construction Tool explains how to identify and measure waste through the use of a value stream mapping tool, interviews and observations. To fully understand the reason behind the waste, the tool recommends that Toyota's Practical Problem-Solving Process and/or an Ishikawa diagram is used to study the waste. Furthermore, the Lean Construction Tool aims to guide in what order waste should be reduced by suggesting the use of a Pareto Analysis and/or looking into appropriate KPIs which are useful in measuring the waste as well. By performing these just mentioned activities, estimations of economical and environmental consequences can be made. This will give the construction companies the possibility to work out countermeasures for the wastes in the form of an action proposal plan that will later be implemented.

By using this Lean Construction Tool a company can gain a better understanding of the kinds of waste that exist in their construction processes. Furthermore, the tool can help companies to decide where change needs to begin by getting to the root cause of the problem thus facilitating prioritization of problem and avoiding sub-optimization. This could lead to improved efficiency of construction activities resulting in lower operational costs, increased profit margin and reduced environmental damages.

A part of the Lean Construction Tool is to conduct VSM studies which was done by the authors and proved to be a simple and powerful tool to use in the construction industry. These VSMs showed the inefficiency in the industry where value-added work was approximately 44% of the workers time. This has financial implications not only for the each individual project but also for the industry as a whole and the entire national economy. If 40% of the work at a construction site is labeled as value-adding this translated to 15% of the projects costs is wasted. It also affects the GDP as well since the construction industry in countries like Sweden and the UK stand for 10% of the GDP. This would mean that roughly 2% of the Swedish GDP is waste from the construction industry. Even though all of that waste cannot be eliminated it shows that there is potential in trying to tackle construction waste. Increasing the value-adding work from 40% to 45% will save 1.25% on the project cost. It may not sound like a great deal but in monetary terms it is and 1.25% for the entire industry would be a large improvement.

The Lean Construction Tool was validated in a test case and it turned out that the tool worked well. In the validation case the Lean Construction Tool guided how to perform a situation analysis, finding underlying reason behind waste, make prioritization and facilitated estimations of potential consequences of waste reductions. This indicates that tools and methods from lean production/manufacturing can be successfully applied and adopted to the construction industry.

The authors have filled a part of the identified gap but there are still parts that need more research in order to fully remove the gap. More quantitative data is needed as well as metrics to facilitate continuous improvements and benchmarking within the industry.

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Appendix A – Literature Summary

	Lean (Toyota Production System, Lean manufacturing, lean produoction)	Lean Construction	Techniques/Tools/Methods (for waste reduction, root casuse analysis, problem solving etc.)	Lean in service, healthcare, retail, insurance, etc	Construction Industry	Project Management	Performance Indicators
LEAN LITERATURE							
Allway and Corbett, 2002. *Shifting to lean service: Stealing a page from manufacturers's playbook*				X			
Black and Miller, 2008. *The Toyotya Way to healthcare excellence*				X			
Gordon, 2001. *Lean and Green: Profit for the workplace and the environment*	X						
Graban, 2008. *Lean Hospitals - Improving Quality, Patient Safety and Employee Satisfaction*				X			
Hines, Holwe and Rich, 2004. *Learning to evolve - a review of contemporary lean thinking*	X						
King and Lenox, 2001. *Lean and Green? An empirical examination of the relationship between lean production and environmental performance*	X						
Krafcik, 1988. *Triumph of the lean production system*	X						
Liker and Meier, 2005. *The Toyota Way Fieldbook*			X				
Liker, 2004. *The Toyota Way*	X		X				
Monden, 1993. *Toyota Production System: An integrated approach to Just-In-Time*	X		X				
Ohno, 1988. *Toyota Production System: Beyond Large-Scale Production*	X						
Qui and Chen, 2009. *Evaluate the environmental impacts of implementing lean in production process of manufacturing industry*	X		X				
Rother and Shook, 2003. *Learning to See: value stream mapping to create value and eliminate muda*			X				
Rother, 2010. *Lean Kata - managing people for improvement, adaptiveness, and superior results*	X		X				
Shingo, 1989. *A study of the Toyota Production System*	X		X				
Slomp, Bokhorst and Germs, 2009. *A lean production control system for high-variety/low-volume environments: a case study implementation*				X			
Sobek and Jimmerson, 2004. *A3 report: tool for process improvement*			X	X			

Spear, 2005. *Fixing Healthcare from the Inside, Today*				**X**			
Swank, 2003. *The Lean Service Machine*				**X**			
Wang, 2011. *Lean Manufacturing, business bottom – line based*	**X**						
Womack and Jones, 2005. *Lean Consumption*				**X**			
Womack *et al.,* 1990. *The Machine that changed the World*	**X**		**X**				
CONSTRUCTION LITERATURE							
Akintoye, 2005. *Just-in-time application and implementation for building material management*		**X**	**X**				
Andersson and Ohlsson, 2007. *Förbättringspotential för inköpsstrukturen I byggbranschen*					**X**		
Arditi and Mochtar, 2000. *Trends in productivity improvement in the US construction industry*					**X**	**X**	
Ballard and Howell, 1998. *Shielding Production: Essential Step in Production Control*		**X**				**X**	
Department of the Environment, Transport and the Regions, 1998. *Rethinking Construction*		**X**			**X**		
Department of the Environment, Transport and the Regions, 2000. *KPI Report for the Minister for Construction*					**X**		
Dolio, 2008. *Application of AHP in improving construction productivity from a management perspective*		**X**					
Gadde and Dubois, 2002. *The construction industry as a loosely coupled system: implications for productivity and innovation*					**X**		
Hatmoko and Scott, 2010. *Simulating the impact of supply chain management practice on the performance of medium-sized building projects*					**X**		
Jörgensen and Emmit, 2008. *Lost in transition: the transfer of lean manufacturing to construction*		**X**					
Josephson and Saukkoriipi, 2005. *Slöseri i byggprojekt: Behov av förändrat synsätt*					**X**		
Josephson and Saukkoriippi, 2009*. 31 rekommendationer för ökad lönsamhet I byggandet – Att minska slöseriet!*					**X**		
Kagioglou and Cooper, 2001. *Performance management in construction: a conceptual framework*							**X**
Koskela and Huovila, 1997. *On foundations of concurrent engineering*		**X**					
Lai and Lam, 2010. *Perception of various performance criteria by stakeholders in the construction sector in Hong Kong*					**X**		**X**
Love and Li, 2000. *Quantifying the causes and costs of rework in construction*					**X**		**X**
Lutz and Gabrielsson, 2002. *Byggkommissionen – Byggsektorns struktur och utvecklingsbehov*					**X**		
Nam and Tatum, 1988. *Major characteristic of constructed products and resulting limitations of construction technology*					**X**		
Packham *et al*., 2003. *Partnering in the house building sector: a subcontractor's view*		**X**					
Polat and Arditi, 2005. *The JIT materials management system in developing countries*			**X**		**X**		
Smyth, 2010. *Construction industry performance improvement programmes: the UK case of demonstration projects in the "Continuous Improvement" programme*					**X**		**X**
Stewart and Spencer, 2006. *Six-sigma as a strategy for process improvement on construction projects: a case study*			**X**		**X**		

Sumardi and Anaman, 2004. *Aggregated efficiency analysis of resource use and demand for labour by the construction industry in Brunei Darussalam*					X		
Thomas *et al.*, 2003. *Improving labor flow reliability for better productivity as lean construction principle*		X	X				
Vrijhoef and Koskela, 2000. *The four roles of supply chain management in construction*					X		
Warszawski, 1990. *Industrialization and Robotics in Buildings: A Managerial Approach*					X		
Winch and Carr, 2000. *Processes, maps and protocols: understanding the shape of the construction process*			X		X		X
Winch, 1987. *The construction firm and the construction process: the allocation of resources to the construction project.*					X		
LEAN CONSTRUCTION LITERATURE							
Arbulu, Ballard and Harper, 2003. *Kanban in Construction*		X	X				
Ballard, 2000. *The last planner system of production control*			X				
Elfving, 2010. *Lean construction - case Skanska*		X					
Eriksson, 2010. *Improving construction supply chain collaboration and performance: a lean construction pilot project*		X					
Green and May, 2005. *Lean construction: arenas of enactment, models of diffusion and the meaning of 'leanness'*		X					
Green, 1999. *The Dark Side of Lean Construction: Exploitation and Ideology*		X					
Howell and Ballard, 1999. *Bringing Light to The Dark Side of Lean Construction: A Response to Stuart Green*		X					
Koskela, 1992. *Application of the new production philosophy to construction*		X	X				
Koskela, 1999. *Management of production in construction: A theoretical view*		X					
Lean Construction Institute, 2007. *Lean Construction Institute: What is Lean Construction*		X					
Marosszeky *et al.*, 2002. *Quality Management Tools for Lean Production:From Enforcement to Empowerment*		X					
Salem *et al.*, 2006. *Lean Construction: from theory to implementation*		X	X				
Saurin *et al.*, 2002. *Safety and production: an integrated planning and control model.*						X	
Soward, 2008. *Lean Construction: New tools and old combine to reduce waste*		X	X				
OTHER LITERATURE							
Atkinson, 1999. *Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria*						X	X
Bankvall *et al.*, 2010. *Interdependence in supply chains and projects in construction*					X		
Bicheno, 1991. *34 for Quality*			X			X	
British Quality Foundation, 2010. *EFQM Excellend Model*							X
Capper, 1998. *A Project-to-Project Approach to Quality*						X	
Chakravorty, 2009. *Process Improvement: Using Toyota's A3 Reports*			X				
Chan and Chan, 2004. *Key performance indicators for measuring construction success*							X

Clary and Wandersee, 2010. *Fishbone Diagrams: Organize Reading Content with a "Bare Bones" Strategy*						X	
Condel *et al.*, 2004. *Error-free pathology: applying lean production methods to anatomic pathodology*				X			
Ferdows, MacHuca and Lewis, 2004. *Rapid-Fire Fulfillment*				X			
Freeman and Beale, 1992. *Measuring Project Success*							X
Gaupta, 2005. *The Six Sigma Performance Handbook*			X			X	
Hannagan, 2008. *Management: Concepts & Practices*			X				
Hines and Rich, 1997. *The seven value stream mapping tools*			X				
Lasa, Laburu and la Casa Vila, 2008. *An evaluation of the value stream mapping tool*			X				
Li and Yang, 2003. *A decision model for self-assessment of business process based on the EFQM excellence model*							X
Li *et al.,* 2009. *Rethinking project management and exploring virtual design and construction as a potential solution*				X	X	X	
Lichtig, 2005. *Ten Key Decisions to a Successful Construction Project - Choosing Something New: The Integrated Agreement for Lean Project Delivery*	X	X			X		
Modig, 2004. *The Impact of Project characteristics on Temporary Logistics Solutions*					X		
Nicholas, 2001. *Project management for business and technology: principles and practice*						X	
Olsson, 2000. *Supply chain management in the construction industry*					X		
Paez *et al*., 2005. *Moving from Lean manufacturing to Lean Construction: Toward a common Socio-technological Framework*		X					
Pinto and Pinto, 1991. *Determinants of cross-functional cooperation in the project implementation process*						X	X
Shim and Siegel, 1999. *Operations Management*						X	
Statistics Sweden, 2011. *Consumer Price Index (CPI)*					X		
Swedish Agency for Public Management, 2009. *Still No Better Boys? A Follow-up of the Building Industry Commission's 2002 report ("You can do better, boys!") (2009:6)*					X		

Appendix B - Case Study Protocol

Interview – Company **Lead Interview:**
Respondent: **Taking Notes:**
Position: **Date:**

Introduction:
- Inform the respondent about what the interviewers are studying
- Objectives with the interview: See Appendix A.3
- Explain how the interview is going to be executed

<u>QUESTIONAIRE</u>
Background Information:
- What is your field of expertise?
- What kind of earlier work or academically experiences do you possess?
- Have you carried out any projects in the construction industry?
- Have you any experience on construction sites?

RQ1 – What type of waste can be identified in construction operations?
- Is it generally difficult to see if an activity is value-adding or not for a project?
- What would value-adding activities look like from a customer perspective?
- What different forms of waste can you imagine that exist on a building site?

RQ2 – How can waste be identified?
- Have you any experience of improvement work?
- What tools and methods can be useful for identifying waste in an organization
- What kind of tools and methods can be appropriate specifically for the construction industry?
- How can these tools and methods be standardized and applied within the construction industry?

RQ3 – How can the identified waste be measured?
- How have you worked with the measurability of results of previous projects?
- How were the metrics chosen and what was the result?
- How is the result visualized?
- What metrics can be appropriate to measure waste?
- What kind of KPIs can be useful for analyzing a construction site?

RQ4 – How is one to decide in what order to reduce waste?
- Who determines in what order the waste reduction is prioritized?
- How do you determine what problem to deal with first?
- Is there a way to determine how difficult a problem is to solve?
- Do you use a method to assure that local optimization is avoided?

RQ5 - What potential effects could a lean approach have on a construction site?
- What kind of consequences might waste reduction result in?
- Would the benefits of a waste elimination approach overrun the efforts needed?

Appendix C – Overview Interviews

			Construction P. 1	Construction P. 2	Construction P. 3	Lean Expert 1	Lean Expert 2	Lean Expert 3	C.Academic 1	C. Academic 2	C. Academic 3
RQ1	1.1	Is it generally difficult to see if an activity is value-adding or not in a project?	X	X	X	X	X	X	X	X	X
	1.2	What would value-adding activities look like from a customer perspective?	X	X	X	X	X	X	X	X	X
	1.3	What different forms of waste can you imagine that exist on a building site?	X	X	X	X	X	X	X	X	X
RQ2	2.1	Have you any experience of improvement work?	X	X	X	X		X	X	X	
	2.2	What tools and methods can be useful for identifying waste in an organization?	X	X	X	X	X	X	X	X	X
	2.3	What kind of tools and methods can be appropriate specifically for the construction industry?		X	X	X	X	X	X	X	X
	2.4	How can these tools and methods be standardized and applied within the construction industry?	X	X	X	X	X	X		X	X
RQ3	3.1	How have you worked with the measurability of results of previous projects?	X	X	X	X		X	X	X	
	3.2	How were the metrics chosen and what was the result?				X	X		X	X	X
	3.3	How is the result visualized?	X			X	X	X			X
	3.4	What metrics can be appropriate to measure waste?	X	X	X	X	X	X		X	X
	3.5	What kind of KPIs can be useful for analyzing a construction site?	X	X	X	X	X	X	X	X	X
RQ4	4.1	Who determines in what order the waste reduction is prioritized?	X	X	X		X			X	X
	4.2	How do you determine what problem to deal with first?	X	X	X	X	X	X	X	X	X
	4.3	Is there a way to determine on what level to solve the problem or how deep into the causes to go?	X			X	X			X	
	4.4	Do you use a method to assure that local optimization is avoided?	X	X	X	X	X	X	X	X	X
RQ5	5.1	What kind of consequences might waste reduction result in?	X	X	X	X	X	X	X	X	X
	5.2	Would the benefits of a waste elimination approach overrun the efforts needed?	X	X	X	X	X	X	X	X	X

[x] = Responded
[o] = Not able to respond
[ ] = Question not asked

Appendix D – Interviews

In this section a brief description of the nine interviewees will be given, including information about their academically background and working experience. This is of importance in order to increase the understanding for what they have based their answers on when answering the interview questions.

Appendix D.1 – Interviews Construction Industry Practitioners

Appendix D.1.1 – Interview Construction Practitioner 1

Date of interview: *2011-03-23*
Lead interviewer: *Arleroth, Jens*
Taking notes: *Kristensson, Henrik*

Description:

The person has worked earlier within the hotel market and tourism but changed field after had studying a two year long KY-education within "Purchasing" and "Supply Chain". After an internship at one of the largest construction companies in Sweden the person was hired by the same company. The person is now the logistic manager at one of the company's, for the moment, largest projects.

Objectives with the interview:

The overall objective of the interview was to get the Construction Industry Practitioner's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how the Construction Practitioner depicts their own industry in terms of efficiency and change averse and later compare their perspective with the perspective of non-construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.1.2 – Interview Construction Practitioner 2

Date of interview: *2011-03-25*
Lead interviewer: *Arleroth, Jens*
Taking notes: *Kristensson, Henrik*

Description:

The person study three years at a Swedish University and has a bachelor degree in Construction Engineering. The person thesis concerned unnecessary work operations at construction sites. This person is today employed as a Construction Foreman for a lean construction project at one of largest construction companies in Sweden.

Objectives with the interview:

The overall objective of the interview was to get the Construction Industry Practitioner's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how the Construction Practitioner depicts their own industry in terms of efficiency and change averse and later compare their perspective with the perspective of non-construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.1.3 – Interview Construction Practitioner 3

Date of interview: *2011-03-25*
Lead interviewer: *Arleroth, Jens*
Taking notes: *Kristensson, Henrik*

Description:
The person has a background as a carpenter but has since 1987 worked as a Site Manager for one of the largest construction companies in Sweden. With many years experience of the construction field the person is now involved in his first project where all the construction workers have participated in lean courses.

Objectives with the interview:
The overall objective of the interview was to get the Construction Industry Practitioner's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how the Construction Practitioner depicts their own industry in terms of efficiency and change averse and later compare their perspective with the perspective of non-construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.2 – Interviews Lean Experts

Appendix D.2.1 – Interview Lean Expert 1

Date of interview: *2011-03-23*
Lead interviewer: *Arleroth, Jens*
Taking notes: *Kristensson, Henrik*

Description:
Is a senior lecturer and researcher at the division of Logistics and Transportation, Department of Technology Management and Economics at a Swedish University. This person's research is focused on manufacturing planning and control, materials supply systems and lean production. Much focus has been on lean since 2001 when cooperation with Japanese researchers started which has resulted in several visits of the Japanese industry. The person has acted as a coach for different industries within the field of the person's expertise.

Objectives with the interview:
The overall objective of the interview was to get the Lean Expert's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person standing outside the construction industry with theoretical and practical experience in lean depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.2.2 – Interview Lean Expert 2

Date of interview: *2011-04-04 and 2011-04-08*
Lead interviewer: *Kristensson, Henrik*
Taking notes: *Arleroth, Jens*

Description:
This person is a Swedish entrepreneur and researcher in the Build Environment. The research has been conducted at a Swedish University with a focus on efficiency issues in the construction industry. The person is today the CEO of a company that is a specialist in business development for community building and has also been a columnist for the construction industry newspaper "Byggindustri" for some years.

Objectives with the interview:
The overall objective of the interview was to get the Lean Expert's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person standing outside the construction industry with theoretical and practical experience in lean depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.2.3 – Interview Lean Expert 3

Date of interview: *2011-04-21*
Lead interviewer: *Kristensson, Henrik*
Taking notes: *Kristensson, Henrik*

Description:
Lean Expert 3 has a history as portfolio director at a large company in the automotive industry. As of 2000 he has been working with 'Produktionslyftet' and 'Leanforum Bygg'. He has over the years gained a great deal of experience in lean and effective construction and through several visits to Japan has seen the possibilities of lean construction.

Objectives with the interview:
The overall objective of the interview was to get the Lean Expert's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person standing outside the construction industry with theoretical and practical experience in lean depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.3 – Interviews Construction Academics

Appendix D.3.1 – Interview Construction Academic 1

Date of interview: *2011-03-24*
Lead interviewer: *Kristensson, Henrik*
Taking notes: *Arleroth, Jens*

Description:
The person is a professor in Building Economics at the division of Construction Management at a Swedish University and has current studies within the fields of: waste in building projects, learning capability in building projects, performance measurement from a customer perspective, project leadership and coaching, and measuring poor quality costs in construction companies.

Objectives with the interview:
The overall objective of the interview was to get the Construction Academic's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person with more advanced academic credentials depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.3.2 – Interview Construction Academic 2

Date of interview: *2011-03-28*
Lead interviewer: *Kristensson, Henrik*
Taking notes: *Arleroth, Jens*

Description:
The interview subject studied at a Swedish University for five years taking a masters degree in Civil Engineering. The person's thesis was a case study of value added resources in the brief and design stage. This person is today as an industry PhD student at the same Swedish University and employed by one of Sweden's largest construction companies.

Objectives with the interview:
The overall objective of the interview was to get the Construction Academic's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person with more advanced academic credentials depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix D.3.3 – Interview Construction Academic 3

Date of interview: *2011-03-30*
Lead interviewer: *Arleroth, Jens*
Taking notes: *Kristensson, Henrik*

Description:
The person is today a consultant at an analytic and technology company that provides consulting services for sustainable development in houses & industry, transport & infrastructure and environment & energy. The person has a history both in construction and as a PhD student. This person has a doctorate from a Swedish University. This person worked at one of the largest construction companies in Sweden developing alternative logistics solutions for the construction industry as well as project development.

Objectives with the interview:
The overall objective of the interview was to get the Construction Academic's perspective of waste in internal construction operations. The gathered data was later compared to the data collected during the theoretical study in order to pin point similarities, differences and if there exist knowledge gaps in any of the different groups. Furthermore, another objective behind the interview was to hear how a person with more advanced academic credentials depicts and views the construction industry in terms of efficiency and change averseness. This perspective was later compared with the perspective of other non-construction practitioners and construction practitioners. The collected data from the interview is a part of the whole set of data, which will, in the end, answer the five RQs in this master's thesis.

Appendix E – Six Lean Principles

Lean-related aspects implemented in the pilot project by Eriksson (2010)

Core Elements	Aspects	Lean Stages
Waste Reduction	Housekeeping[b]	Stage 1[b]
	Just in Time Deliveries[d]	Stage 1[d]
	Joint IT Tools[d]	Stage 3[d]
	Prefabrication[d]	Stage 3[d]
Process focus	Last planner[e]	Stage 3[e]
	Self control[c]	Stage 3[c]
	Milestones[a]	Stage 1[a]
End customer focus	Concurrent engineering[a]	Stage 3[a]
	LImited bid invitation[a]	Stages 2+3[a]
	Soft parameters in bid evaluation[a]	Stages 2+3[a]
Continuous improvements	Long-term contracts[b]	Stages 2+3[b]
	Performance indicators[a]	Stage 1[a]
	Special interest groups[e]	Stage 3[e]
	Training[c]	Stage 3[c]
	Suggestions from workers[c]	Stage3
Cooperative Relationships	Broad partnering team[a]	Stage 2[a]
	Collaborative tools[a]	Stage 2[a]
	Share gain/pain[a]	Stage 1[a]
System perspective	Coherent procurement decisions[a]	Stage 3[a]
	Large scope contracts[c]	Stage 3[a]
	Properly balanced objectives[b]	Stage 3[b]

Notes: [a]Aspects that were explicitly used to a large extent; [b]aspects that were implicitly used to a large extent; [c]aspects that were explicitly used to some extent; [d]aspects that were implicitly used to some extent; and [e]aspects that were not used at all

"The four aspects related to Stage 1 were utilized in the project to a fairly large extent. Milestones and the gain share/ pain share arrangement were explicit strategies, whereas housekeeping and just-in-time deliveries were used more implicitly. This finding is in line with the earlier argument that Lean Stage 1 is the default that is performed in many efficient construction projects, although they do not involve explicit lean thinking. Also the aspects related to Stage 2 were explicitly utilized to a large extent in order to establish cooperative relationships among the supply chain actors, which was the explicit aim of the pilot project. The aspects related to Stage 3 were used to a lower extent, for which reason there is still a long way to go in order to obtain full- fledged lean construction."

Appendix F - KPI

Appendix F.1 – Construction KPIs

The KPI levels and their associated indicators are shown in the table below (Department of the Environment, Transport and the Regions, 2000). The definitions for the different levels are given in section Appendix C.2.

Group	Indicators	Level
Time	1. Time for Construction 2. Time Predictability – Design 3. Time Predictability – Construction 4. Time Predictability – Design & Construction 5. Time Predictability – Construction (Client Change Orders) 6. Time Predictability – Construction (Project Leader Change Orders) 7. Time to Rectify Defects	Headline Headline Headline Operational Diagnostic Diagnostic Operational
Cost	1. Cost for Construction 2. Cost Predictability – Design 3. Cost Predictability – Construction 4. Cost Predictability – Design and Construction 5. Cost Predictability – Construction (Client Change Orders) 6. Cost Predictability – Construction (Project Leader Change Orders) 7. Cost of Rectifying Defects 8. Cost In Use	Headline Headline Headline Operational Diagnostic Diagnostic Operational Operational
Quality	1. Defects 2. Quality Issues at Available for Use 3. Quality Issues at End of Defect Rectification Period	Headline Operational Operational
Client Satisfaction	1. Client Satisfaction Product – Standard Criteria 2. Client Satisfaction Service – Standard Criteria 3. Client Satisfaction – Client-Specified Criteria	Headline Headline Operational
Change Orders	1. Change Orders – Client 2. Change Orders – Project Manager	Diagnostic Diagnostic
Business Performance	1. Profitability (company) 2. Productivity (company) 3. Return on Capital employed (company) 4. Return on Value Added (company) 5. Interest Cover (company) 6. Return on Investment (client) 7. Profit Predictability (project) 8. Ratio of Value Added (company) 9. Repeat Business (company) 10. Outstanding Money (project) 11. Time taken to reach Final Account (project)	Headline Headline Operational Operational Operational Operational Operational Diagnostic Diagnostic Diagnostic Diagnostic
Health and Safety	1. Reportable Accidents (inc fatalities) 2. Reportable Accidents (non-fatal) 3. Lost Time Accidents 4. Fatalities	Headline Operational Operational Operational

Appendix F.2 – Definition of KPI Levels

Definition of KPI Levels (Department of the Environment, Transport and the Regions, 2000)

	Level	Definition
1	Headline Indicators	Provide a measure of the overall, rude state of health of a firm
2	Operational Indicators	Operational Indicators – bear on specific aspects of a firm's activities and should enable management to identify and focus on specific areas for improvement
3	Diagnostic Indicators	Diagnostic Indicators – provide information on why certain changes may have occurred in the headline or operational indicators and are useful in analyzing areas for improvement in more detail

Appendix G – Value Stream Mapping Observation Protocol

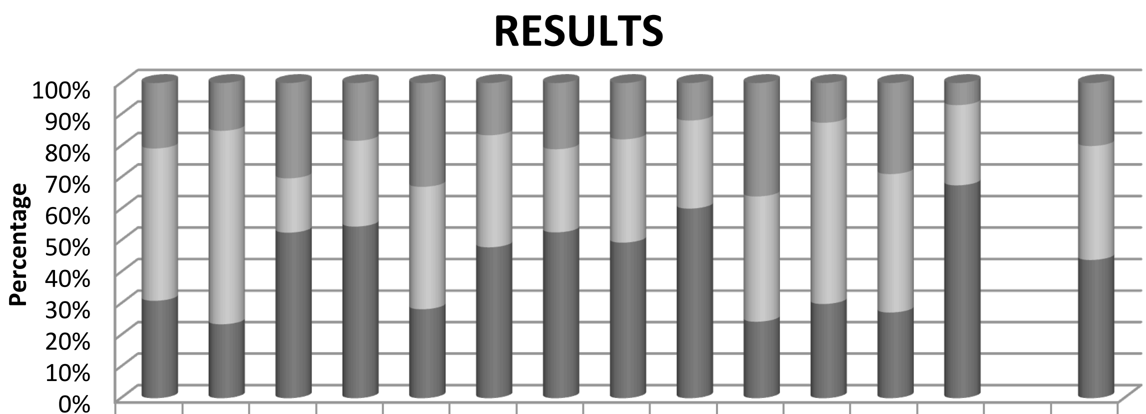
Company:	Date:
Construction Site:	Observer:
Value Flow:	Page:

Activity (A, B, C, D, M, W)	Description	Classification	Start	End	Duration

Appendix H – Value Stream Mapping Data Collection

Appendix H.1 – Summary

		VA		NVA		NW		TOTAL	
		Time	Percentage	Time	Percentage	Time	Percentage	Time	Percentage
½ Day	Pipe1	01:04:36	30,91%	01:41:00	48,33%	00:43:24	20,77%	03:29:00	100%
	Vent1	00:18:59	23,45%	00:49:42	61,40%	00:12:16	15,15%	01:20:57	100%
	Brick1	00:58:47	52,52%	00:19:17	17,23%	00:33:51	30,25%	01:51:55	100%
	Wall1	01:26:59	54,46%	00:43:27	27,20%	00:29:17	18,33%	02:39:43	100%
1 Day	Pipe2	01:38:18	28,22%	02:15:16	38,84%	01:54:43	32,94%	05:48:17	100%
	Pipe3	02:50:01	47,88%	02:06:16	35,56%	00:58:50	16,57%	05:55:07	100%
	Brick2	02:57:13	52,62%	01:28:51	26,38%	01:10:45	21,01%	05:36:49	100%
	Wall2	02:23:25	49,37%	01:35:10	32,76%	00:51:54	17,87%	04:50:29	100%
	Wall3	03:00:10	60,17%	01:23:40	27,94%	00:35:37	11,89%	04:59:27	100%
	Weld1	00:47:15	24,27%	01:17:21	39,73%	01:10:04	35,99%	03:14:40	100%
	Weld2	01:24:03	29,90%	02:41:40	57,51%	00:35:24	12,59%	04:41:07	100%
	Weld3	01:17:16	27,19%	02:04:49	43,92%	01:22:06	28,89%	04:44:11	100%
	Elec1	04:09:26	67,54%	01:33:58	25,44%	00:25:54	7,01%	06:09:18	100%



	Pipe1	Vent1	Brick1	Wall1	Pipe2	Pipe3	Brick2	Wall2	Wall3	Weld1	Weld2	Weld3	Elec.1		TOT.
NW	20,77%	15,15%	30,25%	18,33%	32,94%	16,57%	21,01%	17,87%	11,89%	35,99%	12,59%	28,89%	7,01%		20,00%
NVA	48,33%	61,40%	17,23%	27,20%	38,84%	35,56%	26,38%	32,76%	27,94%	39,73%	57,51%	43,92%	25,44%		36,15%
VA	30,91%	23,45%	52,52%	54,46%	28,22%	47,88%	52,62%	49,37%	60,17%	24,27%	29,90%	27,19%	67,54%		43,86%

Appendix H.2 – Short Studies (A half day)

Appendix H.2.1 – Pipes no.1

Company: Bravida	Date: 2011-04-19
Construction Site: Clarion Hotel Post	Observer: Arleroth & Kristensson
Value Flow: Construction Worker - Plumber	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Walk to job site after break	NVA	09:18:28	09:20:36	00:02:08
Preparation	Prepare pipe for welding	VA	09:20:36	09:20:44	00:00:08
Walk	To material	NVA	09:20:44	09:21:06	00:00:22
Material	Find material	NVA	09:21:06	09:21:12	00:00:06
Walk	Walk back	NVA	09:21:12	09:26:06	00:04:54
Preparation	Prepare pipe for welding	VA	09:26:06	09:27:45	00:01:39
Walk	To next work site	NVA	09:27:45	09:29:59	00:02:14
Construct	Weld pipes	VA	09:29:59	09:32:48	00:02:49
Walk	Walk to next work site	NVA	09:32:48	09:34:10	00:01:22
Construct	Weld pipes	VA	09:34:10	09:38:54	00:04:44
Material	Carry tools to next site	NW	09:38:54	09:40:52	00:01:58
Discussion	Small talk	NVA	09:40:52	09:41:57	00:01:05
Material	Carry tools to next site	NW	09:41:57	09:45:54	00:03:57
Walk	Walk to material	NVA	09:45:54	09:48:59	00:03:05
Material	Look for material	NVA	09:48:59	09:49:39	00:00:40
Discussion	Small talk	NVA	09:49:39	09:50:34	00:00:55
Material	Pick up material	NVA	09:50:34	09:50:41	00:00:07
Walk	Walk back to work site	NVA	09:50:41	09:54:03	00:03:22
Material	Get material in order	NVA	09:54:03	09:57:29	00:03:26
Discussion	Small talk	NVA	09:57:29	09:58:40	00:01:11
Preparation	Prepare material	NW	09:58:40	10:02:34	00:03:54
Construct	Install pipes	VA	10:02:34	10:14:57	00:12:23
Walk	Walk to material	NVA	10:14:57	10:19:38	00:04:41
Material	Find material	NVA	10:19:38	10:20:15	00:00:37
Walk	Walk back to work site	NVA	10:20:15	10:21:14	00:00:59
Discussion	Stop and talk to another worker	NVA	10:21:14	10:22:29	00:01:15
Material	Set material aside	NVA	10:22:29	10:22:42	00:00:13
Discussion	Small talk	NVA	10:22:42	10:23:02	00:00:20
Material	Handling material and tools	NVA	10:23:02	10:24:39	00:01:37
Construct	Install pipes	VA	10:24:39	10:25:30	00:00:51
Discussion	Discuss work with colleague	NW	10:25:30	10:28:27	00:02:57
Construct	Install pipes	VA	10:28:27	10:34:32	00:06:05
Break	Taking a break	NVA	10:34:32	10:35:25	00:00:53
Construct	Install pipes	VA	10:35:25	10:37:30	00:02:05
Preparation	Prepare more material	NW	10:37:30	10:38:49	00:01:19
Construct	Install pipes	VA	10:38:49	10:39:52	00:01:03
Material	Look for tools	NVA	10:39:52	10:41:17	00:01:25
Discussion	Discuss where tools may be	NVA	10:41:17	10:44:54	00:03:37
Walk	Walk to where tools may be	NVA	10:44:54	10:47:16	00:02:22
Material	Look for tools	NVA	10:47:16	10:49:50	00:02:34
Walk	Going for tools	NVA	10:49:50	10:50:59	00:01:09
Material	Look for tools	NVA	10:50:59	10:54:01	00:03:02
Walk	Going for tools	NVA	10:54:01	10:54:58	00:00:57

Material	Find tools	NVA	10:54:58	10:55:48	00:00:50
Walk	Going for material	NVA	10:55:48	10:57:49	00:02:01
Material	Look for material	NVA	10:57:49	10:58:16	00:00:27
Walk	Going for material elsewhere	NVA	10:58:16	10:59:16	00:01:00
Material	Pick up material	NVA	10:59:16	11:01:17	00:02:01
Discussion	Discuss what to do next	NVA	11:01:17	11:02:14	00:00:57
Material	Handle material for next job	NVA	11:02:14	11:04:00	00:01:46
Walk	Walk to next job site	NVA	11:04:00	11:19:41	00:15:41
Material	Move material	NW	11:19:41	11:38:10	00:18:29
Construct	Install pipe	VA	11:38:10	11:58:45	00:20:35
Walk	Walk to material storage	NVA	11:58:45	12:01:15	00:02:30
Material	Pick up material	NVA	12:01:15	12:01:58	00:00:43
Walk	Walk to pick up tools	NVA	12:01:58	12:02:36	00:00:38
Material	Pick up tools	NVA	12:02:36	12:04:41	00:02:05
Walk	Walk to job site	NVA	12:04:41	12:06:46	00:02:05
Construct	Install pipe	VA	12:06:46	12:07:41	00:00:55
Walk	Walk to next site	NVA	12:07:41	12:08:13	00:00:32
Preparation	Prepare material	NW	12:08:13	12:10:26	00:02:13
Walk	Going to place for installation	NVA	12:10:26	12:11:10	00:00:44
Construct	Install pipe	VA	12:11:10	12:18:04	00:06:54
Walk	To Colleague	NVA	12:18:04	12:21:49	00:03:45
Discussion	Discuss with colleague	NVA	12:21:49	12:25:24	00:03:35
Break	Bathroom	NVA	12:25:24	12:30:17	00:04:53
Material	Handle material	NVA	12:30:17	12:31:12	00:00:55
Discussion	Discuss work with colleague	NW	12:31:12	12:39:49	00:08:37
Construct	Install pipe	VA	12:39:49	12:44:14	00:04:25
Walk	Walk to material	NVA	12:44:14	12:46:15	00:02:01
Material	Handle material	NVA	12:46:15	12:47:28	00:01:13
TOTAL					**03:29:00**
VA					**31%**
NVA					**48%**
NW					**21%**

Appendix H.2.2 – Ventilation

Company: Bravida	Date: 2011-04-19
Construction Site: Clarion Hotel Post	Observer: Arleroth & Kristensson
Value Flow: Construction Worker – Ventilation	Pages: 1

Activity	Description	Classification	Start	End	Duration
Walk	Walk to material	NVA	14:10:05	14:15:10	00:05:05
Material	Pick up material	NW	14:15:10	14:15:44	00:00:34
Walk	Walk to work site	NVA	14:15:44	14:16:25	00:00:41
Material	Move material	NVA	14:16:25	14:21:12	00:04:47
Walk	To find material	NVA	14:21:12	14:21:36	00:00:24
Material	Pick up material	NVA	14:21:36	14:26:17	00:04:41
Walk	Walk to pick up tools	NVA	14:26:17	14:27:34	00:01:17
Material	Pick up tools	NW	14:27:34	14:29:06	00:01:32
Walk	Walk to work site	NVA	14:29:06	14:30:48	00:01:42
Material	Move material	NVA	14:30:48	14:31:40	00:00:52
Preparation	Preparation of ventilation drum	VA	14:31:40	14:34:46	00:03:06
Discussion	Small Talk	NVA	14:34:46	14:34:55	00:00:09
Walk	Walk to material	NVA	14:34:55	14:36:43	00:01:48
Material	Pick up material	NW	14:36:43	14:37:06	00:00:23
Discussion	Small Talk	NVA	14:37:06	14:37:49	00:00:43
Material	Move material	NW	14:37:49	14:41:06	00:03:17
Construct	Preparation of ventilation drum	VA	14:41:06	14:44:02	00:02:56
Discussion	Problem solving	NW	14:44:02	14:46:41	00:02:39
Construct	Preparation of ventilation drum	VA	14:46:41	14:51:51	00:05:10
Material	Handle tools	NW	14:51:51	14:52:44	00:00:53
Preparation	Measuring	NW	14:52:44	14:54:06	00:01:22
Material	Move ventilation drum	NVA	14:54:06	14:56:31	00:02:25
Discussion	Problem solving	NW	14:56:31	14:58:01	00:01:30
Material	Pick up tools and material	NVA	14:58:01	15:00:50	00:02:49
Construct	Install ventilation drum	VA	15:00:50	15:03:30	00:02:40
Material	Move material	NVA	15:03:30	15:04:47	00:01:17
Walk	Walk to tools	NVA	15:04:47	15:05:40	00:00:53
Material	Pick up tools	NVA	15:05:40	15:06:15	00:00:35
Construct	Install ventilation drum	VA	15:06:15	15:07:32	00:01:17
Material	Move material	NVA	15:07:32	15:08:26	00:00:54
Construct	Install ventilation drum	VA	15:08:26	15:09:11	00:00:45
Discussion	Small talk	NVA	15:09:11	15:12:04	00:02:53
Material	Move tools	NW	15:12:04	15:12:10	00:00:06
Construct	Install ventilation drum	VA	15:12:10	15:13:37	00:01:27
Material	Move material	NVA	15:13:37	15:15:05	00:01:28
Walk	Walk with material	NVA	15:15:05	15:17:39	00:02:34
Material	Move material around	NVA	15:17:39	15:17:57	00:00:18
Preparation	Cut metal for holding vent. drum	VA	15:17:57	15:19:35	00:01:38
Material	Move material to another work site	NVA	15:19:35	15:29:03	00:09:28
Walk	Walk back	NVA	15:29:03	15:31:02	00:01:59
TOTAL					**01:20:57**
VA					**24%**
NVA					**61%**
NW					**15%**

Appendix H.2.3 – Wall no.1

Company: TORU Fasad och Väggmontage AB	Date: 2011-04-20
Construction Site: Clarion Hotel Post	Observer: Arleroth & Kristensson
Value Flow: Construction Worker – Drywall	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Walk to position	NVA	10:04:40	10:05:28	00:00:48
Material	Handling tools and material	NVA	10:05:28	10:08:48	00:03:20
Construct	Screwing	VA	10:08:48	10:09:51	00:01:03
Discussion	Problem solving	NW	10:09:51	10:10:28	00:00:37
Material	Handling material	NVA	10:10:28	10:11:53	00:01:25
Preparation	Working with plywood	VA	10:11:53	10:18:24	00:06:31
Material	Measuring material	NW	10:18:24	10:20:23	00:01:59
Construct	Working on wall	VA	10:20:23	10:21:20	00:00:57
Discussion	Problem solving	NW	10:21:20	10:22:14	00:00:54
Construct	Working on wall	VA	10:22:14	10:25:49	00:03:35
Discussion	Problem solving	NW	10:25:49	10:27:42	00:01:53
Construct	Working on wall	VA	10:27:42	10:42:04	00:14:22
Material	Picking up material	NVA	10:42:04	10:43:42	00:01:38
Construct	Screwing up plywood	VA	10:43:42	10:51:27	00:07:45
Material	handling plywood	NVA	10:51:27	10:59:42	00:08:15
Discussion	Discussing how to proceed	NW	10:59:42	11:07:37	00:07:55
Material	Handling plywook	NVA	11:07:37	11:08:17	00:00:40
Preparation	Cutting plywook	VA	11:08:17	11:09:16	00:00:59
Material	Handling drywall and tools	NVA	11:09:16	11:12:15	00:02:59
Preparation	Cutting drywall	VA	11:12:15	11:31:43	00:19:28
Material	Measuring	NW	11:31:43	11:37:15	00:05:32
Preparation	Cutting drywall	VA	11:37:15	11:45:10	00:07:55
Material	Measuring	NW	11:45:10	11:46:51	00:01:41
Prepration	Cutting drywall	VA	11:46:51	11:49:22	00:02:31
Material	Handling material and tools	NVA	11:49:22	11:51:38	00:02:16
Discussion	Discussing next move	NW	11:51:38	11:52:05	00:00:27
Material	Moving material	NW	11:52:05	11:55:47	00:03:42
Walk	Walking to material	NVA	11:55:47	11:59:19	00:03:32
Material	Moving material	NW	11:59:19	11:59:59	00:00:40
Construct	Put up a few beams	VA	11:59:59	12:01:08	00:01:09
Material	Move material	NVA	12:01:08	12:03:15	00:02:07
Preparation	Cut beams	VA	12:03:15	12:04:36	00:01:21
Material	Handle beams	NVA	12:04:36	12:05:18	00:00:42
Construct	Cut and put up beams	VA	12:05:18	12:12:43	00:07:25
Material	Handle drywall	NW	12:12:43	12:16:40	00:03:57
Construct	Put up beams	VA	12:16:40	12:18:34	00:01:54
Discussion	Small talk	NVA	12:18:34	12:19:11	00:00:37
Material	Fetch tool	NVA	12:19:11	12:19:19	00:00:08
Preparation	Cut and prepare drywall	VA	12:19:19	12:21:00	00:01:41
Material	Handle material and tools	NVA	12:21:00	12:22:06	00:01:06
Preparation	Cut drywall	VA	12:22:06	12:25:56	00:03:50
Material	Move material	NVA	12:25:56	12:31:35	00:05:39
Construct	Put up beams	VA	12:31:35	12:34:37	00:03:02
Material	Fetch beams	NVA	12:34:37	12:35:54	00:01:17
Preparation	Cut beams	VA	12:35:54	12:36:32	00:00:38

Material	Get and fix tools	NVA	12:36:32	12:41:22	00:04:50
Construct	Put up beams	VA	12:41:22	12:42:15	00:00:53
Material	Move material	NVA	12:42:15	12:44:23	00:02:08
TOTAL					**02:39:43**
VA					**55%**
NVA					**27%**
NW					**18%**

Appendix H.2.4 – Bricklayer no.1

Company: Bäckens Puts J. Olsson AB	Date: 2011-04-20
Construction Site: Clarion Hotel Post	Observer: Arleroth, Jens
Value Flow: Construction Worker – Bricklayer	Pages: 1

Activity	Description	Classification	Start	End	Duration
Construct	Working on pillar	VA	13:42:47	13:45:12	00:02:25
Material	Handling bags with material	NW	13:45:12	13:46:14	00:01:02
Construct	Working on pillar	VA	13:46:14	13:50:24	00:04:10
Material	Handling bags with material	NW	13:50:24	13:51:31	00:01:07
Construct	Working on pillar	VA	13:51:31	13:52:34	00:01:03
Discussion	Small talk	NVA	13:52:34	13:53:03	00:00:29
Material	Moving tools and materials	NVA	13:53:03	13:53:37	00:00:34
Walk	Go for pallet lift	NVA	13:53:37	13:55:36	00:01:59
Material	Handling bags with materials	NW	13:55:36	13:59:28	00:03:52
Walk	Return pallet lift	NVA	13:59:28	14:00:09	00:00:41
Discussion	Small talk	NVA	14:00:09	14:00:26	00:00:17
Material	Handling bags with materials	NW	14:00:26	14:01:57	00:01:31
Construct	Working on pillar	VA	14:01:57	14:06:51	00:04:54
Material	Handling bags with materials	NW	14:06:51	14:07:35	00:00:44
Construct	Working on pillar	VA	14:07:35	14:07:51	00:00:16
Material	Handling bags with materials	NW	14:07:51	14:09:07	00:01:16
Construct	Working on pillar	VA	14:09:07	14:14:18	00:05:11
Material	Throwing away scrap material	NVA	14:14:18	14:15:51	00:01:33
Construct	Working on pillar	VA	14:15:51	14:20:24	00:04:33
Material	Throwing away scrap material	NVA	14:20:24	14:21:56	00:01:32
Construct	Working on pillar	VA	14:21:56	14:24:06	00:02:10
Material	Throwing away scrap material	NVA	14:24:06	14:24:36	00:00:30
Discussion	Small talk	NVA	14:24:36	14:25:50	00:01:14
Material	Moving material to facilitate work on another pillar	NVA	14:25:50	14:28:45	00:02:55
Construct	Working on pillar	VA	14:28:45	14:41:01	00:12:16
Discussion	Problem solving	NW	14:41:01	14:45:17	00:04:16
Construct	Working on pillar	VA	14:45:17	14:58:34	00:13:17
Discussion	Problem solving	NW	14:58:34	14:59:37	00:01:03
Material	Moving material and ladder	NVA	14:59:37	15:00:10	00:00:33
Construct	Working on pillar	VA	15:00:10	15:08:42	00:08:32
Discussion	Small talk	NVA	15:08:42	15:10:43	00:02:01
Material	Handling material bags	NW	15:10:43	15:11:16	00:00:33
Discussion	Problem solving	NW	15:11:16	15:12:30	00:01:14
Material	Cleaning of machine	NW	15:12:30	15:25:43	00:13:13
Discussion	Problem solving	NW	15:25:43	15:29:43	00:04:00
Discussion	Small talk	NVA	15:29:43	15:34:42	00:04:59
TOTAL					**01:51:55**
VA					**53%**
NVA					**17%**
NW					**30%**

Appendix H.3 – Long Studies (A whole day)

Appendix H.3.1 – Pipes no.2

Company: Bravida	Date: 2011-04-27
Construction Site: Clarion Hotel Post	Observer: Arleroth, Jens
Value Flow: Construction Worker – Plumber	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Walking to site	NVA	09:14:12	09:17:55	00:03:43
Material	Handling material and tools	NW	09:17:55	09:22:34	00:04:39
Walk	Walking to new place	NVA	09:22:34	09:26:02	00:03:28
Material	Handling material and tools	NW	09:26:02	09:28:33	00:02:31
Discussion	Small talk	NVA	09:28:33	09:30:45	00:02:12
Walk	Walking with tools	NVA	09:30:45	09:36:46	00:06:01
Material	Handling tools and material	NW	09:36:46	09:38:24	00:01:38
Walk	Walking with tools	NVA	09:38:24	09:39:59	00:01:35
Material	Tangle up the cord to a tool	NVA	09:39:59	09:46:06	00:06:07
Preparation	Processing pipes	VA	09:46:06	09:51:03	00:04:57
Discussion	Problem solving	NW	09:51:03	09:58:37	00:07:34
Walk	Picking up tools	NVA	09:58:37	10:03:09	00:04:32
Preparation	Processing pipes	VA	10:03:09	10:06:28	00:03:19
Material	Material planning	NW	10:06:28	10:12:11	00:05:43
Preparation	Processing pipes	VA	10:12:11	10:14:57	00:02:46
Waiting	Waiting on colleague	NVA	10:14:57	10:18:35	00:03:38
Preparation	Processing pipes	VA	10:18:35	10:21:53	00:03:18
Material	Handling tools	NW	10:21:53	10:28:21	00:06:28
Discussion	Small talk	NVA	10:28:21	10:30:05	00:01:44
Walk	Walking away with tools	NVA	10:30:05	10:34:44	00:04:39
Material	Looking for material	NVA	10:34:44	10:39:00	00:04:16
Discussion	Problem solving	NW	10:39:00	10:43:28	00:04:28
Waiting	Waiting on colleague	NVA	10:43:28	10:45:20	00:01:52
Construct	Assembling pipes	VA	10:45:20	10:48:31	00:03:11
Discussion	Problem solving	NW	10:48:31	10:50:04	00:01:33
Walk	Going for tools	NVA	10:50:04	10:53:11	00:03:07
Material	Picking up tools and material	NW	10:53:11	10:54:45	00:01:34
Walk	Going back with materials and tools	NVA	10:54:45	10:58:04	00:03:19
Discussion	Problem solving	NW	10:58:04	11:04:52	00:06:48
Preparation	Processing pipes	VA	11:04:52	11:09:41	00:04:49
Discussion	Small talk	NVA	11:09:41	11:12:22	00:02:41
Construct	Screwing	VA	11:12:22	11:15:14	00:02:52
Material	Handling material	NW	11:15:14	11:17:00	00:01:46
Discussion	Problem solving	NW	11:17:00	11:18:57	00:01:57
Construct	Drilling and processing pipes	VA	11:18:57	11:22:47	00:03:50
Walk	Going after material	NVA	11:22:47	11:25:06	00:02:19
Material	Picking out suitable pipes	NW	11:25:06	11:28:13	00:03:07
Walk	Going back	NVA	11:28:13	11:36:53	00:08:40

Material	Material handling and measuring	NW	11:36:53	11:38:25	00:01:32
Discussion	Problem solving	NW	11:38:25	11:40:17	00:01:52
Material	Handling material and tools	NW	11:40:17	11:42:04	00:01:47
Preparation	Cutting pipes	VA	11:42:04	11:46:58	00:04:54
Material	Looking for tools	NVA	11:46:58	11:47:10	00:00:12
Preparation	Processing pipes	VA	11:47:10	11:49:08	00:01:58
Break	Taking a break	NVA	11:49:08	12:07:12	00:18:04
Walk	Going up to the attic	NVA	12:07:12	12:11:30	00:04:18
Discussion	Problem solving	NW	12:11:30	12:17:29	00:05:59
Walk	Searching for a colleague	NVA	12:17:29	12:20:38	00:03:09
Discussion	Small talk	NVA	12:20:38	12:22:33	00:01:55
Material	Looking for tools and material	NVA	12:22:33	12:27:11	00:04:38
Walk	Going back with material and tools	NVA	12:27:11	12:28:39	00:01:28
Preparation	Processing pipes	VA	12:28:39	12:36:15	00:07:36
Discussion	Small talk	NVA	12:36:15	12:39:02	00:02:47
Preparation	Processing pipes	VA	12:39:02	12:43:50	00:04:48
Material	Handling material	NW	12:43:50	12:44:28	00:00:38
-	LUNCH	-	12:44:28	13:33:36	00:47:08
Discussion	Problem solving	NW	13:33:36	13:44:30	00:10:54
Material	Handling material and tools	NW	13:44:30	13:57:26	00:12:56
Break	Looking for music headset	NVA	13:57:26	14:12:19	00:14:53
Preparation	Processing pipes	VA	14:12:19	14:22:12	00:09:53
Discussion	Problem solving	NW	14:22:12	14:28:42	00:06:30
Material	Handling material	NW	14:28:42	14:36:44	00:08:02
Construct	Cutting pipes	VA	14:36:44	14:43:36	00:06:52
Waiting	Waiting on machine to be finished	NVA	14:43:36	14:45:32	00:01:56
Construct	Welding pipes	VA	14:45:32	14:52:53	00:07:21
Discussion	Small talk	NVA	14:52:53	14:55:06	00:02:13
Construct	Cutting pipes	VA	14:55:06	15:01:41	00:06:35
Material	Handling material and tools	NW	15:01:41	15:06:57	00:05:16
Construct	Processing pipes	VA	15:06:57	15:10:45	00:03:48
Material	Tool breakdown	NVA	15:10:45	15:18:34	00:07:49
Discussion	Small talk	NVA	15:18:34	15:19:34	00:01:00
Material	Handling tools	NW	15:19:34	15:22:08	00:02:34
Construct	Processing pipes	VA	15:22:08	15:25:46	00:03:38
Discussion	Problem solving	NW	15:25:46	15:26:01	00:00:15
Material	Picking up new material	NW	15:26:01	15:30:05	00:04:04
Construct	Processing pipes	VA	15:30:05	15:36:11	00:06:06
Discussion	Problem solving	NW	15:36:11	15:38:49	00:02:38
Construct	Processing pipes	VA	15:38:49	15:44:36	00:05:47
Break	Taking a break	NVA	15:44:36	15:47:17	00:02:41
Walk	Leaving the site	NVA	15:47:17	15:51:37	00:04:20
TOTAL					**05:48:17**
VA					**28%**
NVA					**39%**
NW					**33%**

Appendix H.3.2 – Pipes no.3

Company: Bravida	Date: 2011-04-26
Construction Site: Clarion Hotel Post	Observer: Kristensson, Henrik
Value Flow: Construction Worker – Plumber	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Walk to material	NVA	9:20:04	9:21:53	00.01.49
Material	Pick up material, carry to work site	NVA	9:21:53	9:25:17	00.03.24
Construct	Attach pipe	VA	9:25:17	9:31:03	00.05.46
Discuss	What needs to be done next	NW	9:31:03	9:31:24	00.00.21
Material	Handling tools	NVA	9:31:24	9:32:37	00.01.13
Construct	Attaching pipe	VA	9:32:37	9:33:20	00.00.43
Other	Double checking measurements	NW	9:33:20	9:34:02	00.00.42
Construct	Attach pipe	VA	9:34:02	9:35:58	00.01.56
Material	Handling material and tools	NVA	9:35:58	9:36:32	00.00.34
Preparation	Processing pipes	VA	9:36:32	9:39:19	00.02.47
Material	Moving material	NVA	9:39:19	9:40:46	00.01.27
Construct	Attaching pipe	VA	9:40:46	9:51:51	00.11.05
Material	Retrieving material	NVA	9:51:51	9:52:58	00.01.07
Preparation	Processing pipes	VA	9:52:58	10:02:21	00.09.23
Material	Unpacking, preparing	NW	10:02:21	10:04:48	00.02.27
Walk	Find material	NVA	10:04:48	10:05:17	00.00.29
Material	Handling tools	NVA	10:05:17	10:08:33	00.03.16
Discuss	Small talk	NVA	10:08:33	10:12:14	00.03.41
Material	Tools	NVA	10:12:14	10:12:41	00.00.27
Discuss	Discuss material	NW	10:12:41	10:17:11	00.04.30
Preparation	Measuring, marking	NW	10:17:11	10:18:21	00.01.10
Preparation	Processing pipes	VA	10:18:21	10:23:37	00.05.16
Material	Handling material and tools	NVA	10:23:37	10:33:19	00.09.42
Preparation	Processing pipes	VA	10:33:19	10:34:40	00.01.21
Preparation	Measuring, marking	NW	10:34:40	10:36:14	00.01.34
Preparation	Processing pipes	VA	10:36:14	10:40:03	00.03.49
Material	Looking for material	NVA	10:40:03	10:51:49	00.11.46
Walk	To look for material	NVA	10:51:49	10:53:23	00.01.34
Preparation	Processing pipes	VA	10:53:23	10:57:33	00.04.10
Preparation	Measuring	NW	10:57:33	11:07:09	00.09.36
Walk	Looking for material	NVA	11:07:09	11:08:28	00.01.19
Material	Fetching pipe	NVA	11:08:28	11:10:58	00.02.30
Preparation	Preparing tools	NW	11:10:58	11:12:47	00.01.49
Break	Talking with colleagues	NVA	11:12:47	11:13:02	00.00.15
Preparation	Measuring/Thinking	NW	11:13:02	11:14:19	00.01.17
Preparation	Fitting pipe	VA	11:14:19	11:18:04	00.03.45
Preparation	Measuring	NW	11:18:04	11:19:26	00.01.22
Construct	Attaching pipe	VA	11:19:26	11:22:19	00.02.53
Discuss	Talking with boss	NW	11:22:19	11:29:56	00.07.37
Material	Fetch pipe	NVA	11:29:56	11:31:36	00.01.40
Construct	Cut pipe	VA	11:31:36	11:45:24	00.13.48
Discuss	Problem solving	NW	11:45:24	11:50:04	00.04.40
Material	Retrieve pipe	NVA	11:50:04	11:52:14	00.02.10
Construct	Put up pipe	VA	11:52:14	12:00:29	00.08.15
Preparation	Cut pipe	VA	12:00:29	12:33:00	00.32.31

Discuss	Small talk	NVA	12:33:00	12:34:11	00.01.11
Construct	Weld pipe	VA	12:34:11	12:36:58	00.02.47
Discuss	Telephone	NVA	12:36:58	12:41:33	00.04.35
Construct	Welding pipe	VA	12:41:33	12:43:25	00.01.52
Material	Fix pipe for welding	NVA	12:43:25	12:50:41	00.07.16
Break	Going for lunch	NVA	12:50:41	13:00:00	00.09.19
-	LUNCH	-	13:00:00	13:30:00	00:30:00
Break	Heading back after lunch	NVA	13:30:00	13:35:08	00.05.08
Material	Handling material	NVA	13:35:08	13:38:26	00.03.18
Discuss	Problem solving	NW	13:38:26	13:41:03	00.02.37
Walk	Walk and wait	NVA	13:41:03	13:45:24	00.04.21
Construct	Processing pipes	VA	13:45:24	13:50:57	00.05.33
Material	Retrieve material	NVA	13:50:57	13:53:52	00.02.55
Construct	Weld pipe	VA	13:53:52	13:56:04	00.02.12
Preparation	Measuring, marking	NW	13:56:04	13:58:47	00.02.43
Preparation	Processing pipes	VA	13:58:47	14:00:29	00.01.42
Material	Retrieve material	NVA	14:00:29	14:03:38	00.03.09
Construct	Attach valves	VA	14:03:38	14:10:47	00.07.09
Material	Handling material and tools	NVA	14:10:47	14:11:04	00.00.17
Construct	Attach valves	VA	14:11:04	14:21:12	00.10.08
Discuss	Problem solving	NW	14:21:12	14:22:38	00.01.26
Material	Retrieve material	NVA	14:22:38	14:25:11	00.02.33
Construct	Attach Valves	VA	14:25:11	14:30:02	00.04.51
Material	Handling material and tools	NVA	14:30:02	14:36:15	00.06.13
Construct	Attach valves	VA	14:36:15	14:38:50	00.02.35
Material	Retrieve material	NVA	14:38:50	14:40:16	00.01.26
Construct	Weld pipe	VA	14:40:16	14:46:01	00.05.45
Preparation	Measure	NW	14:46:01	14:50:43	00.04.42
Discuss	Small talk	NVA	14:50:43	14:57:09	00.06.26
Construct	Put up pipe, weld pipe	VA	14:57:09	15:05:26	00.08.17
Discuss	Problem solving	NW	15:05:26	15:10:39	00.05.13
Material	Moving material	NVA	15:10:39	15:13:13	00.02.34
Break	Small talk	NVA	15:13:13	15:14:02	00.00.49
Walk	Moving lift	NVA	15:14:02	15:15:19	00:01:17
Construct	Put up pipe	VA	15:15:19	15:16:51	00:01:32
Material	Retrieve material	NVA	15:16:51	15:18:04	00:01:13
Construct	Processing pipes	VA	15:18:04	15:26:14	00:08:10
Preparation	Measuring	NW	15:26:14	15:31:18	00:05:04
Break	Taking a break	NVA	15:31:18	15:33:56	00:02:38
Material	Handling material	NVA	15:33:56	15:34:43	00:00:47
Waiting	Waiting on colleague	NVA	15:34:43	15:40:38	00:05:55
Material	Picking up material and tools	NVA	15:40:38	15:45:11	00:04:33
TOTAL					**05:55:07**
VA					**48%**
NVA					**35%**
NW					**17%**

Appendix H.3.3 – Bricklayer no.2

Company: Bäckens Puts J. Olsson AB	Date: 2011-04-28
Construction Site: Clarion Hotel Post	Observer: Kristensson, Henrik
Value Flow: Construction Worker – Bricklayer	Pages: 3

Activity	Description	Classification	Start	End	Duration
Material	Get material ready	NVA	9:32:14	9:36:19	00.04.05
Construct	Spray plaster	VA	9:36:19	9:39:27	00.03.08
Break	Talking with colleagues	NVA	9:39:27	9:41:39	00.02.12
Material	Fixing tools	NVA	9:41:39	9:43:21	00.01.42
Construct	Plaster on pillar	VA	9:43:21	9:52:42	00.09.21
Material	Handling material and tools	NVA	9:52:42	9:54:16	00.01.34
Construct	Spray plaster	NVA	9:54:16	9:57:01	00.02.45
Discuss	Discuss work	NW	9:57:01	9:57:56	00.00.55
Construct	Rebar in the plaster	VA	9:57:56	10:04:32	00.06.36
Discuss	Problem solving	NW	10:04:32	10:05:22	00.00.50
Material	Filling up plaster machine	NW	10:05:22	10:07:02	00.01.40
Discuss	Small talk	NVA	10:07:02	10:07:50	00.00.48
Material	Retrieving material	NW	10:07:50	10:08:15	00.00.25
Break	Talking with colleauges	NVA	10:08:15	10:10:02	00.01.47
Construct	Spray plaster	VA	10:10:02	10:11:52	00.01.50
Material	Handling material and tools	NVA	10:11:52	10:13:04	00.01.12
Construct	Spray plaster	VA	10:13:04	10:15:47	00.02.43
Discuss	Peab staff	NW	10:15:47	10:21:29	00.05.42
Material	Fetch ladder	NVA	10:21:29	10:23:28	00.01.59
Construct	Spray plaster	VA	10:23:28	10:27:38	00.04.10
Discuss	Peab staff	NW	10:27:38	10:31:24	00.03.46
Construct	Spray plaster	VA	10:31:24	10:32:57	00.01.33
Discuss	Discussing work	NW	10:32:57	10:35:24	00.02.27
Construct	Spray plaster	VA	10:35:24	10:39:47	00.04.23
Material	Fill machine	NW	10:39:47	10:40:38	00.00.51
Discuss	Boss	NW	10:40:38	10:41:09	00.00.31
Construct	Spray plaster	VA	10:41:09	10:45:12	00.04.03
Material	Moving material	NVA	10:45:12	10:48:38	00.03.26
Discuss	Problem solving	NW	10:48:38	10:50:12	00.01.34
Walk	Looking for material	NVA	10:50:12	10:51:11	00.00.59
Material	Filling up plaster machine	NW	10:51:11	10:53:02	00.01.51
Construct	Pillar	VA	10:54:11	10:55:40	00.01.29
Discuss	With boss, planning	NW	10:55:40	11:02:00	00.06.20
Construct	Spray plaster	VA	11:02:00	11:03:20	00.01.20
Discuss	Problem solving	NW	11:03:20	11:04:17	00.00.57
Construct	Spray plaster	VA	11:04:17	11:08:57	00.04.40
Discuss	Boss and colleagues	NW	11:08:57	11:10:47	00.01.50
Material	Fix tools, fill machine	NVA	11:10:47	11:13:19	00.02.32
Construct	Spray plaster	VA	11:13:19	11:15:00	00.01.41
Material	Fix machine that broke	NVA	11:15:00	11:15:46	00.00.46
Construct	Spray plaster	VA	11:15:46	11:20:32	00.04.46
Material	Retrieve material	NW	11:20:32	11:25:03	00.04.31
Construct	Spray plaster	VA	11:25:03	11:32:43	00.07.40
Discuss	Another group of workers	NVA	11:32:43	11:34:11	00.01.28
-	LUNCH	-	11:34:11	12:15:34	00:42:23

Material	Get set up	NVA	12:15:34	12:17:33	00.01.59
Discuss	Problem solving	NW	12:17:33	12:19:47	00.02.14
Material	Filling up plaster machine	NW	12:19:47	12:33:34	00.13.47
Construct	Spraying plaster	VA	12:33:34	12:34:01	00.00.27
Waiting	Waiting	NVA	12:34:01	12:35:29	00.01.28
Construct	Spraying plaster	VA	12:35:29	12:41:18	00.05.49
Material	Filling up plaster machine	NW	12:41:18	12:41:38	00.00.20
Construct	Spray plaster	VA	12:41:38	12:53:11	00.11.33
Discuss	Small talk	NVA	12:53:11	12:53:57	00.00.46
Material	Ladder, move machine	NVA	12:53:57	12:54:56	00.00.59
Construct	Spray plaster	VA	12:54:56	12:56:48	00.01.52
Material	Filling up plaster machine	NW	12:56:48	12:58:12	00.01.24
Construct	Spray plaster	NVA	12:58:13	13:03:21	00.05.08
Discuss	Problem solving	NW	13:03:21	13:04:24	00.01.03
Material	Filling up plaster machine	NW	13:04:24	13:05:10	00.00.46
Construct	Plaster on pillar	VA	13:05:10	13:08:42	00.03.32
Material	Fetching tools	NVA	13:08:42	13:09:26	00.00.44
Other	Fixing something that went wrong	NVA	13:09:26	13:12:11	00.02.45
Discuss	Small talk	NVA	13:12:11	13:12:57	00.00.46
Construct	Spray plaster	VA	13:12:57	13:20:35	00.07.38
Material	Moving material/tools	NVA	13:20:35	13:21:18	00.00.43
Construct	Smoothing out plaster	VA	13:21:18	13:22:10	00.00.52
Material	Scrap overproduced plaster	NVA	13:22:10	13:22:47	00.00.37
Construct	Smoothing out plaster	VA	13:22:47	13:28:15	00.05.28
Discuss	Problem solving	NW	13:28:15	13:29:12	00.00.57
Material	Move ladder/material	NVA	13:29:12	13:30:17	00.01.05
Construct	Spray plaster	VA	13:30:17	13:35:25	00.05.08
Discuss	Small talk	NVA	13:35:25	13:36:58	00.01.33
Construct	Spray plaster	VA	13:36:58	13:37:36	00.00.38
Material	Move hose/machine	NVA	13:37:36	13:39:43	00.02.07
Discuss	Problem solving	NW	13:39:43	13:42:19	00.02.36
Material	Get ladder, material	NVA	13:42:19	13:44:12	00.01.53
Construct	Spray plaster	VA	13:44:12	13:55:39	00.11.27
Material	Move ladder+hose	NVA	13:55:39	14:04:29	00.08.50
Discuss	Small talk	NVA	14:04:29	14:06:03	00.01.34
Construct	Smooth out plaster	VA	14:06:03	14:09:13	00.03.10
Material	Filling up plaster machine	NW	14:09:13	14:10:46	00.01.33
Construct	Smooth out plaster	VA	14:10:46	14:19:24	00.08.38
Material	Fill plaster machine	NW	14:19:24	14:20:01	00.00.37
Construct	Spray plaster	VA	14:20:01	14:22:15	00.02.14
Material	Filling up plaster machine	NW	14:22:15	14:22:59	00.00.44
Construct	Spray plaster	VA	14:22:59	14:25:18	00.02.19
Discuss	Problem solving	NW	14:25:18	14:29:11	00.03.53
Construct	Spray plaster	VA	14:29:11	14:35:17	00.06.06
Material	Move hose+ladder	NVA	14:35:17	14:37:51	00.02.34
Construct	Spray plaster	VA	14:37:51	14:39:08	00.01.17
Material	Filling up plaster machine	NW	14:39:08	14:41:03	00.01.55
Construct	Spray plaster	VA	14:41:03	14:50:01	00.08.58
Material	Handling material and tools	NVA	14:50:01	14:51:04	00.01.03
Construct	Smooth out plaster	VA	14:51:04	14:55:12	00.04.08
Material	Scrap overproduced plaster	NVA	14:55:12	15:01:57	00.06.45
Construct	Smooth out plaster	VA	15:01:57	15:05:12	00.03.15

Discuss	Scrap overproduced plaster	NVA	15:05:12	15:09:07	00.03.55
Construct	Smooth out plaster	VA	15:09:07	15:12:48	00.03.41
Material	Fill machine, find material	NVA	15:12:48	15:14:15	00.01.27
Construct	Spray plaster	VA	15:14:15	15:16:20	00.02.05
Material	Filling up plaster machine	NW	15:16:20	15:17:09	00.00.49
Construct	Spray plaster	VA	15:17:09	15:23:17	00.06.08
Discuss	Discuss work	NW	15:23:17:	15:27:14	00.03.57
Material	Move hose, machine, material	NVA	15:27:14	15:31:19	00.04.05
Construct	Spray plaster	VA	15:31:19	15:34:23	00.03.04
Material	Get ladder and tools	NVA	15:34:23	15:35:08	00.00.45
Construct	Spray plaster	VA	15:35:08	15:43:31	00.08.23
Material	Fix machine, finish for the day	NVA	15:43:31	15:52:22	00.08.51
TOTAL					**05:37:35**
VA					**53%**
NVA					**26%**
NW					**21%**

Appendix H.3.4 – Wall no.2

Company: TORU Fasad och Väggmontage AB	Date: 2011-04-27
Construction Site: Clarion Hotel Post	Observer: Arleroth, Jens
Value Flow: Construction Worker – Drywall	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Walking to position	NVA	10:05:03	10:07:00	00:01:57
Material	Throwing away scrap material	NVA	10:07:00	10:10:43	00:03:43
Discuss	Problem solving	NW	10:10:43	10:11:18	00:00:35
Material	Handling material and tools	NW	10:11:18	10:12:55	00:01:37
Construct	Building wall	VA	10:12:55	10:31:56	00:19:01
Material	Moving material	NW	10:31:56	10:33:33	00:01:37
Construct	Building wall	VA	10:33:33	10:42:37	00:09:04
Discuss	Problem solving	NW	10:42:37	10:43:59	00:01:22
Construct	Building wall	VA	10:43:59	10:53:28	00:09:29
Material	Throwing away scrap material	NVA	10:53:28	10:55:01	00:01:33
Construct	Cutting of material	VA	10:55:01	10:57:12	00:02:11
Break	Cleaning site	NVA	10:57:12	10:58:51	00:01:39
Material	Handling material and tools	NW	10:58:51	10:59:49	00:00:58
Construct	Building wall	VA	10:59:49	11:07:19	00:07:30
Other	Redo work	NVA	11:07:19	11:11:13	00:03:54
Construct	Shaping material	VA	11:11:13	11:17:08	00:05:55
Material	Cleaning and sorting	NVA	11:17:08	11:37:49	00:20:41
Discuss	Problem solving	NW	11:37:49	11:39:20	00:01:31
Material	Cleaning and sorting	NVA	11:39:20	11:50:04	00:10:44
Construct	Building wall	VA	11:50:04	12:02:04	00:12:00
Other	Tool breakdown	NVA	12:02:04	12:06:37	00:04:33
Construct	Building wall	VA	12:06:37	12:14:45	00:08:08
Discuss	Problem solving	NW	12:14:45	12:18:07	00:03:22
Other	Redo work	NVA	12:18:07	12:21:14	00:03:07
Construct	Building wall	VA	12:21:14	12:27:11	00:05:57
Discuss	Problem solving	NW	12:27:11	12:29:02	00:01:51
Construct	Building wall	VA	12:29:02	12:31:50	00:02:48
Material	Moving material	NVA	12:31:50	12:36:57	00:05:07
Discuss	Problem solving	NW	12:36:57	12:41:34	00:04:37
Construct	Building wall	VA	12:41:34	12:44:29	00:02:55
-	LUNCH	-	12:44:29	13:24:54	00:40:25
Discuss	Small talk	NVA	13:24:54	13:26:58	00:02:04
Construct	Building wall	VA	13:26:58	13:29:33	00:02:35
Material	Looking for material	NVA	13:29:33	13:31:47	00:02:14
Construct	Building wall	VA	13:31:47	13:49:05	00:17:18
Material	Handling material	NW	13:49:05	13:50:16	00:01:11
Discuss	Problem solving	NW	13:50:16	13:52:22	00:02:06
Walk	Going for material	NVA	13:52:22	13:55:24	00:03:02
Material	Picking up material	NVA	13:55:24	13:57:29	00:02:05
Construct	Building wall	VA	13:57:29	14:05:41	00:08:12

Other	Looking for tools	NVA	14:05:41	14:08:55	00:03:14
Discuss	Small talk	NVA	14:08:55	14:10:40	00:01:45
Construct	Building wall	VA	14:10:40	14:15:12	00:04:32
Discuss	Problem solving	NW	14:15:12	14:16:36	00:01:24
Construct	Building wall	VA	14:16:36	14:17:58	00:01:22
Discuss	Problem solving	NW	14:17:58	14:26:10	00:08:12
Construct	Building wall	VA	14:26:10	14:30:23	00:04:13
Material	Material planning	NW	14:30:23	14:34:18	00:03:55
Construct	Building wall	VA	14:34:18	14:44:42	00:10:24
Discuss	Problem solving	NW	14:44:42	14:45:04	00:00:22
Material	Moving material and scrap bins	NVA	14:45:04	14:52:01	00:06:57
Discuss	Problem solving	NW	14:52:01	14:54:19	00:02:18
Material	Moving material	NW	14:54:19	15:06:53	00:12:34
Discuss	Problem solving	NW	15:06:53	15:09:15	00:02:22
Material	Moving material and cleaning site	NVA	15:09:15	15:23:40	00:14:25
Construct	Building wall	VA	15:23:40	15:33:31	00:09:51
Material	Gathering material	NVA	15:33:31	15:35:57	00:02:26
TOTAL					**04:50:29**
VA					**49%**
NVA					**33%**
NW					**18%**

Appendix H.3.5 – Wall no.3

Company: TORU Fasad och Väggmontage AB	Date: 2011-04-27
Construction Site: Clarion Hotel Post	Observer: Kristensson, Henrik
Value Flow: Construction Worker – Drywall	Pages: 2

Activity	Description	Classification	Start	End	Duration
Preparation	Preparing	NVA	10:07:00	10:09:15	00.02.15
Preparation	Measuring	NW	10:09:15	10:11:15	00.02.00
Material	Fixing material and tools	NVA	10:11:15	10:11:47	00.00.32
Preparation	Measuring	NW	10:11:47	10:13:05	00.01.18
Preparation	Cutting, preparing material	VA	10:13:05	10:29:38	00.16.33
Material	Moving material	NVA	10:29:38	10:31:02	00.01.24
Construct	Putting up drywalls	VA	10:31:02	10:43:10	00.12.08
Other	Fixing a wrong	NVA	10:43:10	10:43:52	00.00.42
Construct	Putting up drywalls	VA	10:43:52	10:59:40	00.15.48
Waiting	Wait	NVA	10:59:40	11:00:11	00.00.31
Preparation	Processing material	VA	11:00:11	11:06:00	00.05.49
Material	Moving material	NVA	11:06:00	11:07:22	00.01.22
Construct	Putting up drywall	VA	11:07:22	11:08:01	00.00.39
Material	Tools	NVA	11:08:01	11:08:48	00.00.47
Construct	Putting up drywall	VA	11:08:48	11:22:10	00.13.22
Material	Moving material, tools	NVA	11:22:10	11:24:39	00.02.29
Construct	Putting up beams	VA	11:24:39	11:26:45	00.02.06
Material	Retrieving material, tools	NVA	11:26:45	11:31:03	00.04.18
Construct	Putting up drywall	VA	11:31:03	11:32:47	00.01.44
Preparation	Measuring	NW	11:32:47	11:36:43	00.03.56
Material	Moving tools	VA	11:36:43	11:37:21	00.00.38
Discuss	Problem solving	NW	11:37:21	11:37:53	00.00.32
Material	Moving Material	NVA	11:37:53	11:51:01	00.13.08
Construct	Putting up drywall	VA	11:51:01	11:59:21	00.08.20
Preparation	Measuring	NW	11:59:21	12:01:03	00.01.42
Discuss	Small talk	NVA	12:01:03	12:03:27	00.02.24
Other	Fix broken tool	NVA	12:03:27	12:06:44	00.03.17
Construct	Putting up walls	VA	12:06:44	12:09:34	00.02.50
Preparation	Measuring	NW	12:09:34	12:11:52	00.02.18
Construct	Putting up walls	VA	12:11:52	12:14:11	00.02.19
Discuss	Problem solving	NW	12:14:11	12:15:35	00.01.24
Material	Handling material and tools	NVA	12:15:35	12:18:48	00.03.13
Preparation	Cutting drywall	VA	12:18:48	12:20:15	00.01.27
Discuss	How to proceed	NW	12:20:15	12:21:31	00.01.16
Construct	Putting up walls	VA	12:21:31	12:32:02	00.10.31
Material	Moving tools	NVA	12:32:02	12:32:24	00.00.22
Preparation	Measuring	NW	12:32:24	12:34:47	00.02.23
Material	Retrieving material	NVA	12:34:47	12:37:01	00.02.14
Preparation	Cutting drywall	VA	12:37:01	12:39:39	00.02.38
Preparation	Measuring	NW	12:39:39	12:43:43	00.04.04

Construct	Putting up drywall	VA	12:43:43	12:45:56	00.02.13
-	LUNCH	-	12:45:56	13:20:29	00:34:43
Discuss	Small talk	NVA	13:20:29	13:24:37	00.04.08
Preparation	Measuring	NW	13:24:37	13:28:16	00.03.39
Construct	Putting up drywall	VA	13:28:16	13:29:15	00.00.59
Preparation	Measuring	NW	13:29:15	13:32:41	00.03.26
Construct	Putting up drywall	VA	13:32:41	13:36:41	00.04.00
Walk	To get material	NVA	13:36:41	13:38:10	00.01.29
Material	Handling material and tools	NVA	13:38:10	13:38:45	00.00.35
Construct	Caulking, putting up drywall	VA	13:38:45	13:42:17	00.03.32
Material	Fixing with tools	NVA	13:42:17	13:43:27	00.01.10
Construct	Putting up walls	VA	13:43:27	13:49:24	00.05.57
Material	Fixing tools	NVA	13:49:24	13:50:12	00.00.48
Discuss	Problem solving	NW	13:50:12	13:51:21	00.01.09
Preparation	Measuring	NW	13:51:21	13:53:13	00.01.52
Preparation	Cutting drywall	VA	13:53:13	14:06:43	00.13.30
Preparation	Measuring	NW	14:06:43	14:09:12	00.02.29
Preparation	Cutting drywall	VA	14:09:12	14:27:17	00.18.05
Material	Handling material and tools	NVA	14:27:17	14:29:46	00.02.29
Preparation	Cutting beams	VA	14:29:46	14:32:02	00.02.16
Discuss	Problem solving	NW	14:32:02	14:34:11	00.02.09
Break	Bathroom	NVA	14:34:11	14:43:10	00.08.59
Material	Moving material	NVA	14:43:10	14:52:01	00.08.51
Construct	Caulking, drywall	VA	14:52:01	14:57:26	00.05.25
Material	Moving material	NVA	14:57:26	15:02:48	00.05.22
Preparation	Cutting drywall	VA	15:02:48	15:06:42	00.03.54
Material	Moving material	NVA	15:06:42	15:07:36	00.00.54
Construct	Putting up walls	VA	15:07:36	15:09:53	00.02.17
Discuss	Small talk	NVA	15:09:53	15:10:47	00.00.54
Construct	Cutting, put up drywall	VA	15:10:47	15:31:57	00.21.10
Material	Handling material and tools	NVA	15:31:57	15:41:00	00.09.03
TOTAL					**04:59:27**
VA					**60%**
NVA					**28%**
NW					**12%**

Appendix H.3.6 – Welding no.1

Company: Gothia Mekaniska AB	Date: 2011-04-21
Construction Site: Clarion Hotel Post	Observer: Arleroth
Value Flow: Construction Worker – Welding	Pages: 2

Activity	Description	Classification	Start	End	Duration
Waiting	Waiting on material	NVA	09:27:22	09:31:23	00:04:01
Discussion	Small talk	NVA	09:31:23	09:32:23	00:01:00
Material	Unloading steel gate	NW	09:32:23	09:39:12	00:06:49
Discussion	Problem solving	NW	09:39:12	09:40:59	00:01:47
Walk	Heading to workplace	NVA	09:40:59	09:41:04	00:00:05
Discussion	Problem solving	NW	09:41:04	09:46:24	00:05:20
Walk	Heading to workplace	NVA	09:46:24	09:51:14	00:04:50
Construct	Painting of gate	VA	09:51:14	09:52:36	00:01:22
Discussion	Problem solving	NW	09:52:36	09:54:11	00:01:35
Material	Moving material	NW	09:54:11	09:54:17	00:00:06
Construct	Processing gate	VA	09:54:17	09:57:31	00:03:14
Discussion	Problem solving	NW	09:57:31	09:58:52	00:01:21
Construct	Processing gate	VA	09:58:52	10:00:21	00:01:29
Material	Collecting materials and tools	NVA	10:00:21	10:03:50	00:03:29
Discussion	Small talk	NVA	10:03:50	10:04:24	00:00:34
Construct	Grinding of the gate	VA	10:04:24	10:13:53	00:09:29
Discussion	Problem solving	NW	10:13:53	10:15:17	00:01:24
Material	Moving the gate	NW	10:15:17	10:18:58	00:03:41
Discussion	Problem solving	NW	10:18:58	10:21:33	00:02:35
Break	Smoking	NVA	10:21:33	10:29:13	00:07:40
Material	Moving the gate	NW	10:29:13	10:33:51	00:04:38
Construct	Processing the gate	VA	10:33:51	10:35:52	00:02:01
Material	Fitting of the gate	NW	10:35:52	10:37:10	00:01:18
Construct	Processing the gate	VA	10:37:10	10:44:37	00:07:27
Material	Fitting of the gate	NW	10:44:37	10:50:42	00:06:05
Construct	Welding on the gate	VA	10:50:42	10:53:16	00:02:34
Discussion	Problem solving	NW	10:53:16	10:54:03	00:00:47
Construct	Grinding of the gate	VA	10:54:03	10:54:57	00:00:54
Discussion	Problem solving	NW	10:54:57	10:56:57	00:02:00
Construct	Welding	VA	10:56:57	10:57:51	00:00:54
Material	Fitting of the gate	NW	10:57:51	10:58:36	00:00:45
Construct	Welding	VA	10:58:36	11:01:54	00:03:18
Material	Fitting of the gate	NW	11:01:54	11:03:17	00:01:23
Discussion	Phone call/Problem solving	NW	11:03:17	11:04:17	00:01:00
Break	Coffee	NVA	11:04:17	11:37:53	00:33:36
Material	Handling material and tools	NVA	11:37:53	11:45:51	00:07:58
Construct	Cutting of gate	VA	11:45:51	11:53:27	00:07:36
Walk	Looking for material	NVA	11:53:27	11:54:21	00:00:54
Material	Moving material	NW	11:54:21	11:55:27	00:01:06
Discussion	Problem solving	NW	11:55:27	12:21:51	00:26:24
Construct	Cutting of gate	VA	12:21:51	12:28:48	00:06:57
Discussion	Small talk	NVA	12:28:48	12:30:27	00:01:39
Material	Gather material and tools	NVA	12:30:27	12:38:12	00:07:45
Walk	Leaving the site	NVA	12:38:12	12:42:02	00:03:50
TOTAL					**03:14:40**
VA					**24%**

NVA	**40%**
NW	**36%**

Appendix H.3.7 – Welding no.2

Company: Gothia Mekaniska AB	Date: 2011-04-29
Construction Site: Clarion Hotel Post	Observer: Arleroth, Jens
Value Flow: Construction Worker – Welding	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Joining team	NVA	09:14:41	09:16:22	00:01:41
Break	Smoking	NVA	09:16:22	09:19:59	00:03:37
Walk	Heading to position	NVA	09:19:59	09:25:00	00:05
Construct	Processing with sealing material	VA	09:25:00	09:33:43	00:08:43
Discuss	Problem solving	NW	09:33:43	09:35:25	00:01:42
Construct	Using bolt gun	VA	09:35:25	09:40:00	00:04:35
Waiting	Waiting for others to finishing their work	NVA	09:40:00	09:42:25	00:02:25
Construct	Sealing	VA	09:42:25	09:45:08	00:02:43
Material	Reload sealing tool	NW	09:45:08	09:45:51	00:00:43
Construct	Sealing	VA	09:45:51	09:47:32	00:01:41
Walk	Pick up material	NVA	09:47:32	09:49:33	00:02:01
Waiting	Waiting for others to finish their work	NVA	09:49:33	09:51:54	00:02:21
Material	Moving material	NW	09:51:54	09:55:27	00:03:33
Discuss	Problem solving	NW	09:55:27	09:59:00	00:03:33
Waiting	Waiting on tools	NVA	09:59:00	10:01:53	00:02:53
Waiting	Waiting on material	NVA	10:01:53	10:07:33	00:05:40
Waiting	Waiting for others to finish their work	NVA	10:07:33	10:08:17	00:00:44
Walk	Pick up material	NVA	10:08:17	10:11:02	00:02:45
Waiting	Waiting for others to finish their work	NVA	10:11:02	10:20:05	00:09:03
Material	Waiting on material	NVA	10:20:05	10:29:06	00:09:01
Discuss	Problem solving	NW	10:29:06	10:38:07	00:09:01
Waiting	Waiting for others to finish their work	NVA	10:38:07	10:39:34	00:01:27
Walk	Picking up material	NVA	10:39:34	10:42:02	00:02:28
Construct	Using bolt gun	VA	10:42:02	10:46:32	00:04:30
Material	Reload bolt gun	NW	10:46:32	10:47:05	00:00:33
Construct	Using bolt gun	VA	10:47:05	10:50:50	00:03:45
Discuss	Problem solving	NW	10:50:50	10:52:42	00:01:52
Construct	Sealing	VA	10:52:42	10:55:19	00:02:37
Break	Buying beverage in a nearby shop	NVA	10:55:19	11:19:33	00:24:14
Waiting	Waiting for others to finish their work	NVA	11:19:33	11:27:58	00:08:25
Material	Moving material	NW	11:27:58	11:30:12	00:02:14
Construct	Using bolt gun	VA	11:30:12	11:50:47	00:20:35
Waiting	Waiting for others to finish their work	NVA	11:50:47	11:52:45	00:01:58
Walk	Picking up material	NVA	11:52:45	11:53:52	00:01:07
Waiting	Waiting for others to finish their work	NVA	11:53:52	11:58:57	00:05:05
Waiting	Waiting on material	NW	11:58:57	12:02:53	00:03:56
Construct	Using bolt gun	VA	12:02:53	12:07:31	00:04:38
Waiting	Waiting for others to finish their work	NVA	12:07:31	12:13:41	00:06:10
Walk	Picking up material	NVA	12:13:41	12:14:56	00:01:15
Waiting	Waiting for others to finish their work	NVA	12:14:56	12:37:46	00:22:50
Construct	Shaping of metal	VA	12:37:46	12:43:45	00:05:59
Material	Handling material and tools	NW	12:43:45	12:45:06	00:01:21
Construct	Using bolt gun	VA	12:45:06	12:48:13	00:03:07
Material	Moving material	NW	12:48:13	12:51:16	00:03:03

Construct	Using screwdriver	VA	12:51:16	12:57:15	00:05:59
	LUNCH	-	12:57:15	13:38:57	00:41:42
Discuss	Small talk	NVA	13:38:57	13:42:19	00:03:22
Construct	Using bolt gun	VA	13:42:19	13:43:22	00:01:03
Material	Cleaning of tools	NW	13:43:22	13:50:26	00:07:04
Waiting	Waiting for others to finish their work	NVA	13:50:26	14:01:48	00:11:22
Discuss	Problem solving	NW	14:01:48	14:02:33	00:00:45
Construct	Using bolt gun	VA	14:02:33	14:07:19	00:04:46
Waiting	Waiting for others to finish their work	NVA	14:07:19	14:25:52	00:18:33
Construct	Cutting metal and using bolt gun	VA	14:25:52	14:35:14	00:09:22
Material	Gathering material	NVA	14:35:14	14:37:30	00:02:16
TOTAL					**04:41:07**
VA					**30%**
NVA					**57%**
NW					**13%**

Appendix H.3.8 – Welding no.3

Company: Gothia Mekaniska AB	Date: 2011-04-29
Construction Site: Clarion Hotel Post	Observer: Kristensson, Henrik
Value Flow: Construction Worker – Welding	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	Joining team	NVA	09:14:34	09:16:15	00:01:41
Break	Smoking	NVA	09:16:15	09:19:52	00:03:37
Walk	Heading to position	NVA	09:19:52	09:24:53	00:05:01
Construct	Processing with sealing material	VA	09:24:53	09:33:36	00:08:43
Discuss	Problem solving	NW	09:33:36	09:35:18	00:01:42
Construct	Shaping material	VA	09:35:18	09:39:53	00:04:35
Waiting	Waiting for others to finishing their work	NVA	09:39:53	09:42:18	00:02:25
Preparation	Shaping material	VA	09:42:18	09:45:01	00:02:43
Material	Cleaning tool	NW	09:45:01	09:45:44	00:00:43
Construct	Shaping material	VA	09:45:44	09:47:25	00:01:41
Walk	Pick up material	NVA	09:47:25	09:49:26	00:02:01
Preparation	Cutting metal	VA	09:49:26	09:51:47	00:02:21
Material	Moving material	NW	09:51:47	09:55:20	00:03:33
Discuss	Problem solving	NW	09:55:20	09:58:53	00:03:33
Preparation	Cutting metal	VA	09:58:53	10:01:46	00:02:53
Waiting	Waiting on material	NVA	10:01:46	10:07:26	00:05:40
Preparation	Cutting metal	VA	10:07:26	10:08:10	00:00:44
Walk	Pick up material	NVA	10:08:10	10:10:55	00:02:45
Preparation	Cutting material	VA	10:10:55	10:19:58	00:09:03
Waiting	Waiting on material	NVA	10:19:58	10:28:59	00:09:01
Discuss	Problem solving	NW	10:28:59	10:38:00	00:09:01
Construct	Shaping material	VA	10:38:00	10:39:27	00:01:27
Walk	Picking up material	NVA	10:39:27	10:41:55	00:02:28
Construct	Shaping material	VA	10:41:55	10:46:25	00:04:30
Material	Changing blade on tool	NW	10:46:25	10:46:58	00:00:33
Preparation	Shaping material	VA	10:46:58	10:50:43	00:03:45
Discuss	Problem solving	NW	10:50:43	10:52:35	00:01:52
Preparation	Cutting material	VA	10:52:35	10:55:12	00:02:37
Break	Buying beverage in a nearby shop	NVA	10:55:12	11:19:26	00:24:14
Preparation	Cutting metal	VA	11:19:26	11:27:51	00:08:25
Material	Handling material	NVA	11:27:51	11:30:37	00:02:46
Waiting	Waiting	NVA	11:30:37	11:34:19	00:03:42
Preparation	Measuring	NW	11:34:19	11:37:23	00:03:04
Walk	To material	NVA	11:37:23	11:38:59	00:01:36
Preparation	Cutting material	VA	11:42:18	11:42:43	00:00:25
Discuss	Small talk	NVA	11:42:43	11:45:32	00:02:49
Preparation	Measuring	NW	11:45:32	11:46:08	00:00:36
Walk	To where material is stored	NVA	11:46:08	11:47:46	00:01:38
Preparation	Measure	NW	11:47:46	11:52:51	00:05:05
Discuss	Small talk	NVA	11:52:12	11:52:51	00:00:39
Walk	Looking for material	NVA	11:52:51	11:54:25	00:01:34
Preparation	Measure where to cut	NW	11:54:25	11:55:13	00:00:48
Preparation	Cutting material	VA	11:55:13	11:56:01	00:00:48
Material	Moving material	NVA	11:56:01	11:59:35	00:03:34

Construct	Processing material	VA	11:59:35	12:03:13	00:03:38
Waiting	Waiting	NVA	12:03:13	12:05:03	00:01:50
Preparation	Measure	NW	12:05:03	12:13:33	00:08:30
Walk	Going back for more material	NVA	12:13:33	12:14:40	00:01:07
Material	Handling of material	NVA	12:14:40	12:17:42	00:03:02
Preparation	Measure	NW	12:17:42	12:23:26	00:05:44
Preparation	Cutting material	VA	12:23:26	12:27:41	00:04:15
Material	Carry material to work site	NVA	12:27:41	12:29:03	00:01:22
Preparation	Measure	NW	12:29:03	12:36:14	00:07:11
Discuss	Problem solving	NW	12:36:14	12:38:09	00:01:55
Preparation	Cutting sheet metal	VA	12:38:09	12:40:38	00:02:29
Material	Putting sheet metal in place	NVA	12:40:38	12:41:12	00:00:34
Construct	Shaping material	VA	12:41:12	12:41:51	00:00:39
Material	Handling material	NVA	12:41:51	12:45:49	00:03:58
Waiting	Waiting	NVA	12:45:49	12:46:24	00:00:35
Discuss	Small talk	NVA	12:46:24	12:47:27	00:01:03
Preparation	Measure	NW	12:47:27	12:48:29	00:01:02
Discuss	Problem solving	NW	12:48:29	12:50:57	00:02:28
Waiting	Wait	NVA	12:50:57	12:51:36	00:00:39
Discuss	Small talk	NVA	12:51:36	12:54:24	00:02:48
Break	Going early to lunch	NVA	12:54:24	13:00:00	00:05:36
-	LUNCH	-	13:00:00	13:30:00	00:30:00
Break	Coming late from lunch	NVA	13:30:00	13:34:32	00:04:32
Other	Measure	NW	13:34:32	13:42:26	00:07:54
Discuss	Problem solving	NW	13:42:26	13:49:18	00:06:52
Walk	Going for more material	NVA	13:49:18	13:50:08	00:00:50
Material	Handling material and tools	NVA	13:50:08	13:52:26	00:02:18
Preparation	Measuring	NW	13:52:26	13:54:56	00:02:30
Preparation	Cutting sheet metal	VA	13:54:56	13:56:21	00:01:25
Material	Tools	NVA	13:56:21	13:57:39	00:01:18
Preparation	Cutting sheet metal	VA	13:57:39	13:58:41	00:01:02
Material	To work site	NVA	13:58:41	14:00:47	00:02:06
Discuss	Small talk	NVA	14:00:47	14:01:01	00:00:14
Preparation	Measure	NW	14:01:01	14:02:25	00:01:24
Waiting	Wait	NVA	14:02:25	14:04:13	00:01:48
Discuss	Small talk	NVA	14:04:13	14:05:35	00:01:22
Walk	Going for more material	NVA	14:05:35	14:06:51	00:01:16
Material	Handling material and tools	NVA	14:06:51	14:08:04	00:01:13
Preparation	Measuring	NW	14:08:04	14:09:17	00:01:13
Preparation	Cutting sheet metal	VA	14:09:17	14:10:14	00:00:57
Material	Carry material	NVA	14:10:14	14:12:29	00:02:15
Preparation	Measuring	NW	14:12:29	14:14:20	00:01:51
Material	Getting tools	NVA	14:14:20	14:16:33	00:02:13
Waiting	Wait	NVA	14:16:33	14:18:19	00:01:46
Preparation	Cutting sheet metal	VA	14:18:19	14:20:58	00:02:39
Preparation	Measure	NW	14:20:58	14:24:00	00:03:02
Preparation	Cutting sheet metal	VA	14:24:00	14:29:32	00:05:32
Material	Tools before going home	NVA	14:29:32	14:31:25	00:01:53
TOTAL					**04:44:11**
VA					**27%**
NVA					**44%**
NW					**29%**

Appendix H.3.9 – Electrician no.1

Company: Bravida	Date: 2011-05-02
Construction Site: Clarion Hotel Post	Observer: Kristensson, Henrik
Value Flow: Construction Worker – Electrician	Pages: 2

Activity	Description	Classification	Start	End	Duration
Walk	To work place	NVA	09:21:14	09:24:54	00:03:40
Preparation	Prepare material	NW	09:24:54	09:26:37	00:01:43
Construct	Electrical cables	VA	09:26:37	09:34:51	00:08:14
Material	Fetch material	NVA	09:34:51	09:35:20	00:00:29
Construct	Drag hose	VA	09:35:20	09:35:59	00:00:39
Material	Get material	NVA	09:35:59	09:36:23	00:00:24
Construct	Electrical cables	VA	09:36:23	10:00:58	00:24:35
Material	Get forgotten material	NVA	10:00:58	10:01:32	00:00:34
Walk	Walk to see where to work next	NVA	10:01:32	10:03:29	00:01:57
Discuss	Small talk colleague	NVA	10:03:29	10:04:01	00:00:32
Walk	Walk to see where to work	NVA	10:04:01	10:08:36	00:04:35
Material	Move material to new site	NW	10:08:36	10:17:18	00:08:42
Preparation	Measuring	NW	10:17:18	10:18:03	00:00:45
Construct	Drilling	VA	10:18:03	10:22:44	00:04:41
Preparation	Measuring	NW	10:22:44	10:24:46	00:02:02
Construct	Drilling	VA	10:24:46	10:34:25	00:09:39
Break	Bathroom inkl walk	NVA	10:34:25	10:41:04	00:06:39
Construct	Electrical cables	VA	10:41:04	11:16:23	00:35:19
Walk	Walk to coffe break	NVA	11:16:23	11:20:18	00:03:55
Break	Coffee	NVA	11:20:18	11:35:43	00:15:25
Walk	Walk from coffee break	NVA	11:35:43	11:40:32	00:04:49
Material	Get missing material	NVA	11:40:32	11:43:12	00:02:40
Construct	Electrical cables	VA	11:43:12	12:28:53	00:45:41
Material	Get missing material	NVA	12:28:53	12:29:17	00:00:24
Construct	Electrical cables	VA	12:29:17	12:50:03	00:20:46
Material	Move to next room	NW	12:50:03	12:54:13	00:04:10
Construct	Electrical calbes	VA	12:54:13	12:55:26	00:01:13
Walk	Walk to bathroom	NVA	12:55:26	13:00:10	00:04:44
Break	Bathroom	NVA	13:00:10	13:05:22	00:05:12
Walk	Walk back	NVA	13:05:22	13:09:55	00:04:33
Material	Fetch material	NW	13:09:55	13:15:46	00:05:51
Construct	Drilling + draging cables	VA	13:15:46	13:17:19	00:01:33
Material	Get tools	NVA	13:17:19	13:18:02	00:00:43
Construct	Electrical cables	VA	13:18:02	13:30:14	00:12:12
-	LUNCH	-	13:30:14	14:00:33	00:30:19
Walk	To work site	NVA	14:00:33	14:06:09	00:05:36
Material	Move to new work site	NVA	14:06:09	14:07:28	00:01:19
Construct	Electrical cables	VA	14:07:28	14:41:58	00:34:30
Material	Get more cables	NVA	14:41:58	14:42:47	00:00:49
Construct	Electrical cables	VA	14:42:47	15:16:24	00:33:37
Material	Move material to new site	NW	15:16:24	15:19:05	00:02:41
Walk	To bathroom	NVA	15:19:05	15:23:57	00:04:52
Break	Bathroom	NVA	15:23:57	15:30:47	00:06:50
Walk	Back from bathroom	NVA	15:30:47	15:34:04	00:03:17
Construct	Electrical cables	VA	15:34:04	15:50:51	00:16:47

Material	Put material back	NVA	15:50:51	15:57:20	00:06:29
Walk	To material container	NVA	15:57:20	16:00:51	00:03:31
TOTAL					**06:09:18**
VA					**68%**
NVA					**25%**
NW					**7%**

Appendix I – Potential Savings

This is a calculation example on PEAB's construction cost for the year 2010. PEAB's net sale for 2010 was 38 billion SEK but the construction segment stand for 56% of this value and the PEAB's Swedish market stand for 85% of this net sale. Therefore, the net sale for PEAB's Swedish construction segment is: 38.000 million SEK x 56% x 85% = 18.088 million SEK. PEAB's profit margin for 2010 was four percent (PEAB, 2010) (100% - 4% = 96%) and the labor cost is usually around 25% (Statistics Sweden, 2004).

The digits written in bold text respond to how the situation at a PEAB construction site is today (the results of the VSMs studies that were made in this master's thesis). From this, the reader can easily follow the potential savings that can be made (the two last columns) if non-value adding activities and necessary waste are reduced.

Net Sale (million SEK)	Profit margin	Labor Cost	VA	NVA	NW	Waste Cost (million SEK)	% of Project Cost	Cost Savings (million SEK + %)	
18 088	96%	25%	40,00%	37,00%	23,00%	2 604,67	14,40%	-167,41	-0,93%
18 088	96%	25%	41,00%	37,00%	22,00%	2 561,26	14,16%	-123,99	-0,69%
18 088	96%	25%	42,00%	37,00%	21,00%	2 517,85	13,92%	-80,58	-0,45%
18 088	96%	25%	43,00%	36,50%	20,50%	2 474,44	13,68%	-37,17	-0,21%
18 088	**96%**	**25%**	**43,86%**	**36,15%**	**20,00%**	**2 437,27**	**13,47%**	**0**	**0,00%**
18 088	96%	25%	44,00%	36,00%	20,00%	2 431,03	13,44%	6,24	0,03%
18 088	96%	25%	45,00%	35,50%	19,50%	2 387,62	13,20%	49,65	0,27%
18 088	96%	25%	46,00%	35,00%	19,00%	2 344,20	12,96%	93,06	0,51%
18 088	96%	25%	47,00%	34,50%	18,50%	2 300,79	12,72%	136,47	0,75%
18 088	96%	25%	48,00%	34,00%	18,00%	2 257,38	12,48%	179,88	0,99%
18 088	96%	25%	49,00%	33,50%	17,50%	2 213,97	12,24%	223,30	1,23%
18 088	96%	25%	50,00%	33,00%	17,00%	2 170,56	12,00%	266,71	1,47%
18 088	96%	25%	51,00%	32,50%	16,50%	2 127,15	11,76%	310,12	1,71%
18 088	96%	25%	52,00%	32,00%	16,00%	2 083,74	11,52%	353,53	1,95%
18 088	96%	25%	53,00%	31,50%	15,50%	2 040,33	11,28%	396,94	2,19%
18 088	96%	25%	54,00%	31,00%	15,00%	1 996,92	11,04%	440,35	2,43%
18 088	96%	25%	55,00%	30,50%	14,50%	1 953,50	10,80%	483,76	2,67%
18 088	96%	25%	56,00%	30,00%	14,00%	1 910,09	10,56%	527,17	2,91%
18 088	96%	25%	57,00%	29,50%	13,50%	1 866,68	10,32%	570,59	3,15%
18 088	96%	25%	58,00%	29,00%	13,00%	1 823,27	10,08%	614,00	3,39%
18 088	96%	25%	59,00%	28,50%	12,50%	1 779,86	9,84%	657,41	3,63%
18 088	96%	25%	60,00%	28,00%	12,00%	1 736,45	9,60%	700,82	3,87%
18 088	96%	25%	61,00%	27,50%	11,50%	1 693,04	9,36%	744,23	4,11%
18 088	96%	25%	62,00%	27,00%	11,00%	1 649,63	9,12%	787,64	4,35%
18 088	96%	25%	63,00%	26,50%	10,50%	1 606,21	8,88%	831,05	4,59%
18 088	96%	25%	64,00%	26,00%	10,00%	1 562,80	8,64%	874,46	4,83%
18 088	96%	25%	65,00%	25,50%	9,50%	1 519,39	8,40%	917,87	5,07%
18 088	96%	25%	66,00%	25,00%	9,00%	1 475,98	8,16%	961,29	5,31%
18 088	96%	25%	67,00%	24,50%	8,50%	1 432,57	7,92%	1 004,70	5,55%
18 088	96%	25%	68,00%	24,00%	8,00%	1 389,16	7,68%	1 048,11	5,79%

18 088	96%	25%	69,00%	23,50%	7,50%	1 345,75	7,44%	1 091,52	6,03%
18 088	96%	25%	70,00%	23,00%	7,00%	1 302,34	7,20%	1 134,93	6,27%

These kinds of estimations can be made for the whole Swedish construction industry. The Swedish construction industry stands for approximately 10% of Sweden's GDP (Lutz & Gabrielsson, 2002) and is relatively stable over time. Since the value of the Swedish GDP for year 2009 was around 3.100 billion SEK (Radio Sweden, 2010) ten percent of this is 310.000 million SEK. This lead to the following estimations:

Net Sale (million SEK)	Profit margin	Labor Cost	VA	NVA	NW	Waste Cost (million SEK)	% of Project Cost	Cost Savings (million SEK + %)	
310 000	96%	25%	40,00%	37,00%	23,00%	44 640,00	14,40%	-2 869,06	-0,93%
310 000	96%	25%	41,00%	37,00%	22,00%	43 896,00	14,16%	-2 125,06	-0,69%
310 000	96%	25%	42,00%	37,00%	21,00%	43 152,00	13,92%	-1 381,06	-0,45%
310 000	96%	25%	43,00%	36,50%	20,50%	42 408,00	13,68%	-637,06	-0,21%
310 000	**96%**	**25%**	**43,86%**	**36,15%**	**20,00%**	**41 770,94**	**13,47%**	**0**	**0,00%**
310 000	96%	25%	44,00%	36,00%	20,00%	41 664,00	13,44%	106,94	0,03%
310 000	96%	25%	45,00%	35,50%	19,50%	40 920,00	13,20%	850,94	0,27%
310 000	96%	25%	46,00%	35,00%	19,00%	40 176,00	12,96%	1 594,94	0,51%
310 000	96%	25%	47,00%	34,50%	18,50%	39 432,00	12,72%	2 338,94	0,75%
310 000	96%	25%	48,00%	34,00%	18,00%	38 688,00	12,48%	3 082,94	0,99%
310 000	96%	25%	49,00%	33,50%	17,50%	37 944,00	12,24%	3 826,94	1,23%
310 000	96%	25%	50,00%	33,00%	17,00%	37 200,00	12,00%	4 570,94	1,47%
310 000	96%	25%	51,00%	32,50%	16,50%	36 456,00	11,76%	5 314,94	1,71%
310 000	96%	25%	52,00%	32,00%	16,00%	35 712,00	11,52%	6 058,94	1,95%
310 000	96%	25%	53,00%	31,50%	15,50%	34 968,00	11,28%	6 802,94	2,19%
310 000	96%	25%	54,00%	31,00%	15,00%	34 224,00	11,04%	7 546,94	2,43%
310 000	96%	25%	55,00%	30,50%	14,50%	33 480,00	10,80%	8 290,94	2,67%
310 000	96%	25%	56,00%	30,00%	14,00%	32 736,00	10,56%	9 034,94	2,91%
310 000	96%	25%	57,00%	29,50%	13,50%	31 992,00	10,32%	9 778,94	3,15%
310 000	96%	25%	58,00%	29,00%	13,00%	31 248,00	10,08%	10 522,94	3,39%
310 000	96%	25%	59,00%	28,50%	12,50%	30 504,00	9,84%	11 266,94	3,63%
310 000	96%	25%	60,00%	28,00%	12,00%	29 760,00	9,60%	12 010,94	3,87%
310 000	96%	25%	61,00%	27,50%	11,50%	29 016,00	9,36%	12 754,94	4,11%
310 000	96%	25%	62,00%	27,00%	11,00%	28 272,00	9,12%	13 498,94	4,35%
310 000	96%	25%	63,00%	26,50%	10,50%	27 528,00	8,88%	14 242,94	4,59%
310 000	96%	25%	64,00%	26,00%	10,00%	26 784,00	8,64%	14 986,94	4,83%
310 000	96%	25%	65,00%	25,50%	9,50%	26 040,00	8,40%	15 730,94	5,07%
310 000	96%	25%	66,00%	25,00%	9,00%	25 296,00	8,16%	16 474,94	5,31%
310 000	96%	25%	67,00%	24,50%	8,50%	24 552,00	7,92%	17 218,94	5,55%
310 000	96%	25%	68,00%	24,00%	8,00%	23 808,00	7,68%	17 962,94	5,79%
310 000	96%	25%	69,00%	23,50%	7,50%	23 064,00	7,44%	18 706,94	6,03%
310 000	96%	25%	70,00%	23,00%	7,00%	22 320,00	7,20%	19 450,94	6,27%