

**VALUE STREAM MAPPING –
A CASE STUDY OF CONSTRUCTION SUPPLY CHAIN
OF PREFABRICATED MASSIVE TIMBER FLOOR
ELEMENT**

VÄXJÖ, 2007-05-23

JOACHIM GUSTAVSSON, 820224-2718, FED370

CINDY MARZEC, 810129-6542, FED370

TUTOR: ÅSA GUSTAFSSON

EXAMINER: HELENA FORSLUND

“THE ROAD TO EXCELLENCE
IS ALWAYS UNDER CONSTRUCTION”

ORGANIZATION VÄXJÖ UNIVERSITY School of Management and Economics		AUTHORS Joachim Gustafsson Cindy Marzec	
TYPE OF DOCUMENT Master Thesis	TUTOR Åsa Gustafsson	EXAMINER Helena Forslund	
TITLE AND SUBTITLE Value stream mapping – A case study of the construction supply chain of massive timber floor element			
ABSTRACT <p>The purpose of this Master Thesis is to study how the value stream mapping concept can be applied along the construction supply chain for prefabricated massive timber floor elements. Identification and qualification of waste are starting points to propose suggestions on how to reduce and/or eliminate them. In order to use the value stream mapping along the construction supply chain, pertinent data has been collected and analyzed. To conduct the value stream mapping, the first three steps of the lean thinking principles in construction have been followed. The first step aims at defining the customer and his value as well as the value for the delivery team and how it is specified in the product. The second step is based on identifying the value stream and this is done through defining the resources and activities needed to manufacture, deliver and install the floor elements. This is conducted by using the VSMM methodology. In addition the current practice should be standardized and key component suppliers should be defined and located. The third and last step identifies non-value adding activities, in other words waste and suggestions on how to remove and/or reduce waste have been reached. Wastes from product defects, transportation waste and waste of waiting were to be found in the construction supply chain. Propositions to reduce and/or eliminate wastes were to implement a more careful planning of the manufacturing process and production schedule, to apply lean production principles in the manufacturing facility and decrease and or eliminate storage time. The study made has shown that in the supply chain of massive timber floor elements at Limnologen there is a big potential to lower costs and increase customer value as value added-time accounted for only 2% of the total time.</p>			
KEY WORDS: Lean production, Lean construction, Element prefabrication, Waste, Massive timber floor system, Multi-storey			
YEAR OF ISSUE 2007	LANGUAGE English	NUMBER OF PAGES 108	
INTERNET/WWW http://www.vxu.se/			

ACKNOWLEDGEMENTS

Our first thanks is addressed to our tutor, Åsa Gustafsson and Lars-Olof Rask without whom this Master Thesis would not have been of this world and we are also sincerely grateful for the valuable help and feedback they provided us while conducting and writing this thesis.

We would like to express our gratitude to all the persons that contributed with providing us information, opinions and valuable insights on the Limnologen project and the construction process. Most of all we would like to address a special thanks to Bengt Abelsson, project engineer at Martinsons Byggsystem AB for taking the time to explain us the process and answer our numerous questions.

We would also like to thank our examiner, Helena Forslund, for her insights and feedbacks.

To everyone, once again... thanks for everything.

VÄXJÖ, MAY 2007

Joachim Gustavsson

Cindy Marzec

DEFINITIONS

CRANE: a machine that lifts and moves heavy weights in suspension, (dictionary.com, 20070517).

ELEMENT PREFABRICATION: The element is manufactured in the environment of a factory where manufacturing processes are controlled. Then the element is transported to the construction site to be assembled together with other elements and sub-assemblies. (Höök & Stehn, 2005:319)

LEAN CONSTRUCTION: Lean construction can be defined as handling a construction project as a temporary production system while delivering the product with maximum value and minimum of waste, (Ballard & Howell, 2004:39).

LEAN PRODUCTION: Lean production refers to the system developed for Toyota as a way to reduce muda (waste in Japanese), in order to optimize flow and value towards the end customer, (Womack et al., 1990:13).

MASSIVE TIMBER FLOOR SYSTEM: A floor system that is composed of several floor elements and made of massive wood.

PREFABRICATION: Refers to fabricating all or part of an object in some place other than its final position, (Ballard & Arbulu, 2004:4).

LIST OF ABBREVIATIONS

JIT:	J UST-IN-TIME
WIP:	W ORK IN P ROCESS
VSM:	V ALUE S TREAM M APPING
VSMM:	V ALUE S TREAM M ACRO M APPING

TABLE OF CONTENTS

1. INTRODUCTION	5
1.1 THEORETICAL BACKGROUND.....	5
1.2 PRACTICAL BACKGROUND.....	6
1.3 PROBLEM DISCUSSION	7
1.4 PROBLEM FORMULATION	8
1.5 PURPOSE.....	8
1.6 THESIS DISPOSITION.....	8
2. METHODOLOGY	10
2.1 SCIENTIFIC PERSPECTIVE	10
2.2 SCIENTIFIC APPROACH.....	11
2.3 RESEARCH METHOD.....	12
2.4 CASE STUDY	12
2.5 DATA COLLECTION	14
2.6 SCIENTIFIC CREDIBILITY	16
2.6.1 VALIDITY	16
2.6.2 RELIABILITY	17
2.6.3 TESTING OF THE RESEARCH DESIGN	18
2.7 SUMMARY	18
2.8 TIMEFRAME	19
3. THEORETICAL FRAMEWORK	20
3.1 CONSTRUCTION NATURE AND PECULIARITIES	21
3.1.1 ONE-OF-A-KIND PRODUCT	21
3.1.2 PRODUCTION LAYOUT	21
3.1.3 ON-SITE PRODUCTION.....	22
3.1.4 TEMPORARY MULTIORGANIZATION	22
3.1.5 COMPLEXITY	22
3.1.6 UNCERTAINTY	23
3.2 PREFABRICATION AND ELEMENT PREFABRICATION	23
3.3 LEAN CONSTRUCTION	24
3.4 VALUE.....	26
3.5 VALUE STREAM	27
3.6 VALUE STREAM MACRO MAPPING (VSMM)	28
3.6.1 SELECTION OF A FAMILY OF PRODUCTS	29
3.6.2 MAP OF THE CURRENT STATE	29
3.6.3 ANALYSIS OF THE MAP OF THE CURRENT STATE	31
3.6.4 MAP OF THE FUTURE STATE	32
3.7 WASTE	32
3.7.1 WASTE IN THE SWEDISH CONSTRUCTION INDUSTRY	33
4. EMPIRICAL FINDINGS	34
4.1 THE SUPPLY CHAIN FOR LIMNOLOGEN.....	34
4.2 MANUFACTURING AND PREFABRICATION	35
4.2.1 THE MANUFACTURER OF THE FLOOR ELEMENT – MARTINSONS GROUP AB.....	35
4.2.2 THE MANUFACTURING PROCESS AT MARTINSONS BYGGSYSTEM AB	36

4.2.3 THE PREFABRICATED FLOOR ELEMENT – TECHNICAL SPECIFICATION	39
4.3 TRANSPORT AND DELIVERY	41
4.3.1 THE SHIPPER - DHL	41
4.3.2 PLANNED DELIVERY SCHEDULE	41
4.3.3 REVISED DELIVERY SCHEDULE	42
4.4 INSTALLATION OF FLOOR ELEMENTS	43
4.4.1 THE BUILDING ENTREPRENEUR - NCC CONSTRUCTION SWEDEN	43
4.4.2 THE INSTALLATION PROCESS AT LIMNOLOGEN	44
4.4.3 DAILY ERROR REPORTS	46
4.4.4 LIMNOLOGEN	46
4.5 CUSTOMER	47
4.5.1 THE BUILDING PROPRIETOR - MIDROC PROPERTY DEVELOPMENT AB	47
5. ANALYSIS	48
5.1 LEAN PRINCIPLE – VALUE	49
5.1.1 DEFINE THE CUSTOMER	49
5.1.2 DEFINE WHAT IS OF VALUE TO THE CUSTOMER	49
5.1.4 DEFINE HOW VALUE IS SPECIFIED BY PRODUCTS	53
5.2 LEAN PRINCIPLE – VALUE STREAM	53
5.2.1 DEFINE ALL RESOURCES REQUIRED FOR PRODUCTION	54
5.2.2 DEFINE ALL ACTIVITIES REQUIRED FOR PRODUCTION	54
5.2.3 STANDARDIZE CURRENT PRACTICE	56
5.2.4 DEFINE AND LOCATE KEY COMPONENT SUPPLIERS	57
5.3 LEAN PRINCIPLE – FLOW	57
5.3.1 IDENTIFY NON-VALUE ADDING ACTIVITIES (WASTE)	58
5.3.2 REMOVE OR REDUCE THE INFLUENCE OF WASTE AS IT IS OBSERVED	66
6. CONCLUSIONS	68
6.1 ANSWER TO THE PROBLEM FORMULATION	68
6.2 REFLECTIONS	70
6.3 SUGGESTIONS FOR FUTURE RESEARCHES	71
BIBLIOGRAPHY	I

LIST OF FIGURES

FIGURE 1.1 – THESIS DISPOSITION MODEL	9
FIGURE 2.1 – SCIENTIFIC PERSPECTIVE	10
FIGURE 2.2 – DEDUCTION AND INDUCTION	11
FIGURE 2.3 – SCIENTIFIC APPROACHES	11
FIGURE 2.4 – RESEARCH METHODS	12
FIGURE 2.5 – CASE STUDIES	13
FIGURE 2.6 – SUMMARY OF METHODOLOGICAL CHOICES	19
FIGURE 3.1 – OVERVIEW OF THEORETICAL FRAMEWORK	20
FIGURE 3.2 – ELEMENT PREFABRICATION	24
FIGURE 3.3 – A NEW VALUE BASED BUILDING PROCESS – 7 C'S	26
FIGURE 3.4 – DIFFERENT CONSTRUCTION FLOWS	28
FIGURE 4.1 – OVERVIEW OF EMPIRICAL FINDINGS	34

FIGURE 4.2 – FACT SHEET	34
FIGURE 4.3 – ACTORS OF INTEREST	35
FIGURE 4.3 – GLUING & PACKING	37
FIGURE 4.5 – CUT & FLOOR HEATING PREPARATION	37
FIGURE 4.6 – T-SHAPED CROSS SECTIONS	37
FIGURE 4.7 – UNDER-ROOF	37
FIGURE 4.8 – PACKING PREPARATION	37
FIGURE 4.9 – EXAMPLE OF A PREFABRICATED FLOOR ELEMENTS	39
FIGURE 4.10 – FLOOR STRUCTURE DRAWING	40
FIGURE 4.11 – AN OVERVIEW OF ASSEMBLY, MANUFACTURING AND DELIVERY OF FLOOR ELEMENTS	42
FIGURE 4.12 – UNLOADING OF ELEMENTS	45
FIGURE 4.13 – LIFTING OF ELEMENTS	45
FIGURE 4.14 – INSTALLATION	45
FIGURE 5.1 – OVERVIEW OF ANALYSIS	48
FIGURE 5.2 – A NEW VALUE BASED BUILDING PROCESS – 7 C's	50
FIGURE 5.3 – FACT SHEET	51
FIGURE 5.4 – VALUE AND NON-VALUE ADDING TIME FOR THE WHOLE PROCESS	60
FIGURE 5.5 – VSM FOR MARTINSONS BYGGSYSTEM AB	61
FIGURE 5.6 – VSM FOR LIMNOLOGEN	61
FIGURE 5.7 – VSM FOR THE STUDIED SUPPLY CHAIN	62
FIGURE 5.8 – ISHIKAWA DIAGRAM REGARDING FLOOR NUMBER 2 AND 3	63

LIST OF TABLES

TABLE 2.1 – OVERVIEW OF CASE STUDY BOUNDARIES	13
TABLE 2.2 – OVERVIEW OF DATA COLLECTION TECHNIQUES	14
TABLE 2.3 – OVERVIEW OF INTERVIEWS	15
TABLE 2.4 – OVERVIEW OF SECONDARY DATA SOURCES	15
TABLE 2.5 – CASE STUDY TACTICS FOR FOUR DESIGN TESTS	17
TABLE 2.6 – TIMEFRAME, ORIGINAL PLAN AND OUTCOME	19
TABLE 3.1 – CONCEPTUALIZATION OF THE LEAN THINKING PRINCIPLES IN CONSTRUCTION	25
TABLE 3.2 – PHYSICAL ACTIONS REQUIRED TO CREATE A PRODUCT	30
TABLE 4.1 – MANUFACTURING PROCESS AT MARTINSONS BYGGSYSTEM AB	38
TABLE 4.2 – DELIVERY SCHEDULE	43
TABLE 4.3 – INSTALLATION STEPS AT LIMNOLOGEN	45
TABLE 4.4 – SUMMARY OF THE DAILY ERROR REPORTS	46
TABLE 5.1 – PHYSICAL ACTIONS AND CORRESPONDING TIME	55
TABLE 5.2 – PHYSICAL ACTIONS AND CORRESPONDING TIME , VALUE CREATING STEPS AND TIME	58
TABLE 5.3 – WASTE ENCOUNTERED IN THE SUPPLY CHAIN CLASSIFIED ACCORDING TO THE SEVEN WASTES CLASSIFICATION	64
TABLE 5.4 – SUMMARY OF THE DAILY ERROR REPORTS	65

LIST OF APPENDIXES

APPENDIX I – MANUFACTURING OF FLOOR ELEMENTS, MARTINSONS BYGGSYSTEM AB’S FACILITY, BYGDSILJUM

APPENDIX II – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL ONE FLOOR ELEMENT

APPENDIX III – FIRST VIEW OF THE CURRENT STATE MAP SHOWING THE CUSTOMER

APPENDIX IV – CURRENT STATE MAP SHOWING ALL FACILITIES

APPENDIX V – CURRENT STATE MAP SHOWING ALL FACILITIES AND DATA BOXES

APPENDIX VI – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES AND TRANSPORT LINK USING TRUCK SHIPPING

APPENDIX VII – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES AND TRANSPORT LINKS USING BOTH TRUCK SHIPPING AND RAIL

APPENDIX VIII – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES, TRANSPORT LINKS AND TIME-AND-STEPS-LINE

APPENDIX IX – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES, TRANSPORT LINKS, TIME-AND-STEPS-LINE AND INFORMATIONFLOW

APPENDIX X – THE ICONS SIGNIFICATION OF THE ICONS USED IN THE THESIS

APPENDIX XI – EXAMPLE OF FLOOR DESIGN IN ONE OF THE LIMNOLOGEN BUILDINGS

APPENDIX XII – DIFFERENT MODELS OF PREFABRICATED FLOOR ELEMENTS

APPENDIX XIII – PHOTOS FROM THE LIMNOLOGEN PROJECT 1

APPENDIX XIV – SUMMARY OF DAILY ERROR REPORTS

APPENDIX XV – PHOTOS FROM THE LIMNOLOGEN PROJECT 2

APPENDIX XVI – DELIVERY AND PRODUCTION SCHEDULE FOR MARTINSONS BYGGSYSTEM AB AND LIMNOLOGEN

APPENDIX XVII – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL 6 PACKAGES OF FLOOR ELEMENTS

APPENDIX XVIII – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL 1 FLOOR ELEMENT

APPENDIX XIX – VSM FOR MARTINSONS BYGGSYSTEM AB

APPENDIX XX – VSM FOR LIMNOLOGEN

APPENDIX XXI – VSMM FOR THE STUDIED SUPPLY CHAIN

1. INTRODUCTION

The purpose of this chapter is to introduce the reader to the concepts of industrialization, lean construction and the Limnologen project. The chapter commences with the background and thereafter associated problems are highlighted and discussed. The problem formulation is outlined and then makes way for the purpose of this Master Thesis. The chapter ends with the continued disposition for the thesis.

1.1 THEORETICAL BACKGROUND

Competition within the construction industry is increasing more and more, (Hong-Minh et al., 2001:49) and therefore in order to stay in the market, companies are looking for ways to build faster, better and cheaper, (Sawyer, 2006:24). Competitiveness can be achieved through different means, for example by delivering a cheap product or marketing a high quality product. To offer a cheap product, the company must be a low-cost producer. (Chase et al, 2006:25) To be able to produce at the lowest cost possible it is essential to identify waste or activities that do not add value to the product since as defined by Womack & Jones (1996), quoted by Saukkoriipi (2004:2) a non value-added activity is “*an activity which absorbs resources but creates no value*”. Waste is a characteristic for supply chains in the construction industry, (Arbulu & Tommelein, 2002:183), and hinders supply chain performance, (Arbulu & Tommelein, 2002:11). This is agreed by Polat & Ballard (2004:1) who argue that one of the major problems in the construction industry is a high level of waste.

One possible solution to the issues of construction is industrialization (i.e. prefabrication and modularisation), (Koskela, 2000:14). Lessing (2006) defines industrialized house-building quoted by Björnfort (2006:1) as “*a thoroughly developed building process with a well-suited organization for efficient management, preparation and control of included activities, flows, resources and results for which highly developed components are used in order to create a maximum customer value*”.

Besides the concept of industrialization, the lean construction concept has been derived from earlier efforts in the manufacturing industry where lean manufacturing has been used for decades. It was originally developed by Toyota in Japan to lower costs and to reach higher performance levels and has now been adapted and implemented into construction processes. (Conte & Gransberg, 2001:10.1; Bertelsen, 2004:47)

Lean Construction can be defined as handling a construction project as a temporary production system while delivering the product with maximum value and minimum of waste, (Ballard & Howell, 2004:39). This can be achieved by developing a value stream that eliminates waiting time and ensures a level schedule, (Naim & Barlow, 2003:594) and to do so organizations have at their disposition a tool called Value-Stream Mapping (VSM). VSM documents graphically every stage concerned by the material and information flows starting from the reception of an order and ending with the delivery to the end customer, (Bulhões et al, 2005:100; Abdumalek & Rajgopal, 2006:235).

1.2 PRACTICAL BACKGROUND

In October, the 6th 2006, the first stone was laid for what is going to be the highest timber multi-storey housing in Sweden, Limnologen. (mpd.midroc.se, 0705007) Limnologen is a group of four wooden buildings that are eight-storied. Only the first two buildings are estimated to an approximate SEK 300 million investment, which will comprise 134 apartments, ranging from one-room to five-room flats. (affkapnytt.se, 070411) Limnologen is located at the tip of the Trummen Lake; which is situated between the university and downtown Växjö. (vallebroar.se, 070411)

The whole building will be built using wood, including the framework, with exception made for the ground floor that will be built in concrete. Wood is advantageous to use in construction projects compared to other materials; because it can be up to 47 times stronger than concrete and at the same time it is 19 times lighter, (Teleman, et al, 2003:22). Wood is relatively resistant against chemicals, acids and alkalis, (Teleman, et al, 2003:48) and furthermore timber frameworks stand fire notably longer than steel constructions, (Teleman, et al, 2003:32). Moreover using more wood in construction projects has positive effects on the environment and diminishes the green house effects. (Teleman, et al, 2003:21) This is because wood absorbs carbon dioxide and emits oxygen. (Teleman, et al, 2003:22)

The massive timber floor system will be prefabricated and supplied by Martinsons Byggsystem AB. Martinsons Byggsystem AB has its facility in Bygdsiljum, a small town located in the North East of Sweden and 1 200 km apart from Växjö. Thus the floor is transported on a trailer in ten elements which are then installed and assembled by NCC, the building entrepreneur. Each floor-level is optimally planned to take ten days for erection

excluding installation of for example sprinkler and water systems and cables, (interview, 070507). The floor system accounts for 6-7% of the total cost of the building (interview, 070516).

1.3 PROBLEM DISCUSSION

If construction companies want to achieve goals like constructing buildings faster, better and cheaper as proposed by Sawyer (2006:24) it is as Ballard and Howell (2004:38-39) argue impossible to hold on to old principles and traditions. To be able to provide cheap products at a high quality construction companies need to find new ways of staying competitive. There is a need to lower costs and at the same time provide as high customer value as possible. This is especially difficult for construction companies since the construction industry is considered to be plagued with high costs and waste (unnecessary material and activities) (Arbulu & Tommelein, 2002:183; Polat & Ballard 2004:1) which hinders supply chain performance (Arbulu & Tommelein, 2002:11). For example it has been documented in a Swedish study of the construction industry that waste corresponds to between 30-35% of the total cost of the projects. The main reason for this is a lack of insight on which activities add value or not to customers. (Josephson & Saukkoriipi, 2005:7) In the same way according to Koskela (2000:132) construction costs in Sweden have been rising since the 1970's.

As Ballard and Howell (2004:38-39) argue there is a need for a new paradigm such as lean construction, since old traditions such as on-site construction have resulted in a lot of construction projects not meeting plans and goals in the specified time. Ever since Koskela (1992) founded the concept of lean construction (stemming from lean production), there has been a lot of research going on discussing whether the lean philosophy can actually be applied in the construction environment or not. A concept closely related to lean construction is industrialized housing using different grades of prefabrication. There are arguments that prefabrication effectively reduces waste and shorten construction lead times (Koskela, 2000:14). However there are also arguments that prefabrication introduces new challenges to effectively manage the supply chain such as just in time (JIT) (Höök & Stehn, 2005:317).

The use of prefabrication of components, elements or volumes is not new in the construction industry. A lot of prefabricated buildings already exist. When considering materials such as wood however the use of prefabrication practices are very rare. In fact the Limnologen project

in Växjö is one of the very first projects in Europe to use construction technology that is based on prefabrication of complete massive timber floor elements. As argued by Serrano et al, (2007:11) the wooden construction supply chain is characterized by a multitude of actors such as sawmills, component-producers, and house-contractors which place new logistics challenges since high coordination is needed for efficient operation. This is confirmed at the Limnologen project, since Thord Ljunggren the project leader points out, it is important that the logistics works as specified (smp.se, 070411). If there is need for high coordination as in the Limnologen project, Picchi (2000:9) argues that it is important to map the whole value stream, identify waste and eliminate it among all chain participants, (Picchi, 2000:9). One tool for undertaking the “mapping” is the extended Value Stream Mapping concept proposed by Womack and Jones (2002), which is also known as the Value Stream Macro Mapping. The VSMM (Value Stream Macro Mapping) is based on regular value stream mapping but is also used to depict an entire supply chain with all of its actors (Fontanini & Picchi, 2004:3).

1.4 PROBLEM FORMULATION

On the basis of the discussion from the paragraphs above the following problem formulation has been developed for this master thesis.

- **How can the value stream mapping be used in a construction supply chain of prefabricated massive timber floor elements?**

1.5 PURPOSE

The purpose of this Master Thesis is to study how the value stream mapping concept can be applied along the construction supply chain for prefabricated massive timber floor elements. Identification and qualification of waste are starting points to propose suggestions on how to reduce and/or eliminate them.

1.6 THESIS DISPOSITION

Figure 1.1 graphically visualizes the disposition of the thesis by presenting all the chapters that are going to be treated.

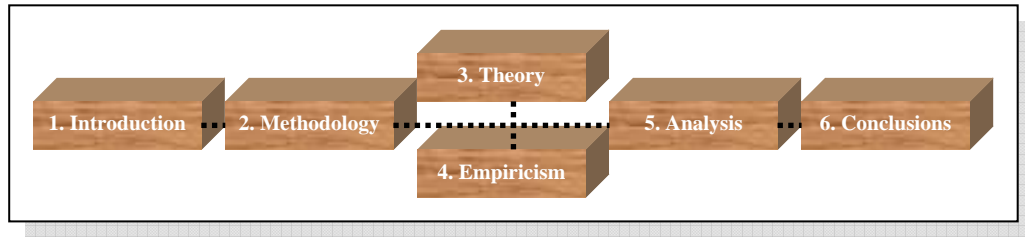


FIGURE 1.1 – THESIS DISPOSITION MODEL

2. METHODOLOGY

The following chapter describes the methodology that has been used when conducting this Master Thesis. Initially, the scientific perspective, scientific approach and research method are presented. Next the case study concept is described and the manner how data was collected. Thereafter scientific credibility of the thesis is discussed. Eventually the summary of the methodological choices and a timeframe will be outlined.

2.1 SCIENTIFIC PERSPECTIVE

There are two important scientific perspectives, the positivistic perspective and the hermeneutic perspective. According to the positivistic perspective the researcher should start with existing theory and create hypotheses that are then tested on a research subject in the real world. Also it assumes that the research problem can be split up into smaller parts that can be studied separately. Another characteristic of the positivistic perspective is that the researcher should avoid being subjective and should also place himself external to the research subject and study it from a distance. (Patel & Davidsson, 1994:24) The hermeneutic perspective could be seen as the opposite to the positivistic perspective. It places the researcher in the centre of the research subject who then collects information by interpreting the reality. As opposed to the positivistic perspective, subjectivity is used to understand the situation. Also the researcher tries to analyse “the whole” rather than smaller parts. Instead of trying to implement theories on the real world, a researcher using the hermeneutic perspective uses real life information to create theories out of existing trends. (Patel & Davidsson, 1994:27)

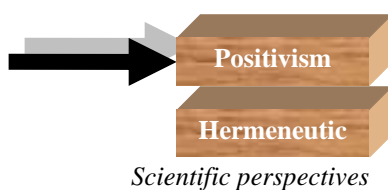


FIGURE 2.1 – SCIENTIFIC PERSPECTIVE

This master thesis is primary conducted from a *positivistic perspective* point of view. This is because existing concepts such as lean construction and value stream macro mapping are first gathered and then implemented on the research subject in order to see how it conforms to current research. The information gathered from several

sources are accepted as is, and are not interpreted – to remain being objective. The scientific perspective undertaken in the thesis is illustrated in figure 2.1.

2.2 SCIENTIFIC APPROACH

There exist two scientific approaches that explain ways to produce general knowledge and draw conclusions on society, organizations and human behaviours – deductive and inductive. These could be seen as the opposites to each other. (Andersen, 1998:28) Deductive research refers to using existing concepts and theories in order to create hypotheses that are tested on a real life case. Inductive research instead refers to the creation of theories out of categories and patterns of real life information, (Andersen, 1998:28; Gummesson, 2000:63).

Figure 2.2 shows the relation between theory and reality when using a deductive or inductive scientific approach.

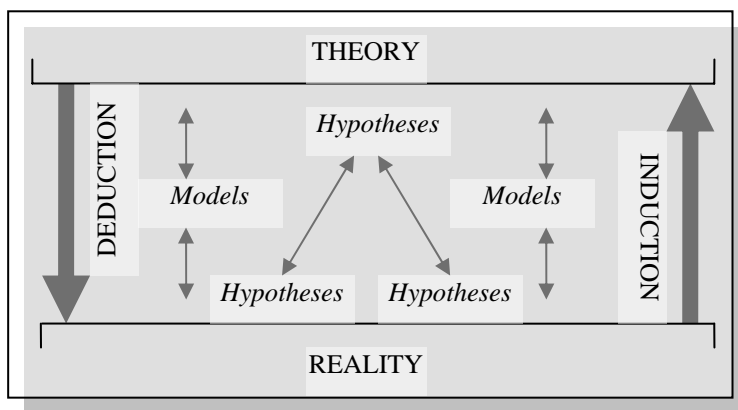


FIGURE 2.2 – DEDUCTION AND INDUCTION

SOURCE: ADAPTED FROM PATEL & DAVIDSSON, (1994:22)

Induction is often used together with explorative case studies, for example when exploring peoples' opinions about their views on their work situation, one can generally conclude on the peoples' work motivation. A number of case studies could then be used to create theories on work motivation. (Andersen, 1998:29)

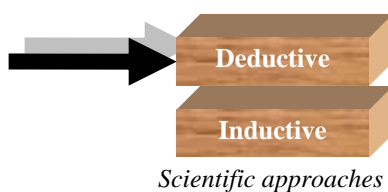


FIGURE 2.3 – SCIENTIFIC APPROACHES

The scientific approach in this master thesis is *deductive* since the approach is based on existing theory. The theory is used to create hypotheses and models are then tested in reality. The deductive approach has been used so that the authors could test manufacturing and construction concepts and apply them on the real construction case in

order to answer the research question and achieve the purpose of this master thesis. The scientific approach used for this thesis is depicted in figure 2.3.

2.3 RESEARCH METHOD

There are two different scientific research methods, quantitative and qualitative. These methods refer to how the researcher chooses to analyse and work with the information that has been gathered from the research subject, (Patel & Davidson, 1994:12). Quantitative research is characterised by a high grade of control, formalization and structure, (Bernt et al, 1986:15). The research method is always using measurement of some sort to create numerical data, (Lundahl & Skärvad, 1999:147) and the numerical data (hard data) is often analysed by using statistical methods. (Bernt et al, 1986:15) Qualitative research, as opposed to quantitative is characterised by a lower grade of control and formalization and is mostly used when trying to understand and create a deeper understanding about a complex real life phenomena (soft data). (Bernt et al, 1986:15) Qualitative research aims at understanding rather than explaining, (Andersen, 1998:31).

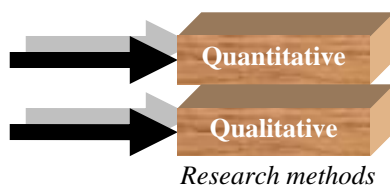


FIGURE 2.4 – RESEARCH METHODS

The chosen research method in the thesis is both *quantitative and qualitative*. Quantitative data has been collected on materials and lead times in the supply chain to determine whether it is possible to reduce lead times and to expose waste.

Qualitative data has been used to get an understanding about the supply chain studied, from the arrival of the wooden boards to the facility in Bygdsiljum to the partial installation of the massive timber floor system at the construction site of Limnologen in Växjö. Furthermore qualitative data was used in order to understand the reasons why the lead times currently look like this.

Quantitative and qualitative data have been gathered from both the producer of the massive timber floor system (Martinssons Byggsystem AB) and the entrepreneur (NCC) since the research described parts of a supply chain. Figure 2.4 illustrates the choice of using both quantitative and qualitative data as research method.

2.4 CASE STUDY

A case study is a research focusing on one or a few occurrences that are analysed into detail. Case studies are the most common form of qualitative research method; however there are

also quantitative forms of case studies. Different types of case studies can be divided into (Lundahl & Skärvad, 1999:185-187):

- Explorative case studies (formulating hypotheses)
- Theoretical case studies (either developing or testing theory)
- Descriptive case studies (giving examples and illustrating)

One benefit of using case studies is that the researcher is studying real cases and is able to collect a lot of information and knowledge from a real situation. (Wallen, 1996:115)

When designing case studies the researcher needs to decide whether to use a single case study or a multiple case study. Single case studies are useful when theory is going to be tested. As Yin (2003:40) points out, one single case study may well meet all conditions required to confirm, challenge or even extend already existing theory. Another argument for using single case studies is when the case is very unique or extreme in its own way. It might be that the case has not previously been accessible to scientific observations, and will therefore give valuable descriptive information. (Yin, 2003:40-43)

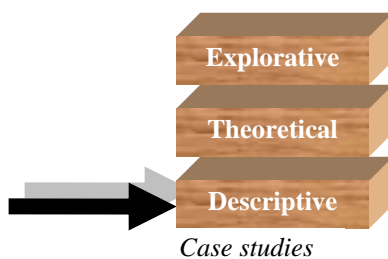


FIGURE 2.5 – CASE STUDIES

The chosen case study is a *descriptive single case study*. It is descriptive in the way that the authors have initiated the research with descriptive theory and have only studied certain aspects/topics of the case that were described thoroughly in detail. Such information is very valuable because of the uniqueness of the case - a multi-storey building constructed of almost only wood. The choice of

specific type of case study is shown in figure 2.5

The boundaries of the conducted case study are shown in table 2.1:

TABLE 2.1 – OVERVIEW OF CASE STUDY BOUNDARIES

CASE STUDY	
Type of case	Timber multi-storey housing project
Type of case study	Descriptive
Focus	Massive timber floor elements
Topics of interest	Manufacturing, assembly, transport, installation
Timeframe	2007-03 – 2007-05

2.5 DATA COLLECTION

Information and different kinds of data could be divided into primary and secondary, depending on who collected the data, (Patel & Davidsson, 1994:56). If the data is collected by the researcher himself, the data is referred to as primary data. All other data, collected by scientists, institutions or other persons are referred to as secondary data. (Andersen, 1998:150)

Data collection techniques can be divided into *stimulus* – using questions, interviews, psychological tests or projections, *observations*, and *secondary data techniques*, (Andersen, 1998:150ff). Table 2.1 presents an overview of different kinds of data collection techniques.

TABLE 2.2 – OVERVIEW OF DATA COLLECTION TECHNIQUES

SOURCE: ANDERSEN, (1998:151)

	PRIMARY DATA		SECONDARY DATA
	Stimuli	Non stimuli	
Qualitative data	<ul style="list-style-type: none"> • Unstructured and semistructured interviews • Projective techniques • Psychological tests 	<ul style="list-style-type: none"> • Observation techniques • Indirect techniques 	Archives, documents, memos, letters, information and registers
Quantitative data	<ul style="list-style-type: none"> • Standardised/structured interviews • Questionnaires • Psychological tests 	<ul style="list-style-type: none"> • Quantitative observation techniques • Indirect techniques 	Public and private registers and statistical data.

As mentioned earlier (see paragraph 2.3) the research method is using both quantitative and qualitative data. This data is based on both primary data and secondary data.

The primary data was collected by the authors by doing open unstructured personal interviews at the job site of Limnologen and also by using phone interviews with Bengt Abellsson at Martinsons Byggsystem AB, in Bygdsiljum. The reason behind using unstructured interviews was to let the respondents formulate their own answers and to have a high flexibility. The information was gathered by at least two persons at each occasion during the face to face and phone interviews. Additionally the phone interviews were recorded and played up on a speaker phone to ensure that the risk of losing information would be as low as possible. The interviews can be considered as semistructured since they were based on flow diagrams

provided by the Limnologen project group presented in appendix I. The interviews were also based on a template of possible physical actions in the process of manufacturing, assembly and delivery of massive timber floor elements. The template is presented in appendix II. The interviews conducted by the authors are shown in table 2.2:

TABLE 2.3 – OVERVIEW OF INTERVIEWS

NAME	COMPANY	POSITION	TYPE OF INTERVIEW	DATE/TIME
Gunnar Sjökvist	NCC	Project supervisor	Personal interview	2007-05-07
Kjell Johansson	Arkitektbolaget AB	Consultant	Limnologen	08.00am
Ulf Cangemark	NCC	Work supervisor	Personal interview	2007-05-11
			Error reports	10.30am
Bengt Abelsson	Martinsons Byggsystem AB	Project Engineer	Phone interview	2007-05-14
			Lead times	10.00am
Bengt Abelsson	Martinsons Byggsystem AB	Project Engineer	Phone interview	2007-05-15
			Lead times	02:00pm
Bengt Abelsson	Martinsons Byggsystem AB	Project Engineer	Phone interview	2007-05-16
			Lead times	01:00pm

The secondary data was collected within the project group including two academic researchers from Växjö University. The project group drew flow diagrams at Martinsons facility and collected quantitative data on lead times on the manufacturing process. The authors were also given access to daily error reports (memos) written by the work supervisor at Limnologen, based on the period: 2007-03-24 – 2007-05-04. In addition on the request of the authors, Bengt Abelsson collected the necessary quantitative data. The types of secondary data that were used in the master thesis are described below in table 2.3:

TABLE 2.4 – OVERVIEW OF SECONDARY DATA SOURCES

DOCUMENT DESCRIPTION	SOURCE
Daily error reports	Ulf Cangemark
Installation manuals of massive timber floor systems	Martinsons Byggsystem AB
Flow diagrams and lead times	The Limnologen project group Data collected at Martinsons in Bygsiljum 2007-05-08
Information from the work team at the Limnologen job site	The Limnologen project group Data collected at Limnologen 2007-05-16

Note: For confidential reasons some of the sources will not be presented in full detail.

Due to confidentiality concerns it is impossible to show the daily error reports, provided by the Limnologen project group, made on site therefore a summary is shown instead. Some details have been left out in purpose and errors, rework and waste concerning other elements than the floor elements have been omitted, see table 4.3 and appendix XIV for a more visible table.

2.6 SCIENTIFIC CREDIBILITY

To reach a high scientific credibility a number of quality criteria need to be taken into consideration. These are presented below.

2.6.1 VALIDITY

Validity can generally be defined as the *absence of systematic measuring errors*, (Rosengren & Arvidsson, 2002:196). In the case of qualitative studies, validity can be divided into construct validity, internal validity and external validity, (Yin, 2003:34)

Construct validity - Refers to using measuring methods that captures the problem in a correct way. The measures should be able to collect information that captures information related to the objective of the research. (Yin, 2003:35) There is a need for a high correspondence between what the researcher intends to measure and what the tool is really measuring. (Patel & Davidsson, 1994:85) To ensure high construct validity two prerequisites are needed - to select specific types of changes (related to the objective of the study) and ensure that the measures reflect the selected changes. (Yin, 2003:35)

Internal validity – Refers to explaining relations between variables, to analyse cause and effects e.g. if a change of variable y is a result from variable x. If the researcher does not take into account that a second variable z could be the cause of the change in y, there is low internal validity. Considering internal validity is only relevant when conducting explanatory case studies. (Yin, 2003:36)

External Validity – Refers to generalization of a case study results to other cases. If the findings of a study can be transferred and applied to a similar case, there is a high external validity. (Yin, 2003:37) With case studies, generalization is problematic, because it is not

certain the results from the case study could be transferred and applied to another case. The results might be case specific. (Wallen, 1996:115) However, a clear distinction should be made between statistical and analytical generalization (results from a case study is generalized on a broader theory), which makes it possible to generalize even when using case studies. (Yin, 2003:37)

2.6.2 RELIABILITY

Reliability is aiming at minimizing errors and biases in a study, (Yin, 2003:37) and can be defined as the *absence of random measuring errors*, (Rosengren & Arvidson, 2002:198). The idea with high reliability is that another researcher should be able to recreate the study with the same result as the first study. This places requirements regarding documentation and descriptions on how the study was done in the first place. Two ways of overcoming reliability issues are the use of protocols and databases. (Yin, 2003:37-38)

Table 2.5 presents suitable tactics for ensuring scientific credibility in different phases of research.

TABLE 2.5 – CASE STUDY TACTICS FOR FOUR DESIGN TESTS

SOURCE: YIN, (2003:34)

TESTS	CASE STUDY TACTIC	Phase of research in which tactic occurs
Construct validity	<ul style="list-style-type: none"> • Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report 	Data collection Data collection Composition
Internal validity	<ul style="list-style-type: none"> • Do pattern-matching • Do explanation building • Address rival explanations • Use logic models 	Data analysis Data analysis Data analysis Data analysis
External validity	<ul style="list-style-type: none"> • Use theory in single-case studies • Use replication logic in multiple-case studies 	Research design Research design
Reliability	<ul style="list-style-type: none"> • Use case study protocol • Develop case study database 	Data collection Data collection

2.6.3 TESTING OF THE RESEARCH DESIGN

Construct validity – To ensure high construct validity a number of different sources have been used during the data collection phase. To have valid information about waste and its different causes there was a need to get views from a number of different informants in the supply chain. As can be seen in table 2.2 and 2.3 there a number of sources of evidence were used. The respondents that were interviewed are highly responsible for managing the supply chain in their area.

The lead-times collected from the project engineer at Martinsons Byggsystem AB during the first two interviews were followed up and reviewed during the last interview. By doing that the lead times were checked so they would be correct and also so that any misunderstandings would be cleared up. Lead times regarding installation of floor elements at the construction site were checked with both the work supervisor (personal interview and error reports 2007-05-11) and the work team (The Limnologen project group meeting 2007-05-16).

Internal validity – Is only a concern for causal case studies (explanatory case studies)

External validity – As Yin (2003:37) suggests there might be difficulties generalizing findings from case studies to other areas of research. One possible solution is to use theory in single case studies as can be seen in table 2.2. The results from this case study should be able to be generalized to other construction cases with similar types of prefabrication. Further the results can be seen as an example of industrialized construction backed up by lean construction theory.

Reliability – If a similar study would be conducted once again with the same sources the results would probably be the same. The chance of being able to replicate the study is high since there is thorough documentation on how data was collected and analysed. The boundaries of the case study were also specified into the detail. This leads the authors of the thesis to believe that the reliability of the study is high.

2.7 SUMMARY

To get an overview of the methodological choices a summary is presented in figure 2.6.

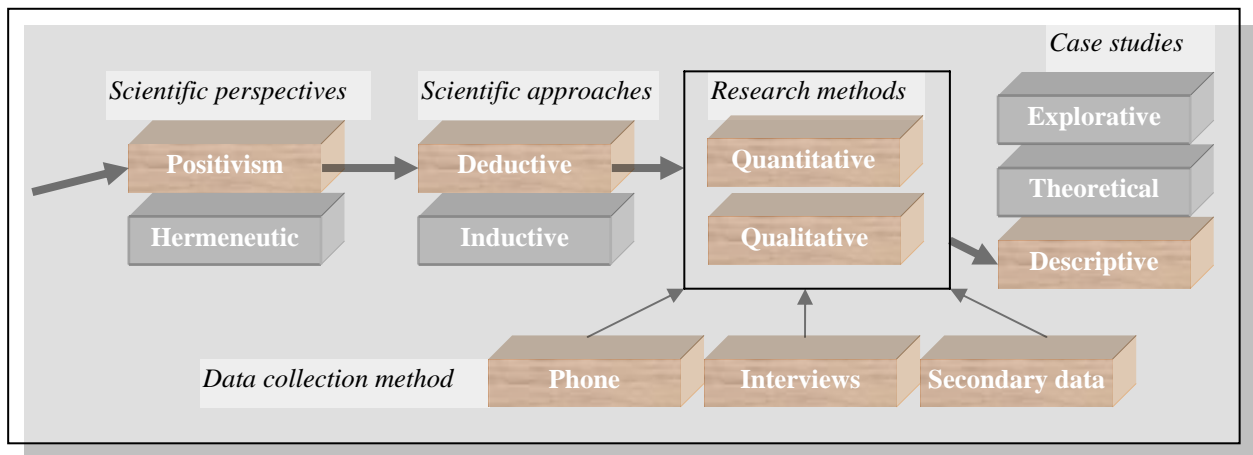
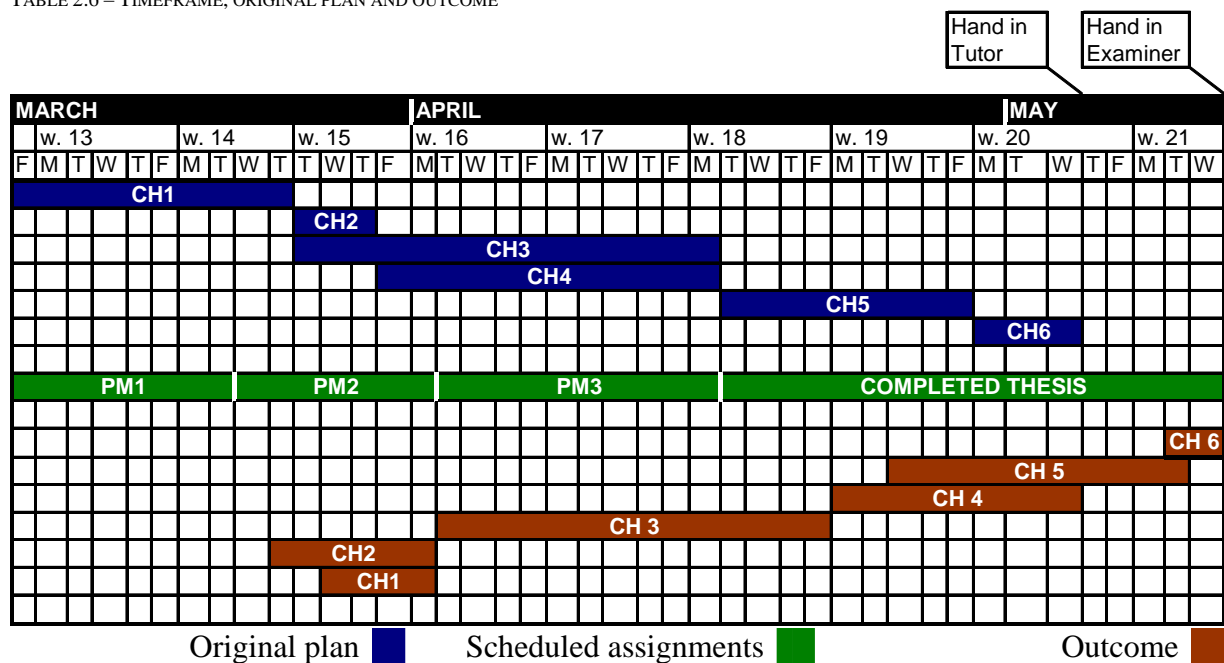


FIGURE 2.6 – SUMMARY OF METHODOLOGICAL CHOICES

2.8 TIMEFRAME

Table 2.6 shows the original plan of the semester and the outcome. The original plan is shown in the upper part (blue), the assignments are shown in the middle (green) and the outcome is shown below (red). As the reader can see the outcome differs quite considerably from the original plan. This is because of a couple of reasons. First of all, due to some initial issues the thesis started off quite late compared to the original plan. Secondly there were some issues with collecting empirical data, which resulted in that the analysis could not be started according to plan.

TABLE 2.6 – TIMEFRAME, ORIGINAL PLAN AND OUTCOME



3. THEORETICAL FRAMEWORK

In this chapter necessary theories regarding construction, lean concepts, value and waste are presented in order to conduct this Master Thesis. This is done to make the reader more acquainted with the subject and also to lay the ground for the analysis.

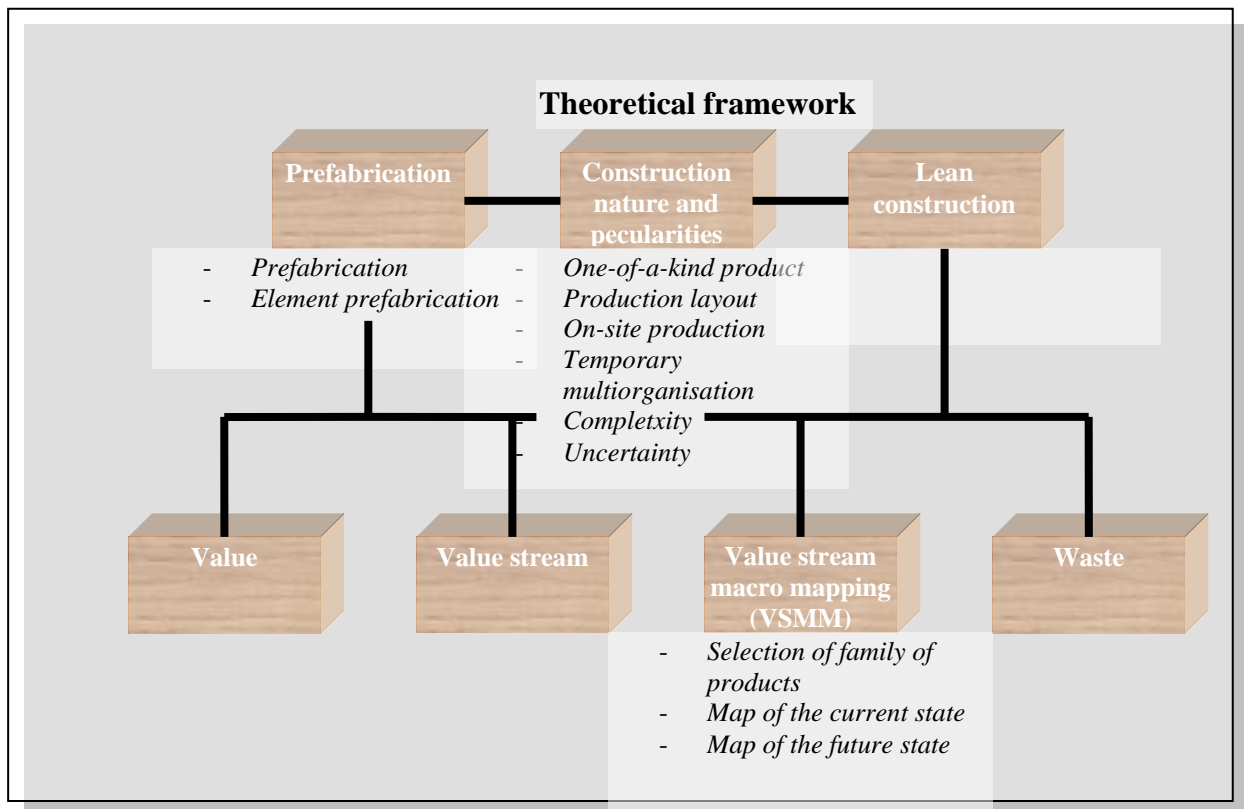


FIGURE 3.1 – OVERVIEW OF THEORETICAL FRAMEWORK

The theoretical framework in figure 3.1 presents all the concepts and theories needed in order to answer the research question of this master thesis. The figure also aims at helping the reader to follow and understand the framework in an easy way. The theory chapter starts off with theories about construction nature and peculiarities which contains all the necessary information to distinguish construction and manufacturing projects. Afterwards the concepts of prefabrication and element prefabrication are explained in order to give the reader some knowledge about the production method used for the massive timber floor system at Limnologen. Lean construction theories are presented, where the meaning of lean is explained more in detail. Furthermore a section presents the value stream macro mapping tool to capture the reader's attention on which procedure will be used to identify waste in the wooden

construction supply chain for the floor system. Additionally value and waste are introduced to give deeper understanding to the reader about what value and non-value added activities mean and how waste is encountered in construction projects.

3.1 CONSTRUCTION NATURE AND PECULIARITIES

Due to its abnormalities, the construction industry is frequently considered in a class of its own as opposed to manufacturing, (Koskela, 1992:44). For instance, manufacturing industry produce finished goods that can often be moved fully to reach retail or end customers. In contrast construction projects manage large units that cannot be easily transported, (Paez et al, 2005:234).

3.1.1 ONE-OF-A-KIND PRODUCT

One-of-a-kind nature is a major characteristic of building or facility that frequently forms the overall shape of the building or facility. This is because the building sites and its surroundings are rarely alike, the designers' views on the best design solutions never accord and most importantly the various end customers have different needs and priorities. (Koskela, 1992:44) Customers play a key role from beginning to end of the construction project as they define the product explicitly with the advice of designers. In the manufacturing industry on the other hand, high-volume standardized units are produced where customization is usually made at the retailer level. (Paez et al, 2005:235)

3.1.2 PRODUCTION LAYOUT

Production layout refers to how production resources are structured in order to do all activities that are needed to deliver products from raw materials. Fixed position production layouts are sometimes referred to as non flow-efficient. (Mattsson & Jonsson, 2005:239) This is because the dimensions of the product make transfer between different work stations difficult. Examples of products encountered in fixed production layout are: ships, aircraft or other very bulky products. The product is assembled at a fixed spot and the production resources therefore have to be moved and organised around the product in order to create all working tasks. This makes the production layout for construction projects considerably different to other production layouts. (Mattsson & Jonsson, 2005:245-246)

3.1.3 ON-SITE PRODUCTION

Construction is an on-site production because installation and assembly take place on the final site, (Koskela, 1992:46; Paez et al, 2005:234). These two activities are the principal ones that increase the product's value while installation of manufactured goods is rather simpler and less value adding, (Paez et al, 2005:234).

3.1.4 TEMPORARY MULTIORGANIZATION

Usually a construction project is a temporary organization intended and erected for the purpose of the specific project. The companies participating in the project have not necessarily worked together before and they are bound to the project by various contractual agreements. The temporary nature can be extended also to the workforce that might have been hired especially for this particular project. This is the reason why it is a temporary multi-organization. (Koskela, 1992:47)

3.1.5 COMPLEXITY

Construction differs to production in complexity. One of the factors increasing the complexity is the number of participants in the supply chain. Picchi (2000:3) identified a number of actors that will affect a construction project. These are:

- | | |
|-------------------------|----------------------------------|
| • Users | • Designers |
| • Owner | • Management and control company |
| • Developer | • General contractor |
| • Real estate companies | • Sub-contractors |
| • Financial agent | • Materials suppliers |
| • City agencies | • Equipment suppliers |

In addition accomplishment of construction activities is tremendously interconnected in erecting a building thus making construction projects significantly complex, (Paez et al, 2005:235). Bertelsen (2003:2) argues also that construction projects should be qualified as complex, dynamic systems. This is because projects must rely on an initial design that engages a number of subassemblies with different variable specifications. Since construction projects are depending on on-site production, the installation of those subassemblies is bonded by the interacting and overlapping activities executed by different contractors; which

make it even more difficult to fulfil a fixed schedule. (Salem et al, 2006:168) As a result to meet the deadlines, the projects' actors face pressures and constraints appear which cause additional costs and/or increase technical difficulties, (Paez et al, 2005:235). In contrast, manufacturing can easily manage the components from the different subassemblies because suppliers are chosen ahead of time in the design phase. The flow of product is smooth because specialized facilities with adequate technology and layout can ensure it. Ultimately the supply network becomes manageable and optimized thanks to repetition. (Salem et al, 2006:168)

3.1.6 UNCERTAINTY

Construction projects are characterized by uncertainty as a direct consequence of on-site and complex production. Great uncertainties exist throughout the project and might not be avoidable, such as weather conditions, soil conditions, owner changes and exceptions erupting from the interface of multiple operations. Exceptions and planned activities are critical to the project and will both establish the project cost outcome. By comparison the manufacturing process's nature allows the reduction of uncertainty thanks to the possibility to take control over the process. It is advantageous to reach a steady state as efficiency can be increased through repetition. (Paez et al, 2005:235)

3.2 PREFABRICATION AND ELEMENT PREFABRICATION

Ballard and Arbulu (2004:4) defines prefabrication as “*making all or part of an object in some place other than its final position*”, that is something that is produced before its final assembly on site. Dictionary.com (070517) defines prefabrication as “*the manufacture of sections of a building at the factory so they can be easily and rapidly assembled at the building site*”

The element is manufactured in the environment of a factory where manufacturing processes are controlled, also called *factory physics*. Then the element is transported to the construction site to be assembled together with other elements and sub-assemblies, called as *construction physics*, and illustrated in figure 3.2. (Höök & Stehn, 2005:319)

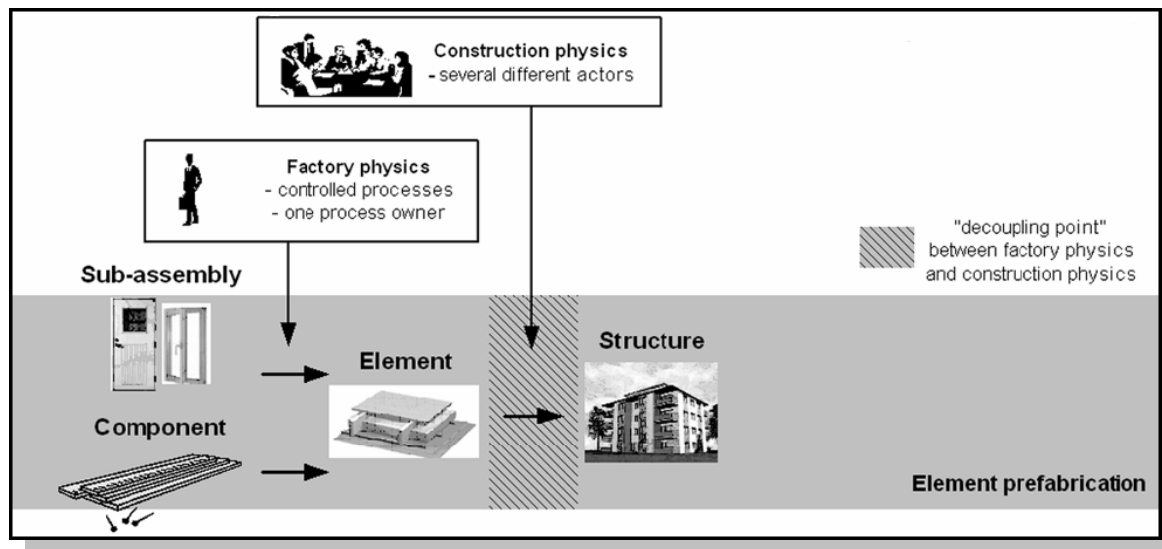


FIGURE 3.2 – ELEMENT PREFABRICATION

SOURCE: ADAPTED FROM HÖÖK, & STEHN, (2005:319)

If used efficiently, prefabrication can shorten lead times, improve quality control, and reduce material waste, stated by Luo et al. (2005), quoted by Björnfot and Sardén, (2006:266). As shown by previous research, house prefabrication reduces waste by reducing some of the peculiarities of construction (e.g. one-of-a-kind, on-site production and a temporary multiorganization). Furthermore prefabrication raises standardisation and repetitiveness both in processes and products and therefore making progress of the construction process more alike to manufacturing than on-site construction. (Höök, 2006:583f)

However even if prefabrication decreases some types of complexity and waste, it brings in other ones through giving new roles to the actors and shifting focus to manufacturing instead as argued by Koskela (2003) quoted by Höök & Stehn, (2005:317).

3.3 LEAN CONSTRUCTION

Lean construction was initially proposed by Koskela (1992) who argued that construction should move beyond lean thinking to develop its own production philosophy. This is required since the peculiarities of construction make the original lean production concept unsuitable for construction projects. (Björnfot, 2006:16) Taking construction peculiarities into account Koskela (1992:22) summarized the lean construction concept into 11 principles:

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

3. Reduce variability
4. Reduce cycle times
5. Simplify by minimizing the number of steps, parts and linkages
6. Increase output flexibility
7. Increase process transparency
8. Focus control on the complete process
9. Build continuous improvement into the process
10. Balance flow improvement with conversion improvement
11. Benchmark

Björnfot (2006:27-32) argues that even though the principles originally developed by Koskela (1992) have been widely used in lean construction literature and there has been a lot of further research, there seems to be no accepted view upon how lean construction should be defined. However Björnfot (2006:21-22) thinks that a narrow definition might actually obstruct future development initiatives. Further he argues that lean construction should rather be based upon the five main lean principles as was developed by Womack and Jones (see section 3.2.1) but with a few additions and modifications. The conceptualization of the lean thinking principles in construction as developed by Björnfot (2006:21-22) is presented in table 3.1.

TABLE 3.1 – CONCEPTUALIZATION OF THE LEAN THINKING PRINCIPLES IN CONSTRUCTION

SOURCE: BJÖRNFOT, (2006:21-22)

Lean principle	Conceptualization in construction
1. Value	<ul style="list-style-type: none"> • Define the customer • Define what is of value to the customer • Define what is of value to the delivery team • Define how value is specified by products
2. Value stream	<ul style="list-style-type: none"> • Define all resources required for production • Define all activities require for production • Standardize current practice • Define and locate key component suppliers
3. Flow	<ul style="list-style-type: none"> • Identify non-value adding activities (waste) • Remove or reduce the influence of waste as it is observed • Identify key performance indicators • Measure performance
4. Pull	<ul style="list-style-type: none"> • Keep the production system flexible to customer requirements • Keep the production system adaptable to future customer requirements • Exercise a conscious effort at shortening lead and cycle times

	<ul style="list-style-type: none"> • Perform work at the last responsible moment
5. Perfection	<ul style="list-style-type: none"> • Keep the production system transparent for all involved stakeholders • Capture and implement experience from completed projects • Exercise a conscious effort at improving value for customers • Exercise a conscious effort at improving the execution of work

3.4 VALUE

Convey (1991) defines a value added activity as “An activity which contributes to the customer's perceived value of the product or service. A non-value added activity is one which, if eliminated, would not detract from the customer's perceived value of the product or service” as quoted by Saukkorriipi (2004:2). Looking more precisely at construction, Koskela (1992:17) presents his definition, that a value added activity is one that “converts material and/or information towards what is required by the customer”, and that a non value added activity “takes time, resources and space but does not add value” (Koskela 1992:17). Both these definitions correspond well with the argument made by Emmitt et al. (2005:2) that it is the client/customer/society that specify the value. However, identifying value added and non-value added activities can be problematic. This is because people generally have difficulty to tell them apart.

Emmitt et al. (2005:59-63) propose a value based building process model that consists of four main phases and three main formal activities – the phases are customer needs and concept when designing value and construction and consume when delivering value. The formal activities are contact, contract and control. Figure 3.3 shows a value based building process model:

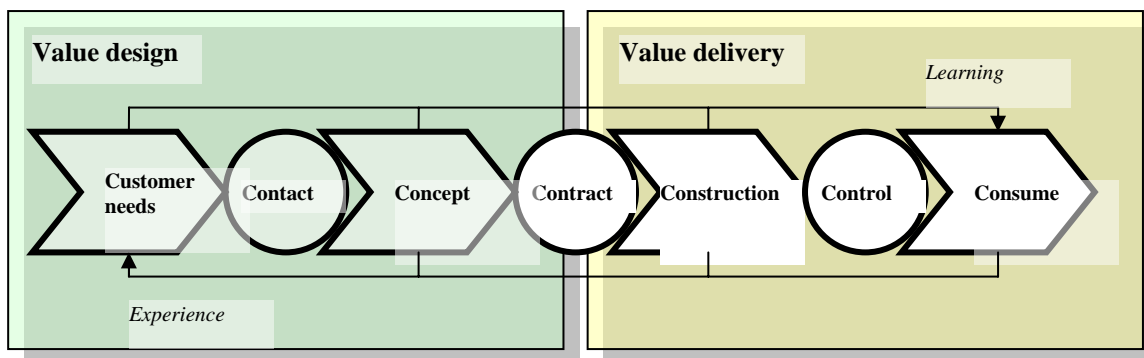


FIGURE 3.3 – A NEW VALUE BASED BUILDING PROCESS – 7 C'S

SOURCE: EMMITT ET AL (2005:60)

Emmitt et al. (2005:60-63) defines the concepts as followed:

1. Customer needs – in this phase the customer writes down and maps the project needs and values.
2. Contact – in this step the customer contacts all the stakeholders.
3. Concept – here is written down a document including the client needs.
4. Contract – a contract is agreed upon when the value design work is established carefully and completely. This step represents the conversion from the value design to the value delivery phase.
5. Construction – here the client's role is being less active. The main contractor together with the subcontractors works on production planning and activities.
6. Control – in this phase the control of the project is carried out to make sure that the product is free from errors and that it fulfils the customer value specification acquiesced on when the contract was signed.
7. Consume – in this step knowledge, input and feedback from operational and management activities are gathered to gain experience and transfer them to future projects.

Emmitt et al. (2005:2) argue that lean construction efforts should be applied as early as possible in construction projects, preferably already in the design/concept phase. The reason is that spending more time at planning; giving more attention to customer value and handling defects could payoff in the long run. Such planning and using more time for early phases will effectively shorten the construction phase and maximize value/minimize waste. (Emmitt et al., 2005:2)

Matilda Höök (2006:592) studied lean prefabrication and customer value and the conclusions of her study are that to meet customer needs (increased time and cost efficiency, flexibility, customisation and catchy design) in other words to create value to the customer a lean prefabrication strategy is necessary. To reach a lean strategy, control, trust of contractor and product and information transfer need to be reached and obtained so that the construction industry accepts it.

3.5 VALUE STREAM

Picchi (2000:4) argues that the different value streams in construction could be labelled as business, design, job site and supply flows. (Picchi, 2000:4) The business flow is concerned with order to cash, the design flow with concept to launch and the supply flows are concerned with raw materials to customer (compare with the problem-solving task, the information management task, and the physical transformation task in section 3.2.1)

Figure 3.2 shows how the different flows are related to each other in a construction project.

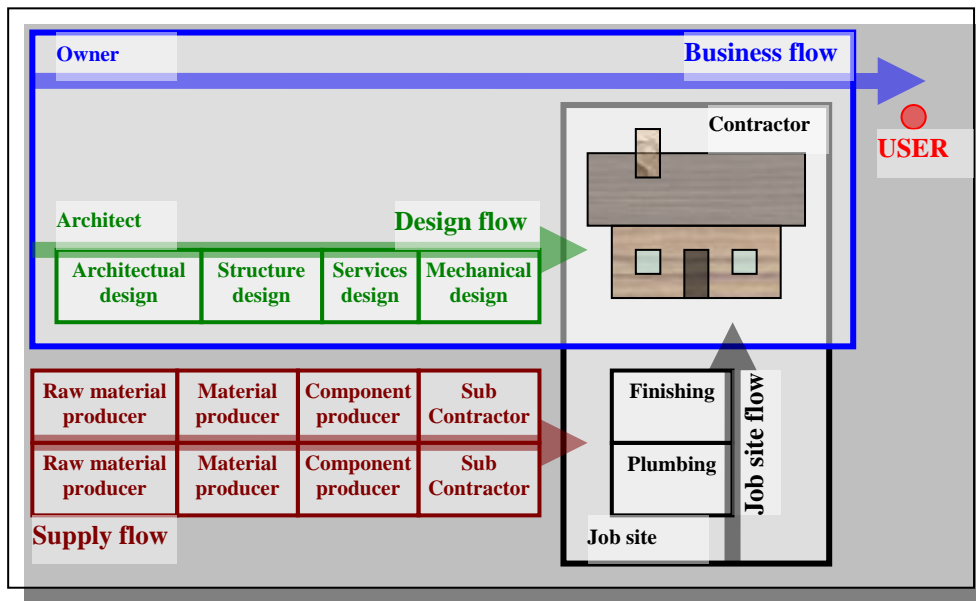


FIGURE 3.4 – DIFFERENT CONSTRUCTION FLOWS

SOURCE: ADAPTED FROM PICCHI, (2000:6)

Picchi (2000:8) points out, that the chosen building material in construction projects could affect the flow drastically. All kinds of materials such as steel, concrete and wood frames are using different technologies and therefore require different processes, work procedures, suppliers and sub-contractors. However, the use of different kinds of prefabrication could be very useful to help create an efficient flow. (Picchi, 2000:8)

3.6 VALUE STREAM MACRO MAPPING (VSMM)

“Value stream mapping is the simple process of directly observing the flows of information and materials as they now occur, summarizing them visually, and then envisioning a future state with much better performance” (Jones & Womack, 2003:1)

The main purpose of VSM is to enable lean implementation, (Bulhões et al., 2005:100). VSM is a pencil and paper tool, which is drawn using standardized icons. The first step is to define a particular product or product family as the target for improvement. The following step is to draw a current state map that is mainly a snapshot catching how things are currently being done. The next step is to draw a future state map that depicts how the system should look like after all the inefficiencies have been eliminated. This map then becomes the basis for making the required changes to the system (Abdulmalek & Rajgopal, 2006:225)

3.6.1 SELECTION OF A FAMILY OF PRODUCTS

To start mapping the process, it must be disaggregated to the level of specific products. In order to do this, one must begin with the furthest point downstream (toward the end consumer) that has to be mapped and define families of product at this point. Characteristically a product family will comprise a group of product variants that passes through comparable processing steps and uses common equipment (Jones & Womack, 2003:1)

3.6.2 MAP OF THE CURRENT STATE

MAPPING THE PHYSICAL FLOW

Once the product family is clearly identified, the map of the current state can be drawn. Then the first step is to “take a walk” along the entire length of the value stream to be mapped, documenting all the actions performed on the product, the facilities, the transport links, all information management actions, and the time required. The first step is to make a list that shows the different the lists of actions to create a product, as seen in table 3.1. In addition it must be recorded on this list the total elapsed time (total product cycle time), which sums the time required to conduct all of the steps on a product. This time is then compared with the actual value creating time, which is the sum of only the value creating steps. to judge whether or not a step adds value or is waste, one has to think like a customer and ask if he would pay less money for the product or be less happy with the product if a given step and its corresponding time were not done. (Jones & Womack, 2003:14)

TABLE 3.2 – PHYSICAL ACTIONS REQUIRED TO CREATE A PRODUCT

SOURCE: ADAPTED FROM JONES & WOMACK, (2003:15ff)

Physical Actions Required to Create a Product			
Total steps	Value Creating Steps	Total Time	Value Creating Time
Raw Materials Supplier:			
Factory X, Location			
1.			
Transport Link 1			
2.			
Second-Tier Supplier:			
Factory Y, Location			
3.			
4.			
Transport Link 2			
6.			
Company Assembly Plant			
Factory Z, Location			
7.			
8.			
Transport Link 3			
9.			

Womack and Jones (2002) states that before to engage in drawing the VSMM, a VSM for each agent must be drawn as quoted by Fontanini and Picchi (2004:4). Then, the drawing of the current state map showing all facilities starting with the customer, see appendix III and IV, can be started. The icons signification can be seen in appendix IX. (Jones & Womack, 2003:18ff)

Furthermore to this preliminary map it will be added a data box placed under each facility, as shown in appendix V. The data box will comprise data on inventories (Raw Materials, Work-In Progress, Finished Goods), the amount of productive time (the number of shifts per day and the number of working days per week), the frequency of the production cycle (displaying how often every parts is made, such as “EPE = 1 Day” in other words “every part every day”), and the defect level (in parts per million) reported by the customer. (Jones & Womack, 2003:22f)

The next step is to include the transport links between the facilities, which can be boat, train, truck or airplane icons as presented in appendix VI and VII. Inside the icon, the frequency of shipments (e.g., “1 x day” = one shipment a day) will be added. Additionally information

about the distance in kilometres, the shipping batch size and the percentage of defective deliveries as noted by the customer will be shown. (Jones & Womack, 2003:25)

Finally a time-and-steps line will be drawn and placed along the bottom of the map and can be visualize in appendix VIII. The line will show the total time for each facility and for each transport and the value creating time for each step. Furthermore the action steps for each facility and transport link will figure on the line. A summary box will be drawn at the end of the line showing, total time, in-plant time, transport time and value creating time. (Jones & Womack, 2003:26)

MAPPING THE INFORMATION FLOW

After mapping the physical flow of the product, one needs to map the information flow. The information flow that will be captured on the map is the frequency of orders, e.g. daily, weekly and monthly and also how the information is transmitted between the facilities, by phone, electronically, fax...(Jones & Womack, 2003:30f) is shown in appendix IX.

3.6.3 ANALYSIS OF THE MAP OF THE CURRENT STATE

The map of the current state is very helpful because it shows how production is presently occurring. Its analysis allows the identification of waste and suggests improvement actions for the design of a new flow, smoother, without returns, which produces the shortest lead time, highest quality, and the lowest cost. In order to design the new flow, one should follow some propositions as guidelines. (Pasqualini & Zawislak, 2005:119)

One way to reduce waste is to produce according to takt time. Takt time is calculated dividing effectively available work time per shift by the amount (of a certain product) ordered by clients per shift. In the case where production rhythm is below takt time, this means that the facility is producing more than the customers are buying, or this is also known as, overproduction. When the contrary is true, or in other words when production is above takt time, this means that the facility is not producing enough. The second proposition is to define if the company should produce for expedition or for a supermarket of finished products. The goal of the third one is to develop a continuous flow where it is possible. The aim of the fourth proposition is to see where the continuous flow is not possible and in this case a supermarket should be used to control production. Based on this it is possible to establish the fifth proposition and send a customer's programming to a production process only. This point

is called pulling process because it controls production rhythms for all previous processes. The last proposition lies in a regular distribution for the production of the different products in the pulling process period, balancing the product mix along manufacturing. (Pasqualini & Zawislak, 2005:119)

3.6.4 MAP OF THE FUTURE STATE

The map of the future state is the last step in VSM, which is the result of the analysis of the map of the current state, steered by the above propositions. This map is a drawing of an “ideal state” which is the best way the process could operate starting from the current state analysis. The aim is to show the company where the wastes are and in what way they can be “attacked” and reduced, and if possible, eliminated. The implementation of the improvements cannot be done at once; first one should concentrate on the most problematic area and little by little reach the “ideal state” pictured by the map of the future state. (Pasqualini & Zawislak, 2005:119)

3.7 WASTE

Waste can be classified into. (Chase et al, 2006:472 and Tersine, 1994:90):

1. Waste from product defects – means that the products must be discarded, reclaimed or reworked and the consequences are extra work and costs
2. Inventory waste – to have more in stock that was is necessary does not any value and binds more capital than needed, in addition lead time increase and the storage takes much more space than necessary
3. Processing waste – rightly formed processes diminish the use of resources and enable to avoid to do the same work several times, unnecessary controls and bottlenecks that limit the process can be also avoided
4. Waste of motion – that comes from working place that are not designed ergonomically which results in for example unnecessary long walking distances
5. Transportation waste – means that time and resources are used unnecessarily
6. Waste of waiting time – happens when the product is not in movement or not taken care of which do not add any value to the product
7. Waste from overproduction – when it is produced more that was is demanded which results in products staying in stock and getting old and can also lead to have to discount the products

3.7.1 WASTE IN THE SWEDISH CONSTRUCTION INDUSTRY

A Swedish construction industry study reveals that waste corresponds to between 30-35% of the total cost of the projects. The report classifies waste into four categorises:

- Defects and controls. Costs for visible and invisible defects are major and even control costs, insurances, thefts and damages are great. Waste in this group makes up for more than 10% of the project total production cost.
- Utilisation of resources. Value mappings show that a surprisingly large share of waste is a result of waiting time, idle machines and material spillage. This kind of waste represents more than 10% of the project total production cost.
- Health and safety. Job site related injuries and sicknesses are so enormous that it needs to be categorized in a separate group. The largest costs are connected to rehabilitation and early retirement pension and burden indirectly the project through taxes. Waste from this group accounts for approximately 12% of the project total production cost.
- System and structures. Waste in this category is excessive transaction documentation costs and represent 5% of the project total production cost. This category of waste is the most understated of the different wastes. There is a tendency in improvements efforts to result more and more comprehensive management system. (Josephson & Saukkoriipi, 2005:7)

4. EMPIRICAL FINDINGS

This chapter commences with the description of the supply chain for Limnologen and the empirical findings will be presented in the same order as the supply chain. This is done in order to get an overview of the process. Detailed and more in-depth information and empirical data that clarifies the various processes the element passes through is added to the different sections.

Figure 4.1 presents an overview of the empirical findings that is to follow in chapter 4.

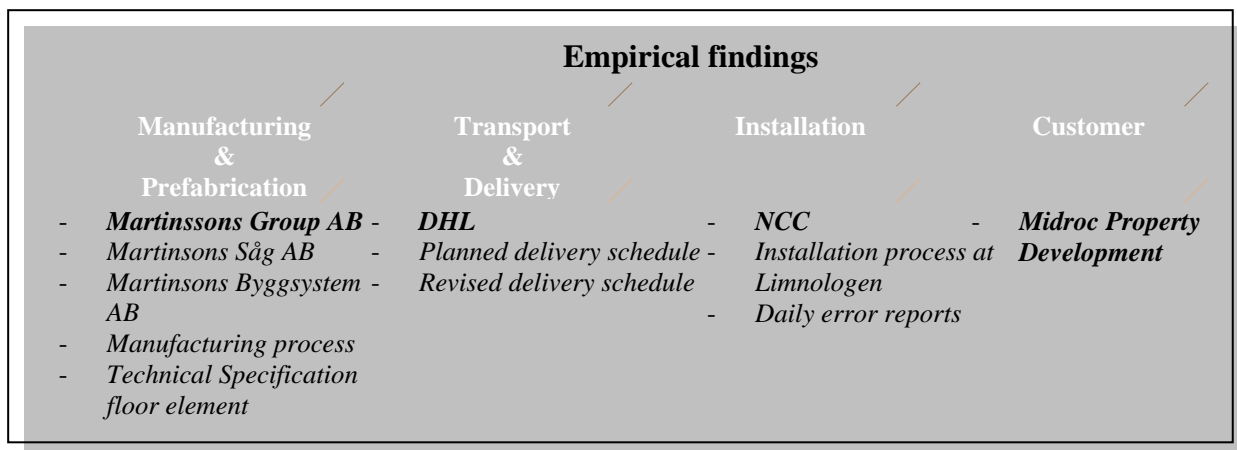


FIGURE 4.1 – OVERVIEW OF EMPIRICAL FINDINGS

4.1 THE SUPPLY CHAIN FOR LIMNOLOGEN

Fact sheet	
Architect:	ArkitektBolaget AB
Building proprietor:	Midroc Property Development AB
Framework supplier:	Martinsons Byggsystem AB
Constructor:	Martinsons Byggsystem AB (floor 2-8) Tyréns AB (ground and floor 1)
Building entrepreneur:	NCC
Weather protection:	Hallbyggarna Jonsereds and Industriteknik

FIGURE 4.2 – FACT SHEET

SOURCE: ADAPTED FROM VESSBY (2007:61)

Figure 4.2 presents all the actors involved with the Limnologen project. However in this Master Thesis not all actors are going to be studied for the simple reason that not all entities are involved with the massive timber floor system. Figure 4.3 illustrates graphically all the actors of interest for this thesis. The supply chain studied starts from loading boards (1) at Martinsons Byggsystem AB (2), and then out of the manufacturing process comes out a massive timber floor system (3) that is afterwards transported on DHL's trailer (4) to the construction site (5). Finally the building entrepreneur NCC (6) installs the floor system at Limnologen (7) on behalf of Midroc Property Development AB (8).

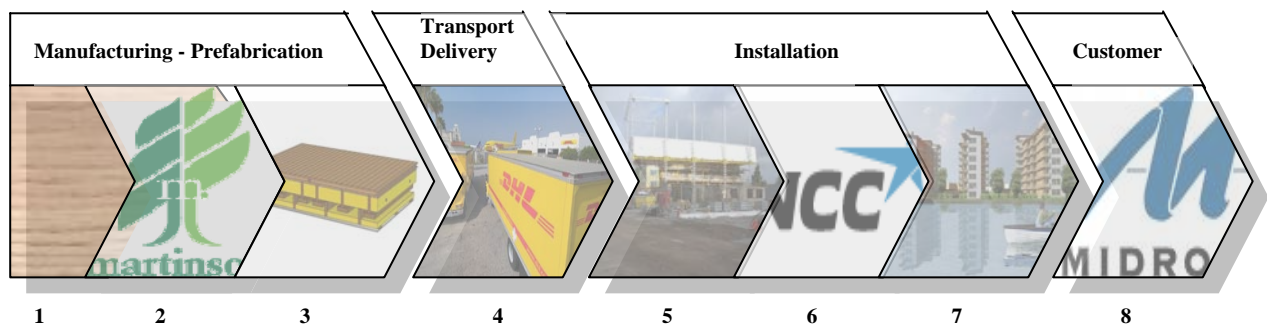


FIGURE 4.3 – ACTORS OF INTEREST

4.2 MANUFACTURING AND PREFABRICATION

4.2.1 THE MANUFACTURER OF THE FLOOR ELEMENT – MARTINSONS GROUP AB



- Number of employees: 400 persons
- Turnover: about SEK 960 million per year

Martinsons Group AB is a specialist when it comes to design and produce timber goods. It is Sweden's largest producer of glue-laminated wood and Scandinavia's leading company concerning timber bridges and massive-tree-frameworks building technology. Martinsons Group AB has seven companies that are specialized on their field of activities (martinsons.se, 070514) and the entities involved in the production and delivery of the massive timber floor system Limnologen are Martinsons Såg AB and Martinsons Byggsystem AB.

Martinsons Såg AB

Martinsons Såg AB is composed of three sawmills, all situated in the North East of Sweden. The first one is located in Avanäs where it is produced sawn timber goods and components. The second sawmill is situated in Bygdsiljum where it is manufactured sawn timber goods, glue-laminated wood and massive tree. The last one is established in Kroksjön and its

assortment is composed of planed timber goods, components and painted products. (martinsons.se, 070514)

Martinsons Byggsystem AB

Martinsons Byggsystem AB takes care of developing, producing and selling housings made of glue-laminated wood and massive timber frameworks. (martinsons.se, 070514)

4.2.2 THE MANUFACTURING PROCESS AT MARTINSONS BYGGSYSTEM AB

In this section the manufacturing process for the floor system is going to be described. In the description text, numbers in parentheses are included which indicate that it is the moment that is going to be used to enable analysis in next chapter. This is made also to help the reader to follow the various steps in the manufacturing and installation process. All the moments are presented in table 4.1 at the end of this section.

The process starts with loading the long wooden boards that have been manufactured at Kroksjön's sawmill (1) for transportation to Martinsons Byggsystem AB's facility in Bygdsiljum (2). After the 70 km long transport, the boards reach their destination point, the facility in Bygdsiljum. They are then unloaded and placed onto temporary storage (3). Afterwards a quick visual check is effectuated in order to detect quality issues (4). Meanwhile the short wooden boards are waiting on spot because they are already in place at the facility in Bygdsiljum as they are prepared at Martinsons own sawmill.



FIGURE 4.3 – GLUING & PACKING

SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.5 – CUT & FLOOR HEATING

PREPARATION

SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.6 – T-SHAPED CROSS SECTIONS

SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.7 – UNDER-ROOF

SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.8 – PACKING PREPARATION

SOURCE: BJÖRNFOT (2006:33)

After the long wooden boards are moved from the temporary storage of boards and are placed on a conveyor belt (line) which includes a number of machines, responsible for gluing and packing boards together into blocks. This process is highly automated (5). See figure 4.4.

The blocks are transported to another conveyor belt where unnecessary material is cut away and also other material is cut in preparation for floor heating (6). See figure 4.5.

When the processing of boards and blocks is finished, the blocks are moved over with the help of an overhead crane to a moving platform (7). The first stage at the platform is to assemble two blocks into an element (8). After that different complements are installed manually and also there is mark up of web and flange by hands (9). Check figure 4.6.

The elements there are finished up with the installation of insulation (11), under-roof (12) and sprinklers (13). Some of the elements are also installed with a drain system but not all of them. These are also performed manually. See figure 4.7.

When ten elements (1/3 of a floor at Limnologen) are finished they are packed and wrapped together into two packages (14). As the elements can be sensitive to chocks they need to be prepared carefully for transportation to avoid damages on the way to Limnologen. Check figure 4.8.

After the packaging and wrapping is finished the packages are placed into storage waiting for further transport to Limnologen (Växjö) (15). The reason for storing the elements is to have a safety margin in case the production takes longer time than expected.

The two finished packages (10 elements) are stocked during three days in the storage and thereafter sent on one trailer (DHL) (16) day 1. The day after, day 2, two new finished packages are sent and last day, day 3, the last two packages. In other words the whole floor (30 elements) is sent in three deliveries in a series of three days (two packages in each delivery).

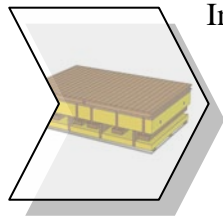
The manufacturing process from step 1 to step 16 are summarized in table 4.1 underneath:

TABLE 4.1 – MANUFACTURING PROCESS AT MARTINSONS BYGGSYSTEM AB

Steps Number	Physical Actions Required to Create and Deliver 1 Element	Total time
	Total Steps	
	Sawmill Kroksjön (long boards)	
1.	Loading Sawmill Kroksjön	15min
	Transport Link 1	
2.	Shipping Kroksjön-Bygdsiljum (70km)	90min
3.	Unloading of boards at facility	15min
4.	Quality check	2min
	Martinssons facility Bygdsiljum	
	<u>Preassembly of blocks</u>	
5.	Glue and packing (long boards and short boards)	20min
6.	Cut off unnecessary material and cut for floor heating	20min
7.	Transport overhead crane to new conveyor belt	5min
	<u>Assembly of elements</u>	
8.	Assembly of two blocks into an element	10min
9.	Marking up web and flange	30min
10.	Various complements are installed	15min
11.	Insulation is installed	30min
12.	Under-roof is installed	12min

13.	Installation of sprinklers	30min
14.	Packaging and wrapping	18min
Transport Link 2		
15.	Storage at facility	3 days
16.	Shipping Bygdsiljum-Limnologen (1169km)	2 days

4.2.3 THE PREFABRICATED FLOOR ELEMENT – TECHNICAL SPECIFICATION



In the following section the reader will be given a detailed description of the different elements and components creating the massive timber floor system and afterwards the manufacturing process will be specified.

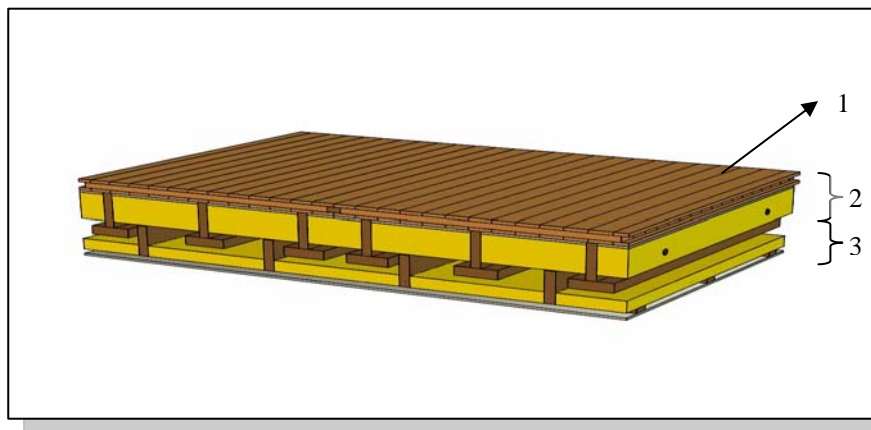


FIGURE 4.9 – EXAMPLE OF A PREFABRICATED FLOOR ELEMENTS
SOURCE MARTINSONS.SE (070514)

The prefabricated floor elements consist of three main elements; the bearing board based on massive timber slab (2), the floor (1) and the under-roof (3), see figure 4.9, figure 4.10 for a closer and detailed view and appendix XII presents different models of prefabricated floor elements.

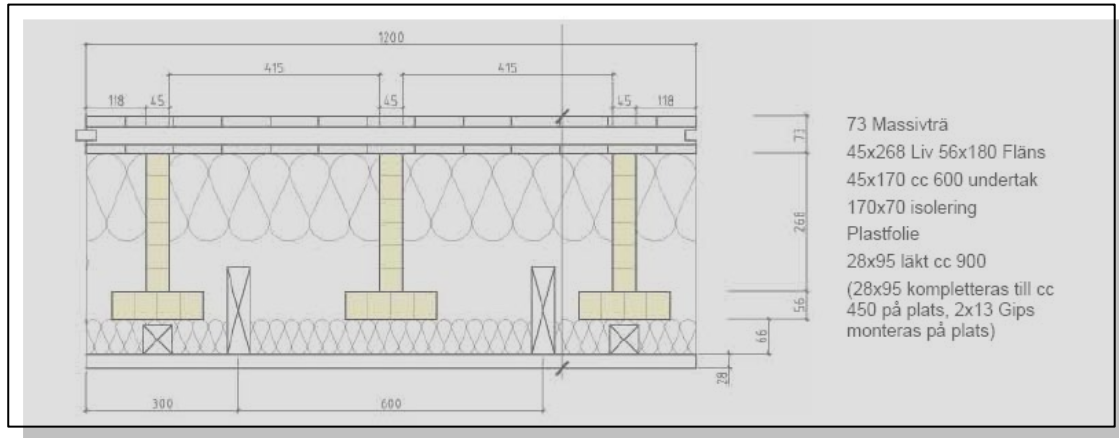


FIGURE 4.10 – FLOOR STRUCTURE DRAWING

SOURCE: BJÖRNFOT (2006:39)

The bearing board is composed of a board of massive timber and glue-laminated beam shaped as a T that is first glued and then screwed to the bearing board to unite them perfectly. The massive timber slab has a double roll; this is because after surface treatment it provides a finished floor for the prefabricated floor elements. The bearing board is assembled in such a way that it is separated (not in contact with) from the under-roof. This prevents noise from travelling between the surfaces. The space between the layers of boards and the under-roof enables installations of sprinkler systems, electricity, ventilation and drain. Two layers of gypsum board cover the under-roof, act as a surface layer and satisfy fire and soundproofing standards. (Björnfot, 2006:39)

Massive timber floor can be adapted according to the span and also to the prefabrication level that is wished. Spans of up to 12 meter are completely possible and this allows open and flexible floor designs. (martinsons.se, 070514)

To complete one floor at Limnologen a total of 30 floor elements (440m²) are needed. (telephone interview, 070507) Therefore to complete seven floors (the first floor is built in concrete) a total of 210 floor elements per floor and that is 840 elements for the complete construction project (four buildings).

4.3 TRANSPORT AND DELIVERY

4.3.1 THE SHIPPER - DHL



- Number of employees: 4 000 persons
- Number of offices, terminals and stations in Sweden: 70 entities

DHL is a market leader in international express, overland transport and airfreight. DHL offers a full range of customised solutions from express document shipping to supply chain management. (dhl.se, 070514) DHL is in charge of transporting the prefabricated floor elements by trailer from Bygdsiljum, Northeast of Sweden to Växjö.

4.3.2 PLANNED DELIVERY SCHEDULE

The deliveries from Martinsons Byggsystem AB to Limnologen have to be coordinated according to agreed specifications and schedule (interview, 070507):

1. *6 packages of elements (30 floor elements total) delivered each 10 days (one floor)* – At Limnologen, NCC is able to finish one floor each 10 days. After that they will lift the hydraulic tent and start off on a new floor. Therefore, the deliveries have been scheduled to arrive when they are needed at the jobsite.
2. *Only two packages of elements (10 floor elements) delivered each day (two on each trailer)* – Due to limited storage space at the jobsite and to avoid congestion, only two packages of elements are allowed to be delivered each day. This is timed to allow the elements to be immediately lifted off the trailer and onto the building, consequently they will not have to be placed in storage.
3. *Deliveries need to be made on time, neither early nor late (JIT)* – It is extremely important that the deliveries are made neither early nor late. If *late* the work process will have to stop, resulting in waiting time for the affected workers. If *early* the elements will have to be lifted off and stored at the jobsite waiting to be installed in the building.
4. *The deliveries will have to be made in the exact sequence* – The elements are individual and can only be installed in one specific place and in one specific sequence. If the deliveries are not arriving in the specified sequence, the work process will again have to stop thus resulting in waiting time. In addition wrong elements will have to be stored at the jobsite awaiting the correct preceding elements to arrive.

5. *The delivered elements need to live up to the agreed specifications and quality* – If the delivered elements have errors and corrections need to be undertaken at the jobsite, this would result in a lot of unnecessary working time. Error reports from Limnologen are written by the work supervisor when necessary and are sent to Martinsons Byggsystem AB once a week. Thus Martinsons Byggsystem AB gains knowledge about errors and reworks and it is able to remedy manufacturing issues when possible (a summary of the error report for the floor system is presented only due to confidentiality concerns and can be found in table 4.3).

Figure 4.11 is showing an overview of assembly, manufacturing and delivery of floor elements. Twenty blocks of wooden boards are assembled into ten floor elements. The floor elements are packed and wrapped into two packages that are then loaded onto trailer for transport to Limnologen.

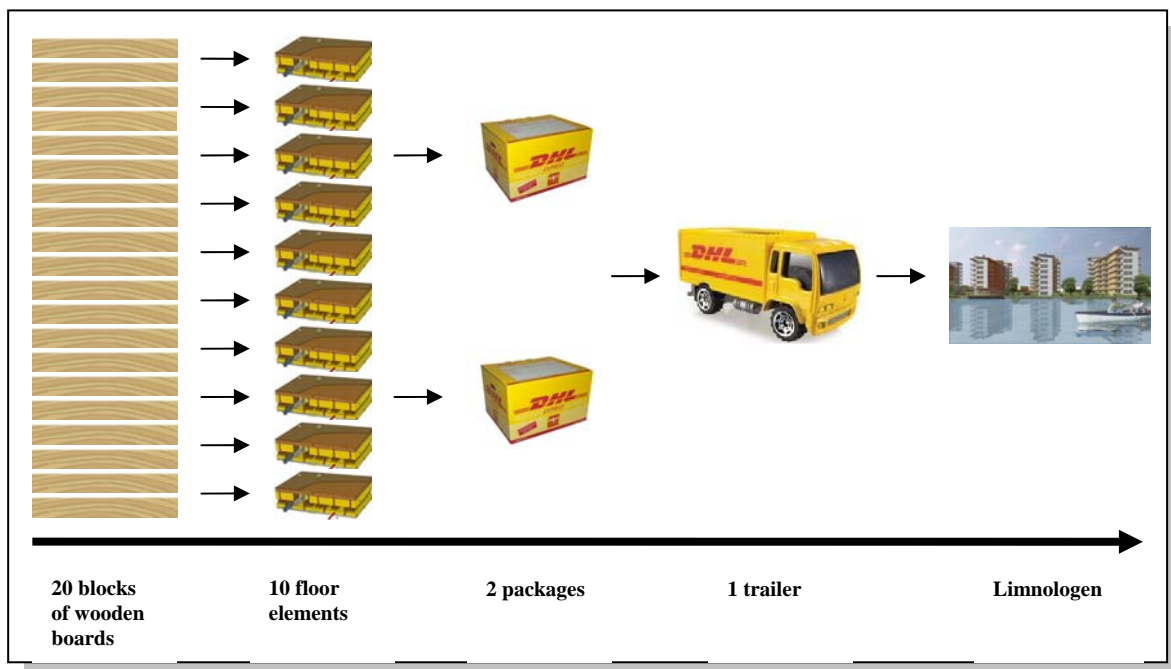


FIGURE 4.11 – AN OVERVIEW OF ASSEMBLY, MANUFACTURING AND DELIVERY OF FLOOR ELEMENTS

4.3.3 REVISED DELIVERY SCHEDULE

Unfortunately there have been difficulties meeting the agreed schedule of ten days for two reasons (revised schedule document & interview, 070507):

1. Martinsons Byggsystem AB has had a *tight production schedule* and difficulties keeping up with deliveries which have resulted in deliveries arriving at the Limnologen construction site too late.
2. There have been problems with lifting of the *hydraulic tent*. The lifting process that was supposed to take 30 minutes has sometimes taken as much time as one day because of technical problems. The current delivery schedule for floor elements has been adjusted to 11 days. Using the current schedule Martinsons Byggsystem AB are able to deliver on time so that the work teams at the Limnologen construction site do not have to wait on delivery. Another factor reducing the risk for waiting time at Limnologen is that deliveries do now take place one day ahead of installation. This means that workers can now start off on a new working day and know that all material needed for installation is already in place.

Table 4.2 is showing an extract of the current delivery schedule at Limnologen for the month of May 2007, the whole schedule can be found in appendix XVI

TABLE 4.2 – DELIVERY SCHEDULE

			MAY					
Datum	Event	Delivery	Datum	Event	Delivery	Datum	Event	Delivery
1			11	Floor 4	Package 3&4	21		
2			12			22	Raise of tent	
3	Raise of tent		13			23		
4			14	Floor 4	Package 5&6	24		
5			15			25		
6			16			26		
7			17			27		
8			18			28		
9			19			29	Floor 5	Package 1&2
10	Floor 4	Package 1&2	20			30	Floor 5	Package 3&4
						31	Floor 5	Package 5&6

4.4 INSTALLATION OF FLOOR ELEMENTS

4.4.1 THE BUILDING ENTREPRENEUR - NCC CONSTRUCTION SWEDEN



- Number of employees: 7 700 persons
- Turnover: about SEK 19.4 billion during 2005

NCC Construction Sweden is active in building and civil engineering construction, housing construction, housing development and building services in Sweden, (ncc.se, 070514). NCC is in charge of installing the massive timber floor system on the construction site, (interview, 070507).

4.4.2 THE INSTALLATION PROCESS AT LIMNOLOGEN



In this section the installation process for the floor system is going to be described. Likewise, for the manufacturing process, it can be found numbers in parentheses in the text that indicates that it is the moment that is going to be used to enable analysis in next chapter. All the moments are presented in table 4.2 at the end of this section. The installation process was acquired via the installation manual of massive timber floor system and the lead times were gathered through one interview with Ulf Cangemark, the work supervisor at Limnologen and through the Limnologen project group.

Every 11th day come a delivery of two packages (10 floor elements). However the deliveries are divided up by three and this means that the deliveries are arriving with one day in between. Thus deliveries take place during three days.



FIGURE 4.12 – UNLOADING OF ELEMENTS
SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.13 – LIFTING OF ELEMENTS
SOURCE: BJÖRNFOT (2006:33)



FIGURE 4.14 – INSTALLATION
SOURCE: BJÖRNFOT (2006:33)

The packages are lifted off the trailer instantly (17) and placed upon the jobsite waiting for the next working day (18). The elements are stored for 24 hours so the work team will not have to wait for deliveries. See figure 4.12 and also appendix XIII for illustration of the overhead crane and on site material waiting for installation.

The next day the packages will be unwrapped and lifted upon the building with an overhead crane and adjusted/installed (19). The installation is made underneath the hydraulic tent which is shown in appendix XIII. The hydraulic tent gives shelter to the floor elements during the complete installation process. See figure 4.13.

After the elements are in place preparations are made for the next element (20). Then sylodynnes (21) and plywood strips (22) are applied on the elements. Further installations such as complete under-roof, assembly of sprinkler systems and finishing on the floor surface will be made once all elements are in place in the building. Check figure 4.14.

The installation process steps from step 17 to step 22 are summarized in table 4.3 underneath:

TABLE 4.3 – INSTALLATION STEPS AT LIMNOLOGEN

Steps Number	Physical Actions Required to Install 1 Element	Total time
	Total Steps	
	Limnologen jobsite	
17.	Unloading of packages	5min
18.	Storage of packages	24h
19.	Installation of elements	10min
20.	Preparation for next element	5min

21.	Sylodynes are applied on the element	10min
22.	Plywoodstrips are applied	15min

4.4.3 DAILY ERROR REPORTS

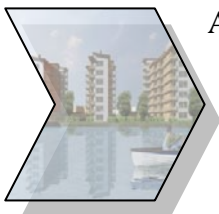
The summary of error reports concerns floor number 2 and 3 (60 elements) during the period from the 24th of March to the 27th of April are shown in table 4.4.

TABLE 4.4 – SUMMARY OF THE DAILY ERROR REPORTS

Started Working Step	Error	Waiting time/ unnecessary working time (hours)	Number of personns involved
Unloading floor element package 1 & 2	Tent not liften up	6	9
	Rebuilding of the crane 1 hour		
	Waiting time for crane operator 1 hour		
	Waiting time for timber worker 4 hours		
Unloading floor element package 3 & 4	Manufaturing errors on floor element 3 hours	5	9
Installation of 8 floor elements	Manufaturing errors on floor element 2 hours		
N/A	Drilling in the floor 1 hour	5	7
N/A	Missing insulation	-	9
	Too high tree blocks in the joist		
Unloading floor element package 1 & 2	Sound proofing carpet wrongly installed on two floor elements	2	8
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 3 & 4	Sound proofing carpet wrongly installed on two floor elements	2	9
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 5	Sound proofing carpet wrongly installed on two floor elements	0,5	9
	Uninstallation of the sound proofing carpet 0,5 hours		
Unloading floor element package 6	Wrongly drilled holes	2	9
Installation of the floor element	Ventilation shaft wrongly installed	-	8

Appendix XV, illustrates the drilling rework and the wrongly installed ventilation shaft and when insulation is missing.

4.4.4 LIMNOLOGEN



As said previously the Limnologen project is a group of four wooden buildings that are eight-storied thus making Limnologen the highest wooden building in Sweden. The whole building will be built using wood, including the framework, with exception made for the ground floor that will be built in concrete. Limnologen is the result of a contest in architecture won by the firm, ArkitektBolaget AB. (vallebroar.se, 070411) The architect Ola Malm, designed the buildings so that all flats have a personal balcony with view over the lake Trummen. (affkapnytt.se, 070411).

The construction was started in October, the 6th 2006, (mpd.midroc.se, 0705007), is planned to be finished by December 2007, (interview, 070507) and should be ready for occupation by February 2008, (fastighetsbyran.se, 070514). In appendix XI the possible design and plan of one of the floors is shown.

4.5 CUSTOMER

4.5.1 THE BUILDING PROPRIETOR - MIDROC PROPERTY DEVELOPMENT AB



- Number of employees: 2 000 persons
- Turnover: SEK 3 billion during 2006

The group Midroc Property Development AB develops, builds and manages commercial real estate properties and flats in Sweden. Midroc group is Sweden's largest developer of projects. (midroc.se, 070514) Midroc Property Development AB is the building contractor for Limnologen, (mpd.midroc.se, 070514) and Midroc Property Development AB total investment for Limnologen reaches SEK 300 million for the first two buildings including 134 flats, (affkapnytt.se, 070411).

5. ANALYSIS

The analysis for this Master Thesis will be conducted according to the first three lean thinking principles in construction.

Figure 5.1 presents an overview of the analysis.

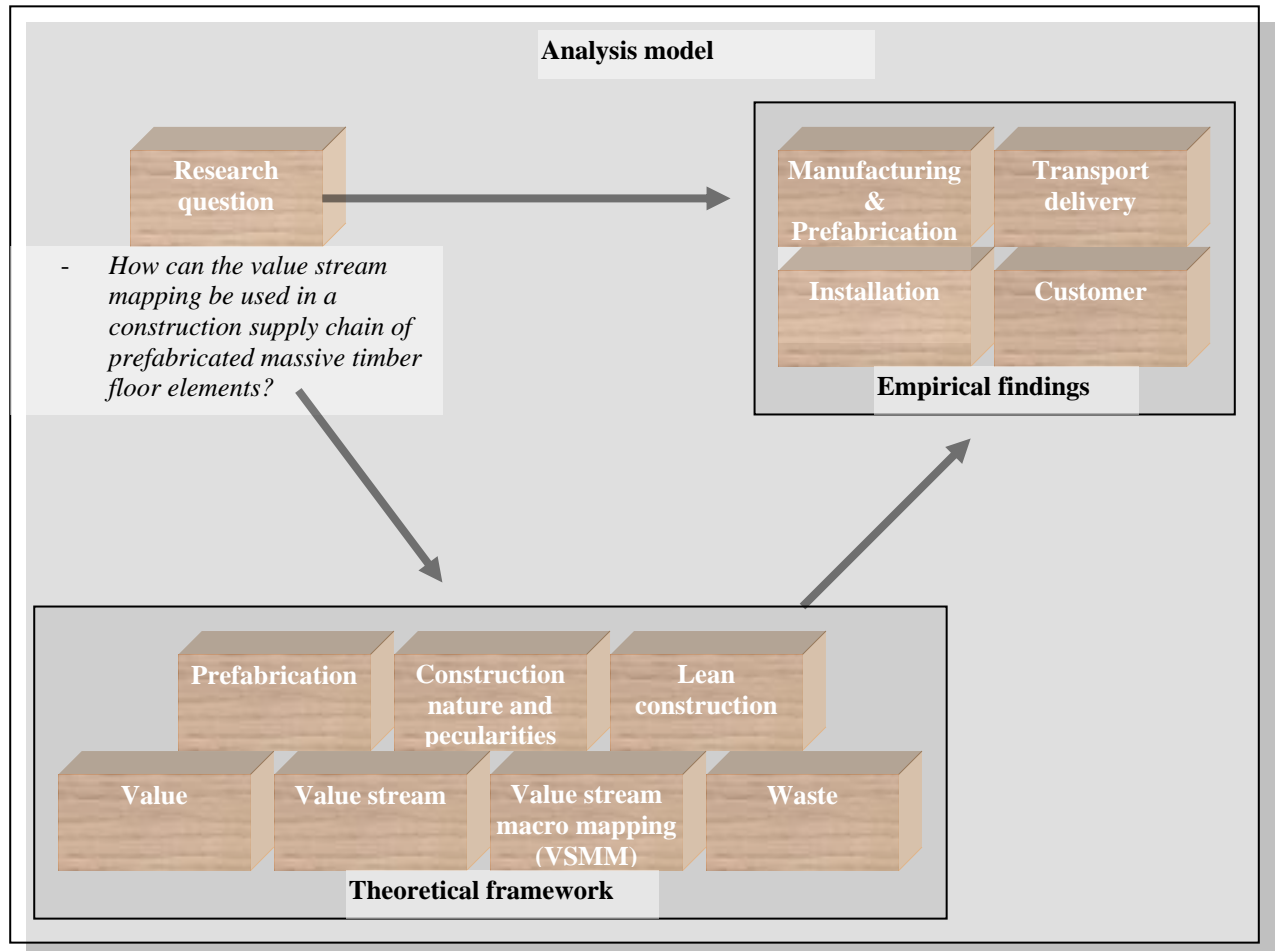


FIGURE 5.1 – OVERVIEW OF ANALYSIS

The analysis for this Master Thesis will be conducted according to the first three lean thinking principles in construction developed by Björnfot (2006:21-22) presented earlier in the theory chapter.

5.1 LEAN PRINCIPLE – VALUE

According to Womack and Jones (2003:16) value is defined by the end customer and created by the producer. Therefore it is crucial to identify the value requested by the customer. Four steps are required for one to be able to specify the value and these are (Björnfot, 2006:21-22):

- Define the customer
- Define what is of value to the customer
- Define what is of value to the delivery team
- Define how value is specified by products

5.1.1 DEFINE THE CUSTOMER

As presented earlier construction projects are complex systems, one of the underlying reasons was because of the great number of participants (users, owner, developer, real estate companies, financial agent, city agencies, designers, management and control company, general contractor, sub-contractors, materials suppliers, equipment suppliers) as argued by Pichi (2000:3). In this case the customer is Midroc Property Development AB. It should not be mistaken with the “end” user of the building that is the private persons who are going to take possessions of the apartments once finished. One could argue that the private persons are the customers but in reality they are Midroc’s customers and therefore not the “direct” customers of the whole construction project.

- The customer is Midroc

5.1.2 DEFINE WHAT IS OF VALUE TO THE CUSTOMER

To identify what is of value to the customer, Midroc Property Development AB, this can be supported with the help of the 7 C’s model (the new value based building process model) proposed by Emmitt et al (2005:8) showed in figure 5.2

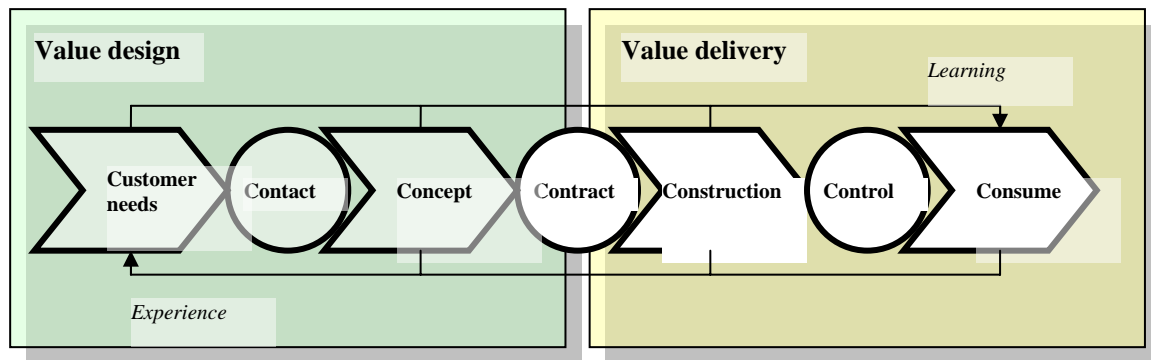


FIGURE 5.2 – A NEW VALUE BASED BUILDING PROCESS – 7 C'S

SOURCE: EMMITT ET AL (2005:8)

However only the value design is of interest in order to define what is of value to the customer, therefore only the first 4 C's of the model will be discussed in this section.

CUSTOMER NEEDS

The customer needs or in other words the society Midroc's needs are:

- Limnologen meets high design standards as it is the result of a contest in architecture,
- A group of four wooden buildings eight-storied high located in an attractive area, that is at the tip of the Trummen Lake,
- The apartments range from one-room to five-room flats, are given view on the lake
- Planned to be finished by December 2007 and ready for occupation by February 2008, therefore enabling that the flats are commercially marketed and sold through the estate agency, Swedbanks Fastighetsbyrå

CONTACT

Midroc Property Development AB contacted various constructors and suppliers that were able to satisfy the needs presented above. The selected companies are presented in figure 5.3:

Fact sheet	
Architect:	ArkitektBolaget AB
Framework supplier:	Martinsons Byggsystem AB
Constructor:	Martinsons Byggsystem AB (floor 2-8) Tyréns AB (ground and floor 1)
Building entrepreneur:	NCC
Weather protection:	Hallbyggarna Jonsereds and Industriteknik

FIGURE 5.3 – FACT SHEET

CONCEPT

The concept of the construction project is a whole building that will be built using wood, including the framework, with exception made for the ground floor that will be built in concrete. Of interest for this study is the element prefabrication. Recollect from section 3.2, Höök and Stehn's (2005:319) definition of an element. The element is manufactured in the environment of a factory where manufacturing processes are controlled, also called *factory physics*. Then the element is transported to the construction site to be assembled together with other elements and sub-assemblies, called as *construction physic*. Consequently a massive timber floor system is manufactured and fully customized (different span and level of prefabrication are made after customer specification) in Martinsons Byggsystem AB's facility. Moreover Martinsons Byggsystem AB's floor element allows open and flexible floor. Then the floor elements are transported on a trailer by DHL to Limnologen where it is assembled with other elements such as walls and sub-assemblies like for example: the sprinkler systems, electricity, ventilation and drain. Finally this leads to the last C that is going to be studied, the contract designs.

CONTRACT

The customer, Midroc Property Development AB reached an agreement, a contract, with Martinsons Byggsystem AB so that the latter delivers a prefabricated massive timber floor system (a total of 840 floor elements for the four buildings at Limnologen). As pointed out earlier, the floor system is adapted after the span and also the prefabrication level wished and required by the customer. The maximal span of the floor system agreed is 12 meter and the floor once installed requires the installation of the following sub-assemblies: the sprinkler systems, electricity, ventilation and drain.

- To sum up, the value to Midroc Development AB is *a flexible and customizable floor element designed to respect costs and time constraints (Höök, 2006:592)*

5.1.3 DEFINE WHAT IS OF VALUE TO THE DELIVERY TEAM

To identify what is of value to the delivery team, Martinsons Byggsystem AB, one can based it on the remaining C's (including contract) of the 7 C's model developed by Emmitt et al (2005:8) showed previously in figure 5.2

CONTRACT

Martinsons Byggsystem AB engaged itself to deliver a prefabricated floor system, customized according to the customer needs, concept and contract as described above.

CONSTRUCTION

Due to the particularity of the massive timber floor system that is, a prefabricated element, this involves that the construction takes place in two phases. That is first the element is manufactured and second the element is installed. Therefore two construction processes take place, one in the factory and one on-site. The planning of the manufacturing process is taken care by Martinsons Byggsystem AB which is planned to take ten days and in reality takes 11 days (excluding installation of the sub-assemblies which has not been studied by the authors since the installation has not commenced yet). The planning is a very important phase this is because as argued earlier waste accounts for 30-35% of the total building project costs. Of importance here is waste coming from defects. Since the element is prefabricated in a factory with controlled processes then defects should not show up during the erection of the floor elements. The planning of the on-site work is made by NCC. In the theory section about construction nature and peculiarities, it was presented six concepts. Of interest in the erection phase, it is that the production layout characterizes Limnologen in that way that the production resources need to be moved and organised around the product as shown in appendix figures VIII. Another interesting peculiarity is the uncertainty factor. In the context of this study, uncertainty has been partially reduced thanks to the hydraulic tent system, shown in appendix figure VIII. This is because the tent shelters the construction site diminishing thus risk of material getting damaged and also allowing NCC's workers to work under rainy weather conditions.

CONTROL

In this phase the control activity is accomplished by Martinsons Byggsystem which must make sure that its product is perfect without any mistakes, this is done through the various inspections made at Martinsons Byggsystem AB's factory. Additionally Martinsons Byggsystem AB must ensure that the delivered product comply with Midroc Property Development AB value specification agreed upon when closing the contract.

CONSUME

It is important on the first place to document meticulously the problems and wastes that happened under the project in order to not repeat the same mistakes when erecting the building number two. This is done through the weekly errors report accomplished by NCC. As Limnologen is Sweden's highest multi-storey timber housing, it is also important that the project is studied so that the industry gather additional knowledge about wooden construction. Additionally the possible success of Limnologen will enable the promotion of using wood in other multi-storey housing.

- To summarize, the value to the delivery team is *to manufacture and deliver customized and defect free prefabricated massive timber floor elements that are then assembled to a floor system and installed at Limnologen*

5.1.4 DEFINE HOW VALUE IS SPECIFIED BY PRODUCTS

To allow the delivery team to create value so that customer needs are being met, the floor elements must be movable/transportable. This is reached thanks to the quality of tree and that is its lightness. As said previously one of the advantageous of building in three was that it was 19 times lighter than concrete. Moreover Martinsons Byggsystem makes sure that the elements are packed properly to avoid damaging risks during the 1 169 km long voyage.

- To resume the value of the floor elements is *to be movable/transportable*

5.2 LEAN PRINCIPLE – VALUE STREAM

The four steps to define the value stream are the following (Björnfot, 2006:21-22):

- Define all resources required for production
- Define all activities require for production
- Standardize current practice
- Define and locate key component suppliers

5.2.1 DEFINE ALL RESOURCES REQUIRED FOR PRODUCTION

As Björnfot (2006:21-22) points out, defining the *resources required for production* is crucial for creating a value stream. Connected to *mapping the physical flow*, as presented by Jones and Womack (2003:14) a list of facilities should be constructed that are included in the specific supply chain of the chosen product or component. For the supply chain of massive timber floor systems, the different actors and facilities would be the ones shown in appendix XVII, namely:

- The sawmill of Martinsons (located in Kroksjön)
- The sawmill of Martinsons (located in Bygdsiljum)
- The assembly facility at Bygdsiljum
- The construction site of Limnologen

These resources/facilities also include production resources such as machines, labour (workforce), raw material (e.g. wooden boards – long and short), components (e.g. ventilation pipes, sprinkler systems, and isolation), tools and time. Without such facilities and resources no assembly of floor elements will take place, no deliveries will be made, and no installation of floor elements will be possible at Limnologen. As the actors in the supply chain might be different from project to project – referred to as a *temporary multiorganization* presented by Koskela, (1992:47) – the required resources might also be different.

- The amount of resources used to manufacture the massive timber floor system cannot be discussed here as these data have not been provided (exception made for time that is going to be presented in next section) therefore this theoretical discussion is the main contribution to this section.

5.2.2 DEFINE ALL ACTIVITIES REQUIRED FOR PRODUCTION

After having identified the required resources for production there is a need to do the same type of identification of required activities in the supply chain (Björnfot, 2006:21-22). That is,

once again connected to *mapping the physical flow* (Jones & Womack, 2003:14) a list of activities that need to be conducted in order to bring raw material to finished product and end customer. To bring the massive timber floor systems to the customer and finished installation in the buildings at Limnologen there are a number of activities/actions that need to be performed. These actions (*the physical flow*) are shown in table 5.1. The actions include activities connected to transport links, processing, assembly and installation.

- All activities required for production are shown in table 5.1

TABLE 5.1 – PHYSICAL ACTIONS AND CORRESPONDING TIME

Steps Number	Physical Actions Required to Create, Deliver and Install 1 Element	Total Time
	Total Steps	
	Sawmill Kroksjön (long boards)	
1.	Loading Sawmill Kroksjön	15min
		Total 15min
	Transport Link 1	
2.	Shipping Kroksjön-Bygdsiljum (70km)	90min
3.	Unloading of boards at facility	15min
4.	Quality check	2min
		Total 107min
	Martinsons facility Bygdsiljum	
	<u>Preassembly of blocks</u>	
5.	Glue and packing (long boards and short boards)	20min
6.	Cut off unnecessary material and cut for floor heating	20min
7.	Transport overhead crane to new conveyor belt	5min
		Total 45min
	<u>Assembly of elements</u>	
8.	Assembly of two blocks into an element	10min
9.	Marking up “liv & flens”	30min
10.	Various complements are installed	15min
11.	Isolation is installed	30min
12.	Under-roof is installed	12min
13.	Installation of sprinklers	30min
14.	Packaging and wrapping	18min
		Total 145min (2,42h)
	Transport Link 2	

15.	Storage at facility	3 days
16.	Shipping Bygdsiljum-Limnologen (1169km)	2 days
		Total 5 days
	Limnologen jobsite	
17.	Unloading of packages	5min
18.	Storage of packages	24h
19.	Installation of elements	10min
20.	Preparation for next element	5min
21.	Sylodynes are applied on the element	10min
22.	Plywoodstrips are applied	15min
		Total 24,75h (incl. 24h storage)

Summary of Physical Actions

Steps	22
Time	8 997 min. = 149.95 h. = 6.25 days
Distance	1239 km over 2 transport links

5.2.3 STANDARDIZE CURRENT PRACTICE

As Koskela (1992:44) points out practice in construction projects is rarely standardized. *Standardization* has mostly been used in manufacturing with *customization* for different *customer preferences* (Paez et al, 2005:235). In the Limnologen project a lot of effort has been made to make standardization possible. The most important initiative is that the floor elements are prefabricated. As Höök (2006:583f) argues, prefabrication increases standardization and repetitiveness so that the construction process gains some of the benefits from manufacturing. The manufacturing process of floor elements at Martinsons Byggsystem AB in Bygdsiljum is highly standardized and automated with machines in the beginning (stage 5-6 – see table 5.1 presented in the section above) while customization is allowed by manual installation and assembly at a later stage (stage 10-13 – see table 5.1 presented in the section above). The process could be compared with manufacturing of cars where standardized modules are brought together, and are later used for assembly and installation where customer preferences play an important role in the process. In Martinsons Byggsystem AB's case that would mean standardization is accomplished by the use of blocks of wooden

boards, while customization is accomplished by allowing for different floor plans (e.g. different floor span, up to 12 meter and different level of prefabrication) and architectural design created by other actors in the supply chain (e.g. different installations of ventilation, sprinkler systems and isolation).

- Standardization and customization are allowed thanks to the prefabrication process

5.2.4 DEFINE AND LOCATE KEY COMPONENT SUPPLIERS

According to Björnfot (2006:21-22) there is a need to define and locate key component suppliers. In the Limnologen project it was not difficult to define and locate key component suppliers. This was because the chosen provider Martinsons Byggsystem AB is considered as to be the leading producer and supplier of massive-tree frameworks building technology. Martinsons Byggsystem AB also had experience from similar construction projects that had been conducted earlier e.g. in Sundsvall. Another reason for using Martinsons Byggsystem AB as a supplier for massive timber floor elements was that they could also supply solutions for walls and other elements. As Picchi (2000:3) argues the complexity of construction is usually high, as the number of participants in the supply chain is many. Therefore the choice of one supplier for the whole wooden frame effectively resulted in a lower complexity for the Limnologen project.

- Martinsons Byggsystem AB is a leader in his market and moreover the facility can provide a holistic solution thus resulting in complexity reduction

5.3 LEAN PRINCIPLE – FLOW

This section will be conducted according to the two steps identified by Björnfot (2006:21-22):

- Identify non-value adding activities (waste)
- Remove or reduce the influence of waste as it is observed

5.3.1 IDENTIFY NON-VALUE ADDING ACTIVITIES (WASTE)

The VSMM method will be applied in order to identify the non-value adding activities in the supply chain for Limnologen.

MAP THE CURRENT STATE

In table 5.1 that was shown earlier was presented the list of every action accomplished on the product and the necessary time to perform the actions. Next step is then to judge whether or not a step adds value or is waste, one has to think like a customer and ask if he would pay less money for the product or be less happy with the product if a given step and its corresponding time were not done. For instance, in the case of installing isolation sprinklers to the floor elements, the answer is clear. Customers do not imagine moving into a flat and discovering on the floor in the middle of the flat, the isolation material accompanied by a polite memo claiming, "Some assembly required". The other 11 steps are also clearly creating value to the customer. By contrast, the remaining manoeuvres such as the transport between the facilities, the storage activities along the value chain and inspection step consume time and are not adding value to the product. This is because the customer is ready to pay less for the product if these activities would disappear. (Jones & Womack, 2003:18) The value creating steps and time are presented table 5.2.

TABLE 5.2 – PHYSICAL ACTIONS AND CORRESPONDING TIME , VALUE CREATING STEPS AND TIME

Physical Actions Required to Create, Deliver and Install 1 Element		Value Creating Steps	Total Time	Value Create Time
Total Steps				
Sawmill Kroksjön (long boards)				
1.	Loading Sawmill Kroksjön		15min	
			Total 15min	
Transport Link 1				
2.	Shipping Kroksjön-Bygdsiljum (70km)		90min	
3.	Unloading of boards at facility		15min	
4.	Quality check		2min	
			Total 107min	
Martinssons facility Bygdsiljum				
<u>Preassembly of blocks</u>				
5.	Glue and packing (long boards and short boards)	1	20min	20 min
6.	Cut off unnecessary material and cut for floor	2	20min	20 min

	heating			
7.	Transport overhead crane to new conveyor belt		5min	
			Total 45min	
	<u>Assembly of elements</u>			
8.	Assembly of two blocks into an element	3	10min	10 min
9.	Marking up “liv & flens”	4	30min	30 min
10.	Various complements are installed	5	15min	15 min
11.	Isolation is installed	6	30min	30 min
12.	Under-roof is installed	7	12min	12 min
13.	Installation of sprinklers	8	30min	30 min
14.	Packaging and wrapping		18min	
			Total 145min	
			(2,42h)	
	Transport Link 2			
15.	Storage at facility		3 days	
16.	Shipping Bygdsiljum-Limnologen (1169km)		2 days	
			Total 5 days	
	Limnologen jobsite			
17.	Unloading of packages		5min	
18.	Storage of packages		24h	
19.	Installation of elements	9	10min	10 min
20.	Preparation for next element	10	5min	5 min
21.	Sylodynes are applied on the element	11	10min	10 min
22.	Plywoodstrips are applied	12	15min	15 min
			Total 24,75h	
Summary of Physical Actions				
		Total	Value	
Steps		22	12	
Time		8 997 min. = 149.95 h. = 6.25 days	207 min.= 3.45 h. = 0.14 days	
Distance		1239 km over 2 transport links		

As revealed by the summary in the table 5.2, the 22 steps performed on one floor element take 8 997 minutes or 6.25 days. By contrast, value adding time accounts for 207 minutes or 0.14 days and the number of steps is reduced to 12. To exemplify these a bit further, ratios can be calculated. The ratios of value-creating time and total time (207 minutes out of 8 997 or 2 %)

and of value-creating steps to total steps (12 out of 22 or 55 %). The value adding time is also illustrated in a pie diagram presented in figure 5.4.

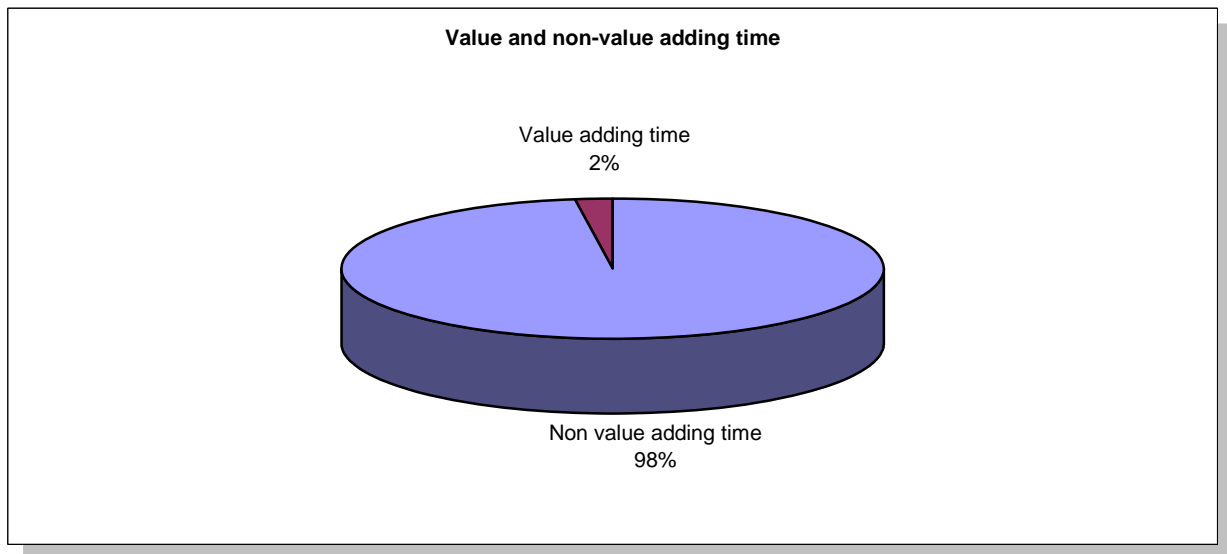


FIGURE 5.4 – VALUE AND NON-VALUE ADDING TIME FOR THE WHOLE PROCESS

Next step is to create a value stream mapping for every actors showing the flow of products and information for the current state. This is the preliminary work necessary to draw the value stream macro mapping map for the whole supply chain.

Figure 5.5 presents the VSM for Martinsons Byggsystem AB, the figure can be found in a bigger format in appendix XIX.

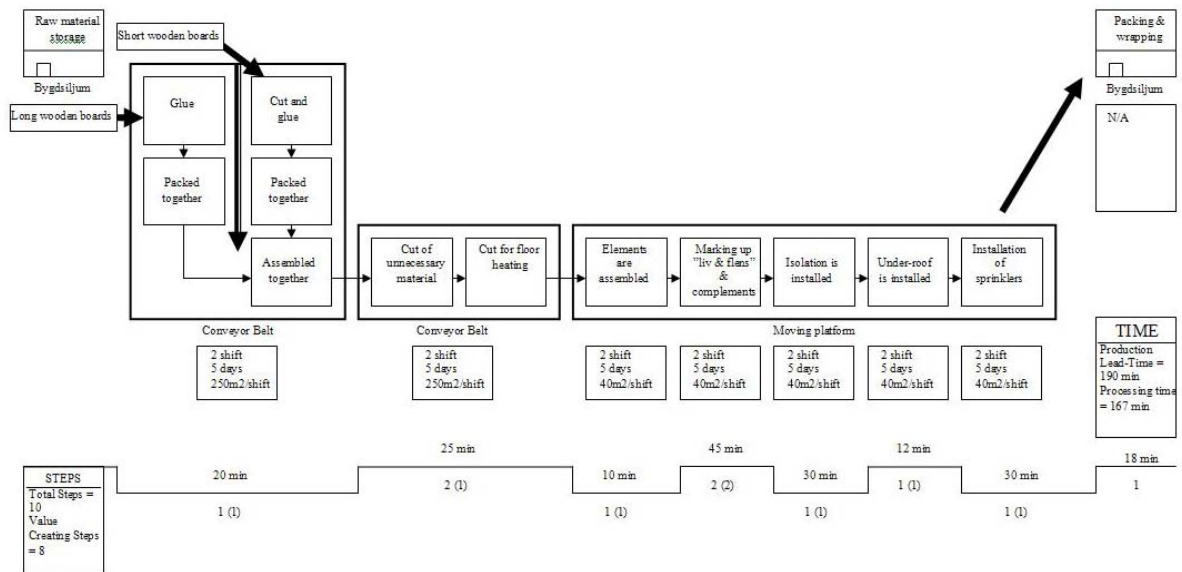


FIGURE 5.5 – VSM FOR MARTINSONS BYGGSYSTEM AB

Figure 5.6 presents the VSM for Limnologen, the figure can be found in a bigger format in appendix XX.

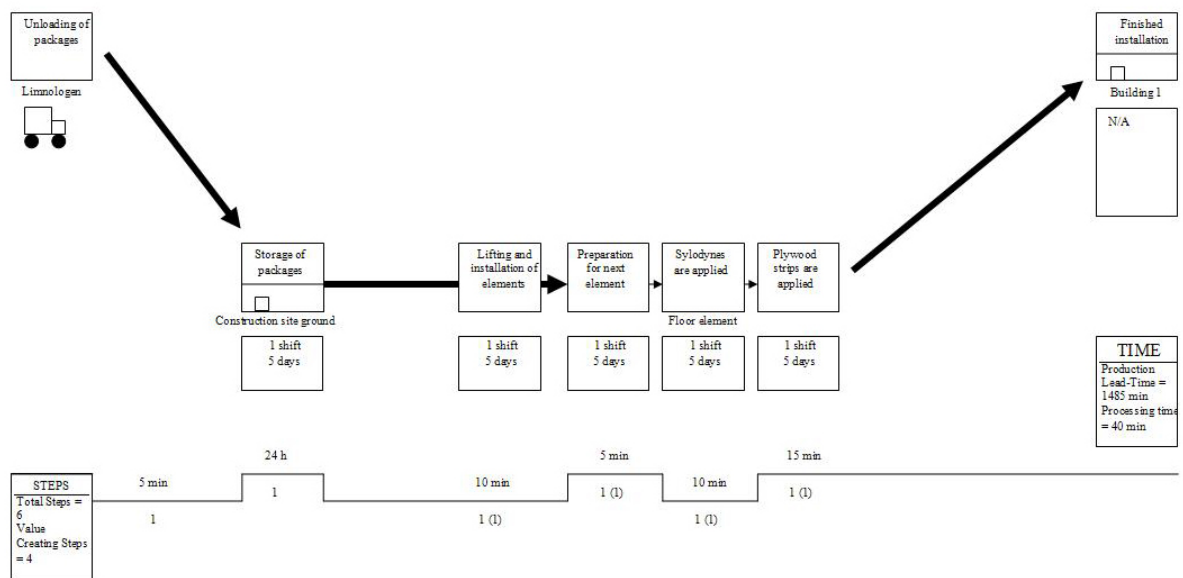


FIGURE 5.6 – VSM FOR LIMNOLOGEN

Figure 5.7 presents the VSMM for studied supply chain, the figure can be found in a bigger format in appendix XXI.

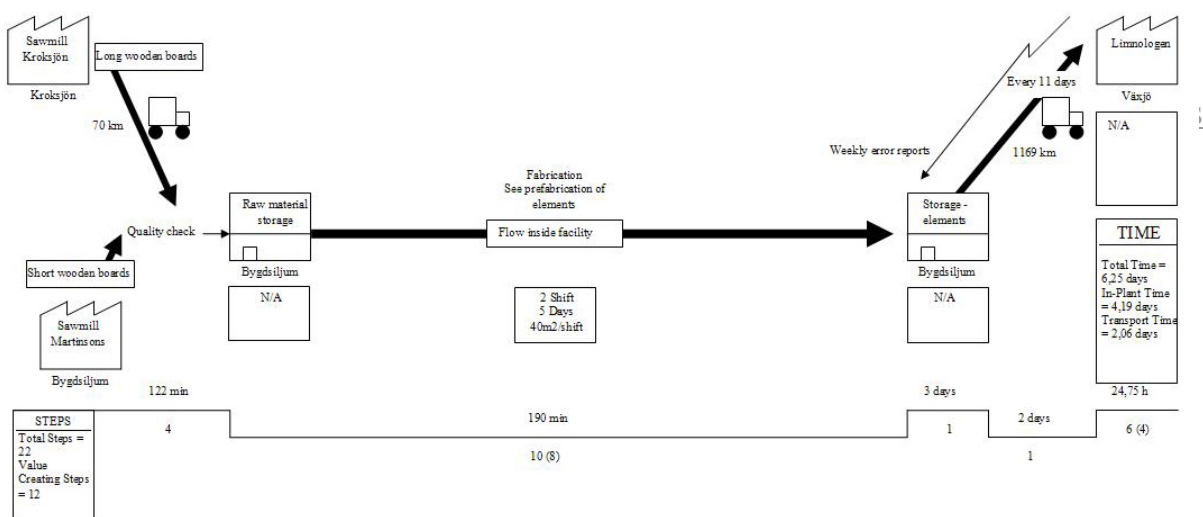


FIGURE 5.7 – VSM FOR THE STUDIED SUPPLY CHAIN

ANALYSIS OF THE MAP OF THE CURRENT STATE – IDENTIFICATION OF WASTE IN THE SUPPLY CHAIN

At the bottom of the VSM can be found the time-and-steps line where the value adding and non-value adding steps are shown. The numbers in parentheses visualize the value adding steps and therefore helps to identify where value is created and where it is not. By analyzing the time-and-steps line VSM, several wastes become evident:

1. The long wooden boards manufactured in Kroksjön are transported to Bygdsiljum.
2. The floor elements are stored three days at Bygdsiljum before to be picked up and delivered to Limnologen.
3. Another phenomenon that is quite obvious is the time it takes to transport the floor element from Bygdsiljum to Växjö.
4. Furthermore the 24 hour storage time at Limnologen is also taking a lot of time.

IDENTIFIED WASTE AT LIMNOLOGEN

Figure 5.8 illustrates an Ischikawa diagram made from the summary of error reports for floor number 2 and 3 that was showed in table 4.3.

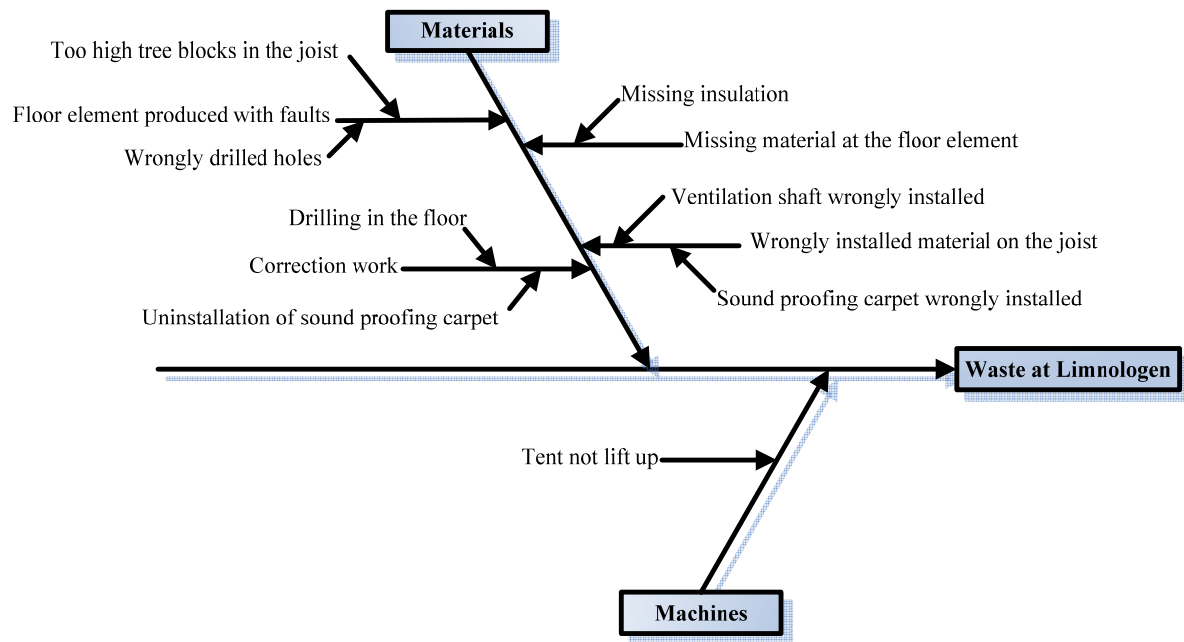


FIGURE 5.8 – ISHIKAWA DIAGRAM REGARDING FLOOR NUMBER 2 AND 3

The identified waste in the supply chain can be classified according to the classification of Chase et al, (2006:472) presented in table 5.3. At the top of the table can be found Chase et al, (2006:472) classification and on the left side is listed all the waste identified in the supply chain for Limnologen.

TABLE 5.3 – WASTE ENCOUNTERED IN THE SUPPLY CHAIN CLASSIFIED ACCORDING TO THE SEVEN WASTES CLASSIFICATION

	1. Waste from product defects	2. Inventory waste	3. Processing waste	4. Waste of motion	5. Transportation waste	6. Waste of waiting time	7. Waste from overproduction
1. Long wooden board transported from Kroksjön					X		
2. Three days storage at Bygdsiljum						X	
3. Transport Bygdsiljum to Växjö					X		
4. 24 hours storage at Limnologen						X	
5. Tent not lift up						X	
6. Manufacturing errors on floor element	X						
7. Drilling in the floor	X						
8. Missing insulation	X						
9. Too high tree blocks in the joist	X						
10. Sound proofing carpet wrongly installed	X						
11. Uninstallation of sound proofing carpet	X						
13. Ventilation shaft wrongly installed	X						

One can notice in table 5.3 that waste encountered in the supply chain for Limnologen can be classified into three of the seven categories. The reason underlying this is due to the lack of provided empirical data. For example data on inventory is lacking and therefore it is not possible to prove that inventory waste is occurring. Waste of motion cannot be studied either since data on walking distances have not been recorded. Waste from overproduction has not been found either simply because Martinsons Byggsystem AB and Midroc Property Development AB agreed on the exact quantities of elements needed. Finally processing waste does not seem to exist in this supply chain, this is maybe because we were maybe not able to capture the process correctly.

Three types of waste characterize this supply chain:

Waste from product defects can only be found on the finished product, that is the floor element and the reason for this is that no data were provided on defects per million on raw material and work in process. Other than that it can be said from the study of the summary in table 5.4 that drilling problems have been encountered on floor 2 and 3, but not at the same place (from studying the error reports). One can notice as well that problems with the sound proofing carpet was a big issue for floor number 3 since five packages were concerned. Generally the nature of the activities (drilling holes, uninstalling and installing material, cutting) are not the same from floor to floor and do not concern the same area either (ventilation, timber, sound proofing carpet and insulation). This requires that the workers are polyvalent and capable of fixing the problems. Moreover in general the reworks concern many persons every time and also many hours. Consequently this kind of waste concerns material, people and time. The probable reasons for these problems to appear are that the construction phase in *Lean principle – value* was not properly defined. Furthermore the customization process of the floor element, that is the process that is made manually at the Bygdsiljum is maybe not completely reliable. Finally Martinsons Byggsystem AB has had a *tight production schedule* and difficulties keeping up with deliveries

TABLE 5.4 – SUMMARY OF THE DAILY ERROR REPORTS

Started Working Step	Error	Waiting time/ unnecessary working time (hours)	Number of personns involved
Unloading floor element package 1 & 2	Tent not liften up	6	9
	Rebuilding of the crane 1 hour		
	Waiting time for crane operator 1 hour		
	Waiting time for timber worker 4 hours		
Unloading floor element package 3 & 4	Manufaturing errors on floor element 3 hours	5	9
Installation of 8 floor elements	Manufaturing errors on floor element 2 hours		
N/A	Drilling in the floor 1 hour	5	7
N/A	Missing insulation	-	9
	Too high tree blocks in the joist		
Unloading floor element package 1 & 2	Sound proofing carpet wrongly installed on two floor elements	2	8
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 3 & 4	Sound proofing carpet wrongly installed on two floor elements	2	9
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 5	Sound proofing carpet wrongly installed on two floor elements	0,5	9
	Uninstallation of the sound proofing carpet 0,5 hours		
Unloading floor element package 6	Wrongly drilled holes	2	9
Installation of the floor element	Ventilation shaft wrongly installed	-	8

The next type of waste is transportation time. Since the element is prefabricated this involves that the product is transported and it can be said that because of transportation, activities such

as loading and unloading take additional time and thus do not add any value to the product. Moreover there are some risks that the goods get damaged under the voyage and therefore risks for even more waste.

The last type of waste identified in the supply chain is waste of waiting time. As shown in table 5.4 the tent resulted in problems the first time it was going to be lifted up. The system was designed to take 30 minutes but six hours were necessary during the first utilization because of technical problems. This resulted in engaging a lot of persons to solve the problem and delaying the erection process as well (workers that have not been able to install any new material/elements). The other type of waiting time is characterized by the storage of the packages before delivery and after delivery. The source of the problem was that Martinsons Byggsystem AB has had a *tight production schedule* and difficulties keeping up with deliveries. This has resulted in deliveries arriving at the Limnologen construction site too late and this led to workers waiting for the floor elements.

- Waste from product defects, occurs at different areas of the floor elements and result in various different activities for rework, thus workers must be polyvalent to perform the rework and this type of waste concerns people, material and time
- Transport waste
- Waste of waiting time

5.3.2 REMOVE OR REDUCE THE INFLUENCE OF WASTE AS IT IS OBSERVED

Suggestions on how to reduce or diminish waste will be discussed in this section. This will be done by first summarizing the probable reasons that were identified and discussed above and then proposing a way on how to maybe rectify the problem.

WASTE FROM PRODUCT DEFECTS

The first reason identified for waste from product defects was the probable incomplete definition of the construction phase, thus to reduce or remove this, Martinsons Byggsystem AB should plan its manufacturing process more carefully.

The second reason recognized for waste from product defects was maybe an unreliable manual manufacturing process at Bygdsiljum. In order to remove or reduce this, maybe a final inspection should be made before the elements are being packed.

The third reason was a tight production schedule, to reduce or remove this problem Martinsons Byggsystem AB has to plan its production schedule better.

More generally lean production principles should be applied at Bygdsiljum to reduce this kind of waste.

It has not been seen similarities of defects between two floors systems however the daily error reports should be sent every day and not once a week as currently done.

TRANSPORTATION WASTE

The long wooden boards manufactured in Kroksjön could be instead manufactured at Bygdsiljum instead, in that way the time it takes to load, transport and unload the boards could be eliminated.

The transport of the floor element from Bygdsiljum to Växjö takes two days thus making the process longer. This time could be reduced by choosing a faster transport mode. Another solution that is quite “unrealistic” but anyway “possible”, is to find a floor system supplier closer to Växjö. One has to think that changing supplier would cause new problems (e.g. searching for a capable supplier, learning how to install a new system) and delay the construction project even more.

WASTE OF WAITING TIME

One of the sources for waiting time was that the tent did not operate as planned, because of technical problems. As we do not have any knowledge in this area it is not impossible to propose a possible solution to reduce this waste. The other source for waiting time was the storage of the elements before and after delivery. The floor elements are stored three days at Bygdsiljum before to be picked up and delivered to Limnologen. As said previously this time is a safety in case of the production varies or is disturbed. This storing could be decreased or eliminated. Furthermore the 24 hour storage time at Limnologen is also questionable since the project is scheduled according to JIT principles, which assumes that no element part should come earlier or later. However a choice need to be made between one, have the elements stored one day and ready for installation, or, two, not have any elements and have to wait for the delivery. Even if the storage does not add any value to the product, it does not add any costs and applying lean construction implies that the flow of products is continuous, thus storage should be eliminated.

6. CONCLUSIONS

The answer to the problem formulation opens this chapter and at last reflections around the thesis together with suggestions for further research are discussed.

6.1 ANSWER TO THE PROBLEM FORMULATION

The problem formulation for this Master Thesis was the following:

- **How can the value stream mapping be used in a construction supply chain of prefabricated massive timber floor elements?**

This case study describes how the value mapping can be used to visualize graphically the flow of material from boards reception to floor elements installation, depicting all the actors involved that is from the manufacturer of the floor elements to building entrepreneur and allowed eventually the identification of waste and attempt to reduce it in the construction supply chain of a prefabricated massive timber floor element.

Before drawing the map, value must be defined at the customer level, the delivery team level and the product level. This is done in order to determine later which activities add value to the product and which do not. It can be concluded from the analysis that the value design (value to the customer) is based as argued by Höök (2006:592) on customization, flexibility, design and time and cost efficient whereas the value delivery (value to the delivery team) are proceeded in two steps, first manufacturing the elements and then assembling them on the construction site. The value specified in the product focuses on its move ability.

Next step, the identification of the value stream, was based upon the VSMM methodology. The activities and resources required to bring the product “to life” were defined and counted and to sum up, the massive timber floor element passes through a total of 22 steps. The process starts with loading the boards at Martinsons and ends with applying plywoodstrips on the job site and this took 6,25 days. Travel distances were recorded to 1 239 km. Thereafter it was discussed that Martinsons Byggsystem AB’s prefabricated element allowed standardization, customisation and moreover reduce complexity.

The final step allowed the mapping of the flow graphically in order to identify waste which was after being reduced and /or removed. It was found that 12 steps were value adding and that their corresponding value create time represented only 2% of the total time. From the VSMM map and the summary of the error reports 13 different wastes were found. To conclude three types of waste were discovered, waste from product defects, transportation waste and waste of waiting time.

Waste from product defects could be reduced or removed if Martinsons Byggsystem AB would plan more carefully its manufacturing process and its production schedule. Moreover it is suggested to add a final inspection before packing the elements, to implement lean production at Bygdsiljum to reduce this kind of waste. Lastly it is advised to send the daily error reports every day. Transportation waste can be eliminated and/or reduced by first manufacturing the long wooden boards manufactured in Bygdsiljum instead of Kroksjön. Second it could be envisaged to choose a faster transportation mode to transport the floor element to Växjö or to find a supplier of floor elements closer to Växjö. The last waste, waiting times could be reduced/eliminated by decreasing or taking away before and after delivery storage.

The focus of the study has looked upon the applicability of value stream mapping in a timber multi-storey housing project in Sweden. It has evaluated if the value stream mapping tool is of any use to the construction industry and specifically construction projects using prefabrication with wooden elements.

Considering the case project Limnologen, a conscious effort seems to have been made regarding both customer value and waste. However the study made has shown that in the supply chain of massive timber floor elements at Limnologen there is big potential to lower costs and increase customer value as value added-time accounted for only 2% of the total time. Regarding elimination of waste leading to cost efficiency VSM seems to have at least the possibility to identify waste for administrative purposes. Even the research conducted in this thesis shows valuable characteristics of the VSM tool for evaluation of construction supply chains. More comprehensive studies taking more data into consideration should be able to highlight a lot of issues in logistics practices.

This VSM study has been able to highlight a number of unnecessary activities in the process of manufacturing wooden floor elements, delivering them and installing them. These activities have been connected to waste such as excessive transport, storage and rework. If more empirical data would have been provided, the VSM tool would most probably have been able to highlight even more waste. With more data provided to the VSM tool, researchers might be able to provide solutions for compressing the whole supply chain, regarding lead-times and inventory.

Researchers should take into consideration that the use of the VSM tool only gives as much information as the data put into it. The model is very dependant on quantitative information - transforming input into output. Therefore there might be difficulties using the VSM tool on projects if there is lack of such information, for example start-up projects. A recommendation for further research using VSM would therefore be to use a very comprehensive database of quantitative data as that would give the best outcomes.

6.2 REFLECTIONS

In the following section reflections upon the study is presented:

This study was based on lead times and information collected from a number of different informants. Because of a lack of time and resources the lead times based in the study were acquired mainly from Bengt Abelson, project engineer at Martinsons Byggsystem AB in Bygdsiljum. If the lead times had been clocked and collected by the researchers themselves the results would have been more detailed. Also the authors would have had more control of how the information had been collected in the first place.

If we had collected the lead times at the Martinsons Byggsystem AB's facility and the construction site by our selves, would the results have been any different? Would the results have been any different if we had asked other people/a greater number of people? Additionally would it have been interesting also to get views from other actors in the supply chain such as DHL and Midroc? Would more thorough error reports have contributed even more (for example information about human errors and other defects)

Additionally it would have been interesting to get more data on the information flow, inventory data and defects to enable us to perform a complete VSMM and to give recommendations on how to reduce/eliminate waste. On the other hand we cannot help but wonder if we would have been able to analyze all the data and provide this master thesis on time. As we are experiencing it now more data to analyze would make it impossible for us to finish the Master Thesis on time or we could suppose that we would have provided and performed a less deep analysis of the data.

Last but not least we wonder also what results it would give to perform the study later into the project? What problems are there studying a construction project in the beginning (early phases)? Are there any benefits from studying the project in the beginning? Would there be any pros and cons?

6.3 SUGGESTIONS FOR FUTURE RESEARCHES

In the following section suggestions are presented for future research within the Limnologen project:

Follow up on error reports

A later follow up on error reports should be done studying if there are any errors occurring in a later state that could have been avoided in the beginning. A study should also be done to see how the error reports sent from Limnologen to Martinsons Byggsystem AB are actually followed up and if there are any improvements to be seen at the construction site.

Learning curve

Such a study should be done at a later stage in the construction process to see how performance has improved in the supply chain. The Limnologen project will take place during 2007-2008 so many opportunities exist to conduct a comprehensive study that would provide information for conducting a learning curve analysis. A learning curve analysis would also show if the expected goal at the Limnologen construction site – to reduce the delivery schedule to the original 10 days – can be actually met.

Consequences of waste

In this study some sources of waste and causes have been highlighted. It has also been shown that waste can ultimately result in difficulties meeting construction project schedules. A future study should be done where economical consequences of waste and delays are identified. It would be interesting to see how contracts are arranged and which actor in the supply chain takes the responsibility for the delays.

Identification of waste in other supply chains

In this study the researchers have identified waste and unnecessary activities in the supply chain of massive timber floor systems. Similar studies should be done to wall elements and other components as well.

More detailed value stream mapping (VSM)

In the future a more comprehensive value stream mapping should be done that is not only taking lead times into consideration but also inventory data and more thoroughly detailed information flow.

BIBLIOGRAPHY

In this part the literature, scientific articles, interviews, websites and other sources that were used to write this master thesis are listed.

PRINTED LITERATURE

Andersen I., (1998), "*Den uppenbara verkligheten – Val av samhällsvetenskaplig metod*", Studentlitteratur, Lund

Bernt I., Krohn M., and Solvang H., (1986), "*Metode valg og metode bruk*", Engers Boktrykkeri A/S, Otta

Chase, R-B., Jacobs, F-R., and Aquilano, N-J., (2006), "*Operations Management for Competitive Advantage*", McGraw-Hill, New York

Gummesson E., (2000), "*Qualitative methods in management research – second edition*", Sage Publications Inc., London

Jones D., and Womack, J., (2003), "*Seeing the Whole – Mapping the extended Value Stream*", The Lean Enterprise Institute, Brookline, USA

Lundahl U., and Skärvad P-H., (1999), "*Utredningsmetodik för samhällsvetare och ekonomer*", Studentlitteratur, Lund

Mattsson S-E, and Jonsson P., (2005), "*Logistik - Läran om effektiva materialflöden*", Studentlitteratur, Lund

Rosengren K. E., and Arvidsson P, (2002), "*Sociologisk metodik*", Liber, Malmö

Patel R., and Davidsson B., (1994), "*Forskningsmetodikens grunder – Att planera, genomföra och rapportera en undersökning*", Studentlitteratur, Lund

Teleman H., Ericsson M., von Platen F., Pekkari M., Eriksson A., Richter N., Lindström M., Thörnqvist T., Alsmarker T., Svensson N., Asplund H., Jakobsson O., Zetterholm G-

B., Baudin A., Wiklund M., Hagstedt J., Askaner Håkansson M., Elgestam Adolfsson C., Österberg S-E., and Kruse J., (2003), "*Trärevolutionen*", Resurscentrum för medialisering av Skog och Trä – Virserums konsthall

Tersine, R., (1994), *Principles of Inventory and Materials Management*, Prentice Hall, New Jersey

Wallen G., (1996), "*Vetenskapsteori och forskningsmetodik*", Studentlitteratur, Lund

Womack J., Jones D. T., Roos D., (1991), "*The machine that changed the world – The story of lean production*", HarperPerennial, New York

Womack J., Jones D. T., (2003), "*Lean thinking – Banish waste and create wealth in your corporation*", Simon & Schuster, Sydney Australia

Yin R. K., (2003), "*Case study research – Design and Methods – Third Edition*", Sage Publications, London

SCIENTIFIC ARTICLES

Abdulmalek F. A., and Rejgopal J., (2006), "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study", *Production Economics*, vol. 107, pp. 223-236

Arbulu R. J., and Tommelein I. D., (2002), "Value stream analysis of construction supply chains: Case study on pipe supports used in power plants", *Construction Engineering and Management Program*, Civil and Environmental Engineering Department, University of California

Ballard, G., and Arbulu, R., (2004), "Making prefabrication lean", *Proc., IGLC-12, July 2004, Copenhagen, Denmark*

Ballard G., and Howell G. A., (2004), "Competing construction management paradigms", *Lean Construction Journal*, vol. 1, pp. 38-45

- Bertelsen, S., (2003), "Construction as a complex system", *Proc., IGLC-11, July 2003, Blacksburg, Virginia, USA*
- Bertelsen S., (2004), "Lean construction: Where are we and how to proceed?", *Lean Construction Journal, Vol 1, p46-69*
- Björnfot A., (2006), "An exploration of lean thinking for multi-storey timber housing construction – Contemporary Swedish practices and future opportunities", *Doctoral Thesis, University of Technology, Luleå*
- Björnfot, (2006), *Inre Hamnen, Sundsvall – Utvärdering av industrialiserat byggande*
- Björnfot, A., and Sardén, Y., (2006), "Prefabrication: A lean strategy for value generation in construction, *Proc., IGLC-14, July 2006, Santiago, Chile*
- Bulhões, I.R., Picchi F.A., and Granja A. D., (2005), "Analysis for continuous flow implementation in construction", *Lean Supply Chain Management*
- Conte, A-S-I., and Gransberg, D., (2001), "Lean construction: from theory to practice, *Transactions of AACE International, pp. 10.1-15.1*
- Emmitt S., Sander D., and Christoffersen A. K., (2005), "The value universe: Defining a value based approach to lean construction", *Lean Construction theory, Denmark*
- Fontanini, P., and Picchi, F., (2004), "Value stream macro mapping – A case study of aluminium windows for construction supply chain" *Proc., IGLC-12, July 2004, Copenhagen, Denmark*
- Hong-Minh, S-M., Barker, R., and Naim, M-M., (2001), "Identifying supply chain solutions in the UK house building sector", *European Journal of Purchasing and Supply Management, vol. 7, no. 1, pp. 49-59*
- Höök, M., (2006), "Customer value in lean prefabrication of housing considering both construction and manufacturing", *Proc., IGLC-14, July 2006, Santiago, Chile*
-

- Höök, M., and Stehn, L., (2005), "Connecting lean construction to prefabrication complexity in Swedish volume element housing", *Proc., IGLC-13*, July 2005, Sydney, Australia
- Josephson, P-E., and Saukkoriipi, L.,(2005), "Slöseri i byggprojekt – behov av förändrat synsätt, Fou-väst, report 0507
- Koskela L., (1992), "Application of the new production philosophy to construction, CIFE Technical Report no. 72, Stanford University, California, USA
- Koskela L., (2000), "An exploration towards a production theory and its application to construction", Dissertation for the degree of Doctor of Technology, VTT Building Technology, Finland
- Naim M., and Barlow J., (2003), "An innovative supply chain strategy for customized housing", *Construction Management and Economics*, vol. 21, pp. 593-602
- Paez, O., Salem, S., Solomon, J., and Genaidy, A., (2005), "Moving from lean manufacturing to lean construction: Toward a common sociotechnological framewok", *Wiley Periodicals*, vol. 15, no., 2, pp. 233-245
- Pasqualini, F., and Zawislak, P-A., (2005), "Value stream mapping in construction: A case study in a Brazilian construction company", *Proc., IGLC-13, July 2005, Sydney, Australia*
- Picchi A. F. (2000),"Lean principles and the construction main flows", Lean enterprise Institute
- Polat G., and Ballard G, (2004), "Waste in Turkish construction: Need for lean construction techniques",
- Salem, O., Solomon, J., and Genaidy, A., (2006), "Lean Construction: From theory to implementation", *Journal of Management in Engineering*, vol. 22, no. 4, pp.168-176
-

Sardén, (2005), "Complexity and learning in timber frame housing – The case of a solid wood pilot project", Ph.D. thesis 2005:43, Luleå University of Technology, Sweden.

Saukkoriipi L. (2004), "Perspectives on no-value added activities: The case of piece-rate in the Swedish construction industry", Building Economics and Management, Chalmers University of Technology, Göteborg

Sawyer, T., (2006), "Build Fast And Innovate", *Engineering News-Record*, vol. 256, no. 1, pp. 24-28

Serrano, E., Bard, H., Petersson, H., Björheden, R., Rask, L-O., Sanati, M., Strand, M., Jonson, B., Nordebo, S., Löwe, W., Tryggesson. H., Schauerte, T., Bergman, L., Löfblad R., Holmstedt, G., and Bengtsson, S., (2007), "Policydokument för Temaområdet" Trä- och Energiteknik, *Fakultetsnämnd*, pp. 1-17

OTHER SOURCES

Vessby, J. (2007), "Konstruktörens roll i byggprocessen", Byggnadstekniska konstruktioner, BYA 934, Föreläsning 1

INTERNET SOURCES

<http://dictionary.reference.com/browse/prefabrication>, 070517

<http://www1.affkapnytt.se/nr-6-06/nr6-06/byfa-1.htm>, 070411

http://www.dhl.se/publish/se/sv/aboutdhl/local_about.high.html, 070514

<http://www.dhl.se/publish/se/sv/aboutdhl/network.high.html>, 070514

<http://www.fastighetsbyran.se/>, 070514

<http://www.martinsons.se/>, 070514

<http://www.martinsons.se/default.asp?id=10053>, 070514

<http://www.martinsons.se/default.asp?id=10473&PTID=&refid=10428>, 070514

<http://www.martinsons.se/default.asp?id=12936>, 070514

<http://www.martinsons.se/default.asp?id=13021>, 070514

<http://www.martinsons.se/default.asp?id=13287>, 070514

http://www.midroc.se/templates/12.asp?page_id=823&menu_id=849, 070514

<http://www.mpd.midroc.se/kommandeprojekt/limnologen.html>, 070514

http://www.ncc.se/templates/GenericPage____2531.aspx?T=TOPNAV, 070514

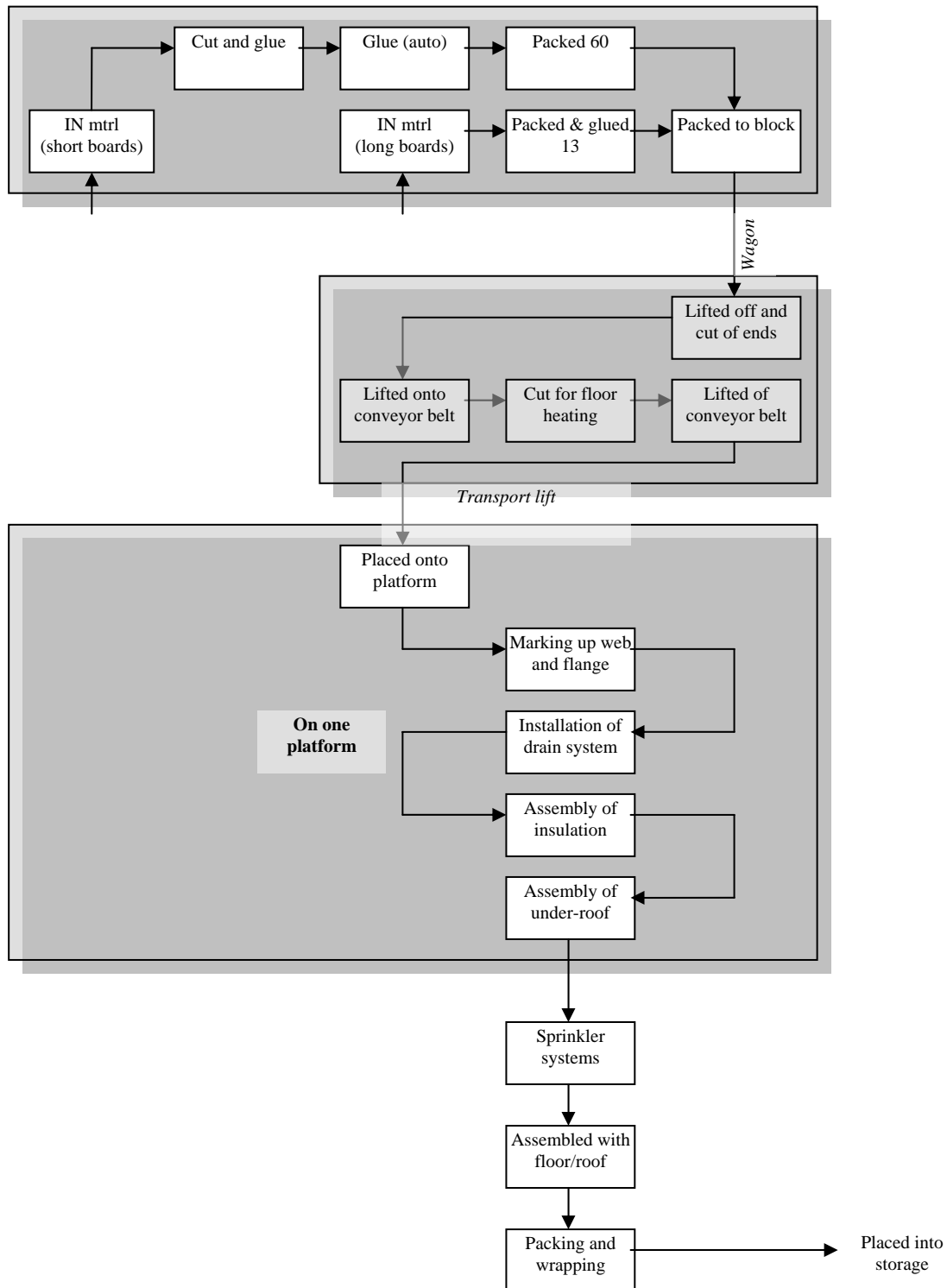
http://www.smp.se/article/800790_101-0-0-0, 070411

<http://www.vallebroar.se/>, 070411

http://www.vallebroar.se/articles/a20/nyhetsbrev_1_2006.pdf, 070411

http://www.vxu.se/td/bygg/trabyggstrategi/fortbildningsseminariet/projekt_limnologen_magnus_skiold.pdf, 070514

APPENDIX I – MANUFACTURING OF FLOOR ELEMENTS, MARTINSONS BYGGSYSTEM AB'S
FACILITY, BYGDSILJUM



APPENDIX II – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL ONE FLOOR ELEMENT

Physical Actions Required to Create, Deliver and Install 1 Floor Element				
	Total Steps	Value Creating Steps	Total Time	Value Create Time
	Sawmill Kroksjön (long boards)			
1.	Loading Sawmill Kroksjön			
	Transport Link 1			
2.	Shipping Kroksjön-Bygdsiljum (70km)			
3.	Unloading of boards at facility			
4.	Quality check			
	Martinssons facility Bygdsiljum			
	<u>Preassembly of blocks</u>			
5.	Glue and packing (long boards and short boards)			
6.	Cut off unnecessary material and cut for floor heating			
7.	Transport overhead crane to new conveyor belt			
	<u>Assembly of elements</u>			
8.	Assembly of two blocks into an element			
9.	Marking up “liv & flens”			
10.	Various complements are installed			
11.	Isolation is installed			
12.	Under-roof is installed			
13.	Installation of sprinklers			
14.	Packaging and wrapping			
	Transport Link 2			
15.	Storage at facility			
16.	Shipping Bygdsiljum-Limnologen (1169km)			
	Limnologen jobsite			
17.	Unloading of packages			
18.	Storage of packages			
19.	Installation of elements			
20.	Preparation for next element			
21.	Sylodynes are applied on the element			
22.	Plywoodstrips are applied			

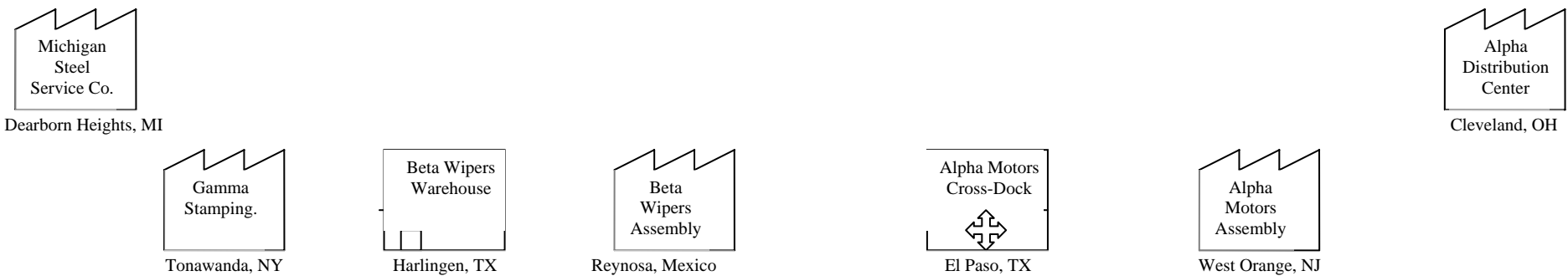
APPENDIX III – FIRST VIEW OF THE CURRENT STATE MAP SHOWING THE CUSTOMER



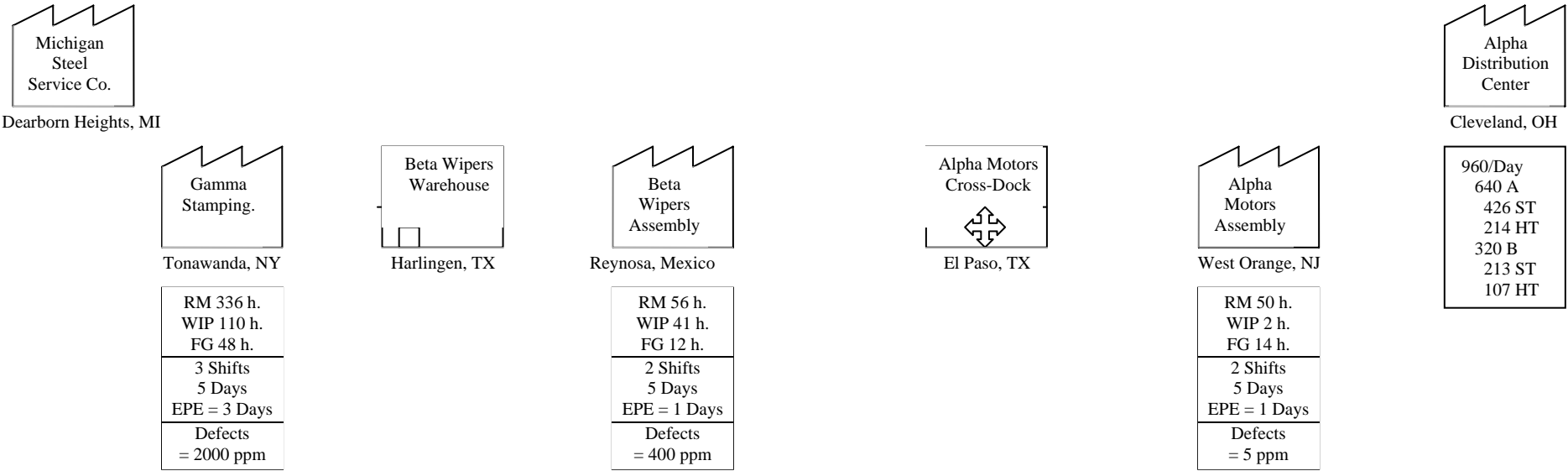
Cleveland, OH

960/Day
640 A
426 ST
214 HT
320 B
213 ST
107 HT

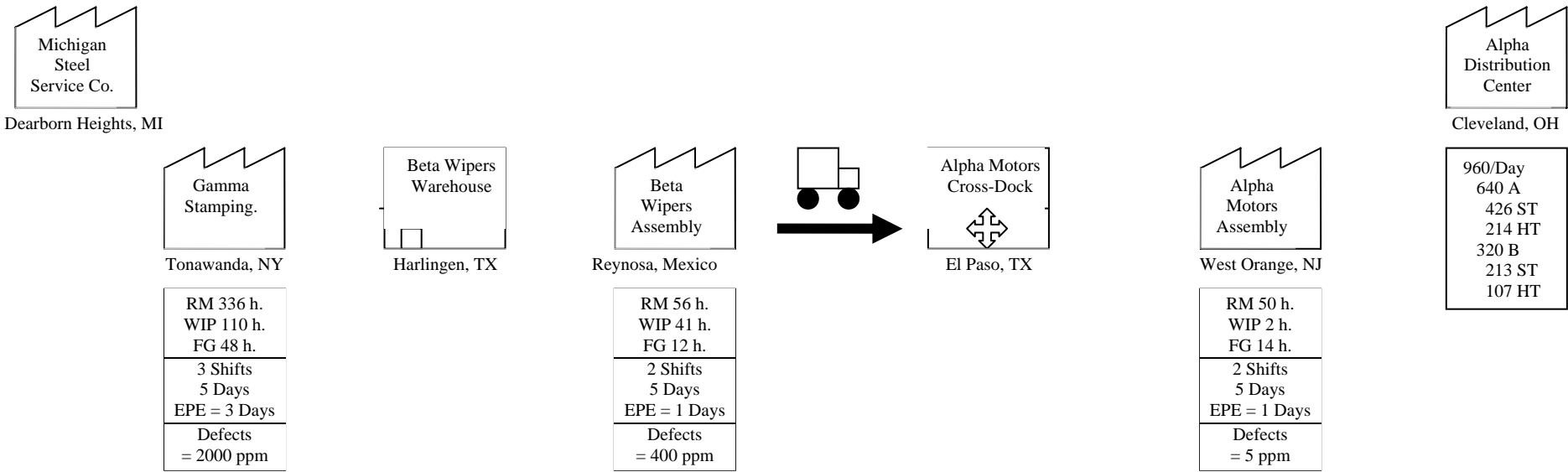
APPENDIX IV – CURRENT STATE MAP SHOWING ALL FACILITIES



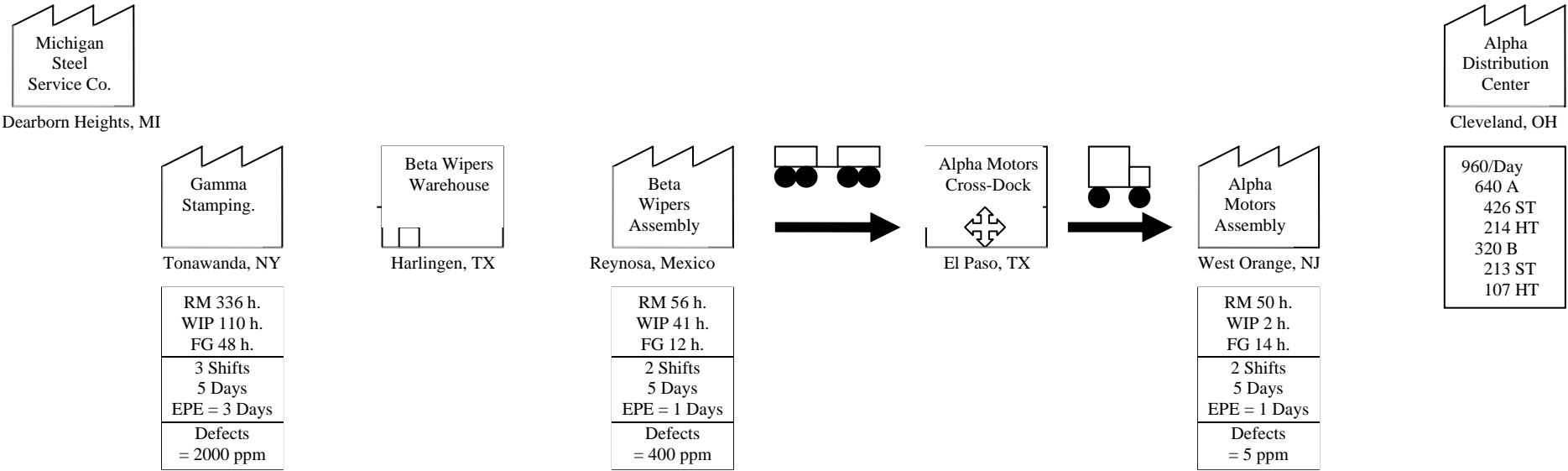
APPENDIX V – CURRENT STATE MAP SHOWING ALL FACILITIES AND DATA BOXES



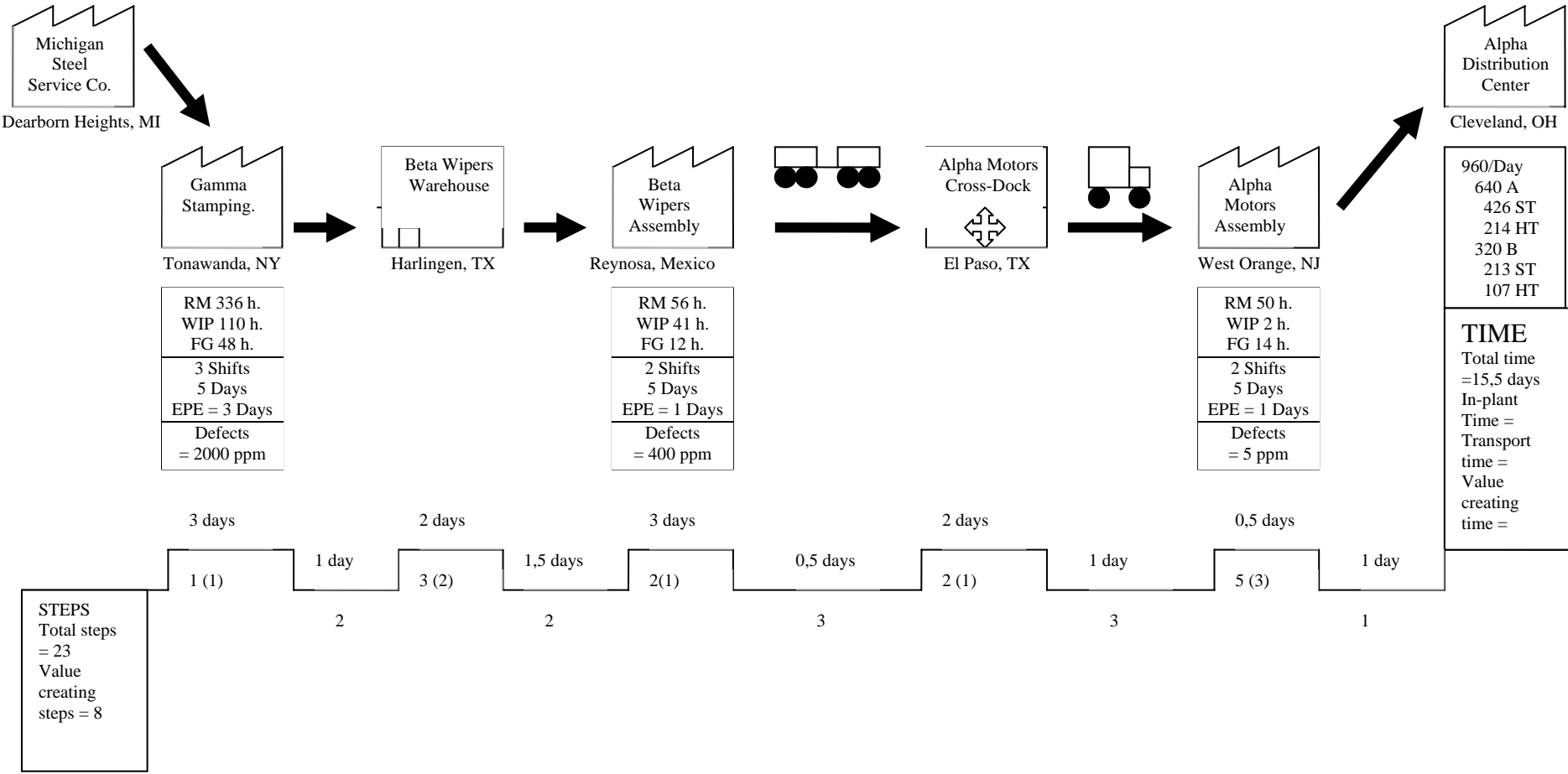
APPENDIX VI – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES AND TRANSPORT LINK USING TRUCK SHIPPING



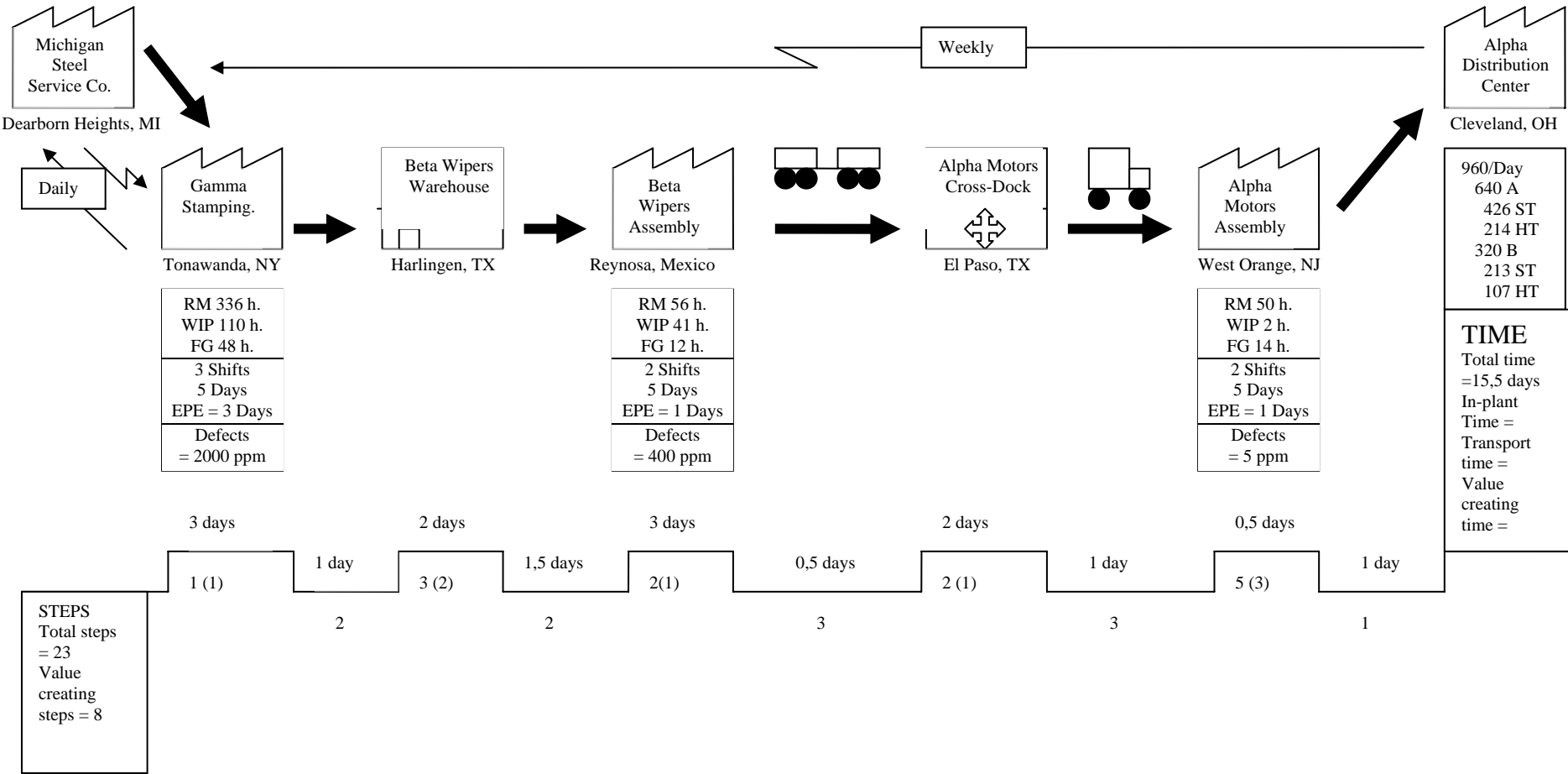
APPENDIX VII – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES AND TRANSPORT LINKS USING BOTH TRUCK SHIPPING AND RAIL



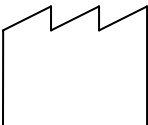
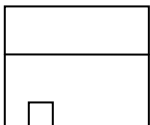
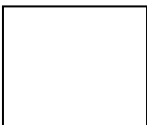



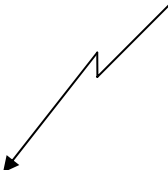

APPENDIX VIII – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES, TRANSPORT LINKS AND TIME-AND-STEPS-LINE



APPENDIX IX – CURRENT STATE MAP SHOWING ALL FACILITIES, DATA BOXES, TRANSPORT LINKS, TIME-AND-STEPS-LINE AND INFORMATIONFLOW



APPENDIX X – THE ICONS SIGNIFICATION OF THE ICONS USED IN THE THESIS

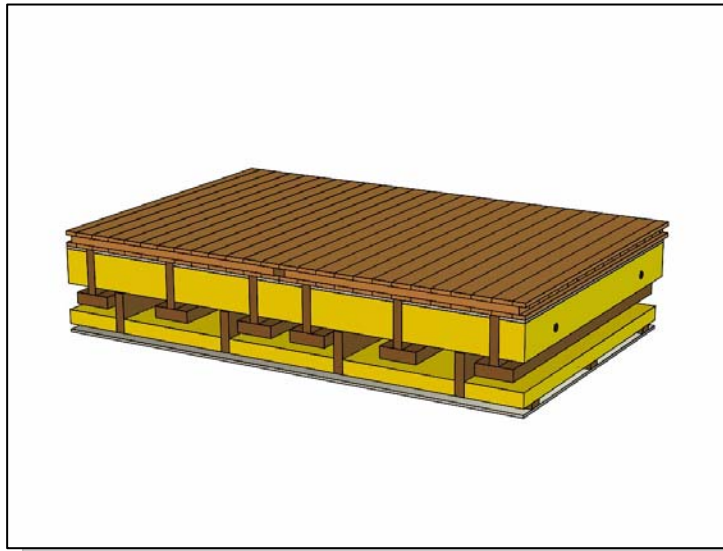
																		
Facility	Storage	Process	Truck Shipment															
																		
Macro Arrow	Micro Arrow	Information Flow	Rail Shipment															
<table><tr><th>STEPS</th></tr><tr><td>Total Steps =</td></tr><tr><td>Value</td></tr><tr><td>Creating Steps</td></tr><tr><td>=</td></tr></table>	STEPS	Total Steps =	Value	Creating Steps	=	<table><tr><td>2 Shift</td></tr><tr><td>5 Days</td></tr><tr><td>40m2/shift</td></tr></table>	2 Shift	5 Days	40m2/shift	<table><tr><th>TIME</th></tr><tr><td>Total Time =</td></tr><tr><td>In-Plant Time</td></tr><tr><td>=</td></tr><tr><td>Transport Time</td></tr><tr><td>=</td></tr><tr><td>Storage Time =</td></tr></table>	TIME	Total Time =	In-Plant Time	=	Transport Time	=	Storage Time =	
STEPS																		
Total Steps =																		
Value																		
Creating Steps																		
=																		
2 Shift																		
5 Days																		
40m2/shift																		
TIME																		
Total Time =																		
In-Plant Time																		
=																		
Transport Time																		
=																		
Storage Time =																		
Summary data box	Data box	Summary time																

APPENDIX XI – EXAMPLE OF FLOOR DESIGN IN ONE OF THE LIMNOLOGEN BUILDINGS

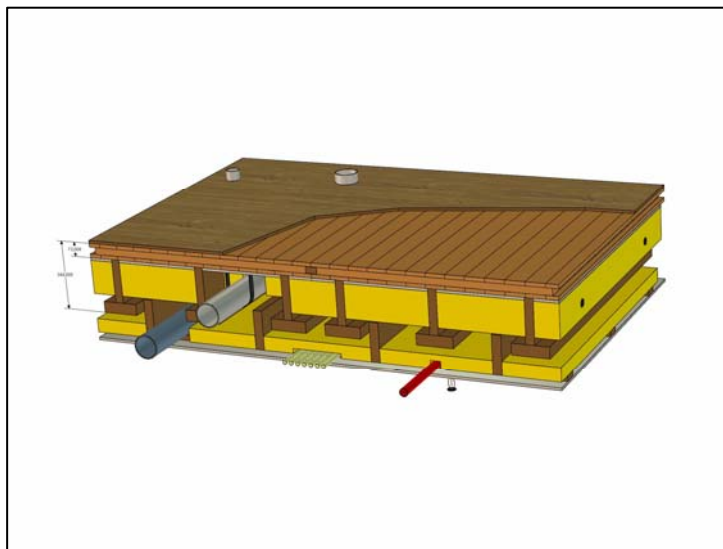


EXAMPLE OF A FLOOR DESIGN IN ONE OF THE BUILDINGS(MDP.MIDROC.SE 070514)

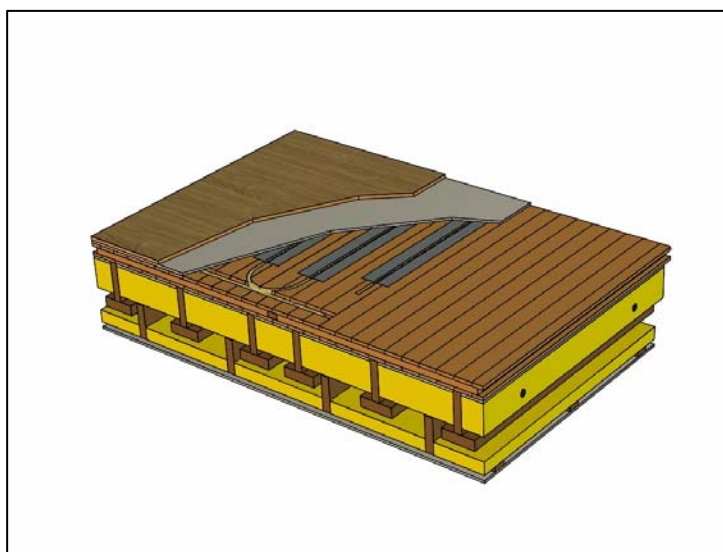
APPENDIX XII – DIFFERENT MODELS OF PREFABRICATED FLOOR ELEMENTS



Prefabricated floor elements without any installation



Prefabricated floor elements with pipes



Prefabricated floor elements with floor heating

DIFFERENT PREFABRICATED
FLOOR ELEMENTS PRODUCED AT
MARTINSONS BYGGSYSTEMAB
(MARTINSONS.SE, 070514)

APPENDIX XIII – PHOTOS FROM THE LIMNOLOGEN PROJECT 1



ILLUSTRATION OF THE HYDRAULIC TENT (LEFT) AND THE OVERHEAD CRANE (RIGHT)



ILLUSTRATION OF ON SITE MATERIAL WAITING FOR INSTALLATION, WALLS AND WINDOWS (LEFT) AND GYPSUM BOARD (RIGHT)

APPENDIX XIV – SUMMARY OF DAILY ERROR REPORTS

Started Working Step	Error	Waiting time/ unnecessary working time (hours)	Number of persons involved
Unloading floor element package 1 & 2	Tent not liften up	6	9
	Rebuilding of the crane 1 hour		
	Waiting time for crane operator 1 hour		
	Waiting time for timber worker 4 hours		
Unloading floor element package 3 & 4	Manufacturing errors on floor element 3 hours	5	9
Installation of 8 floor elements	Manufacturing errors on floor element 2 hours		
N/A	Drilling in the floor 1 hour	5	7
N/A	Missing insulation	-	9
	Too high tree blocks in the joist		
Unloading floor element package 1 & 2	Sound proofing carpet wrongly installed on two floor elements	2	8
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 3 & 4	Sound proofing carpet wrongly installed on two floor elements	2	9
	Uninstallation of the sound proofing carpet 2 hours		
Unloading floor element package 5	Sound proofing carpet wrongly installed on two floor elements	0,5	9
	Uninstallation of the sound proofing carpet 0,5 hours		
Unloading floor element package 6	Wrongly drilled holes	2	9
Installation of the floor element	Ventilation shaft wrongly installed	-	8

APPENDIX XV – PHOTOS FROM THE LIMNOLOGEN PROJECT 2



ILLUSTRATION OF DRILLING REWORK



ILLUSTRATION OF WRONGLY INSTALLED VENTILATION SHAFT (LEFT) AND MISSING INSULATION (RIGHT)

APPENDIX XVI – DELIVERY AND PRODUCTION SCHEDULE FOR MARTINSSONS BYGGSYSTEM AB AND LIMNOLOGEN

	APRIL		MAY		JUNE		JULY	
	Martinssons	Limnologen	Martinssons	Limnologen	Martinssons	Limnologen	Martinssons	Limnologen
1					Production			
2			Production					Package 1&2
3			Storage	Raise of tent				Package 3&4
4			Storage		Production			
5					Production			Raise of tent
6	Production							
7			Storage		Storage	Raise of tent		
8			Transport		Storage			
9	Production		Transport					
10	Production		Production	Package 1&2				
11	Production		Production	Package 3&4	Storage			
12	Production				Transport			
13	Production				Transport			
14			Production	Package 5&6	Production	Package 1&2		
15			Production		Production	Package 3&4		
16	Storage		Production					
17	Storage							
18	Storage				Production	Package 5&6		
19	Transport				Production			
20	Transport				Production			
21			Production		Production			
22			Storage	Raise of tent				
23	Production	Package 1&2	Storage					
24	Production	Package 3&4	Storage					
25	Production	Package 5&6	Transport		Storage			
26	Production				Storage			
27	Production				Storage			
28			Transport		Transport			
29			Production	Package 1&2	Transport			
30			Production	Package 3&4				
31			Production	Package 5&6				

APPENDIX XVII – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL 6
PACKAGES OF FLOOR ELEMENTS

	Physical actions required to create, deliver and install 6 packages of floor elements (30 elements)	
	Total steps	Total time
	Sawmill Kroksjön (long boards)	
1.	Loading Sawmill Kroksjön	15min
		Total 15min
	Transport Link 1	
2.	Shipping Kroksjön-Bygdsiljum (70km)	90min
3.	Unloading of boards at facility	15min
4.	Quality check	2min
		Total 107min
	Martinssons facility Bygdsiljum	
	<u>Preassembly of blocks</u>	
5.	Glue and packing (long boards and short boards)	10h
6.	Cut off unnecessary material and cut for floor heating	10h
7.	Transport overhead crane to new conveyor belt	2,5h
		Total 12,5h
	<u>Assembly of elements</u>	
8.	Assembly of two blocks into an element	5h
9.	Marking up web and flange	15h
10.	Various complements are installed	7,5h
11.	Insulation is installed	15h
12.	Under-roof is installed	6h
13.	Installation of sprinklers	15h
14.	Packaging and wrapping	9h
		Total 72,5h (9,0625 shifts)
	Transport Link 2	
15.	Storage at facility	3 days
16.	Shipping Bygdsiljum-Limnologen (1169km)	2 days
		Total 5days
	Limnologen jobsite	
17.	Unloading of packages	30min
18.	Storage of packages	24h
19.	Installation of elements	5h
20.	Preparation for next element	150min
21.	Sylodynes are applied on the element	5h

22.	Plywoodstrips are applied	7,5h
		Total 44,5h (incl. 24h storage)

Summary of physical actions

Steps 22

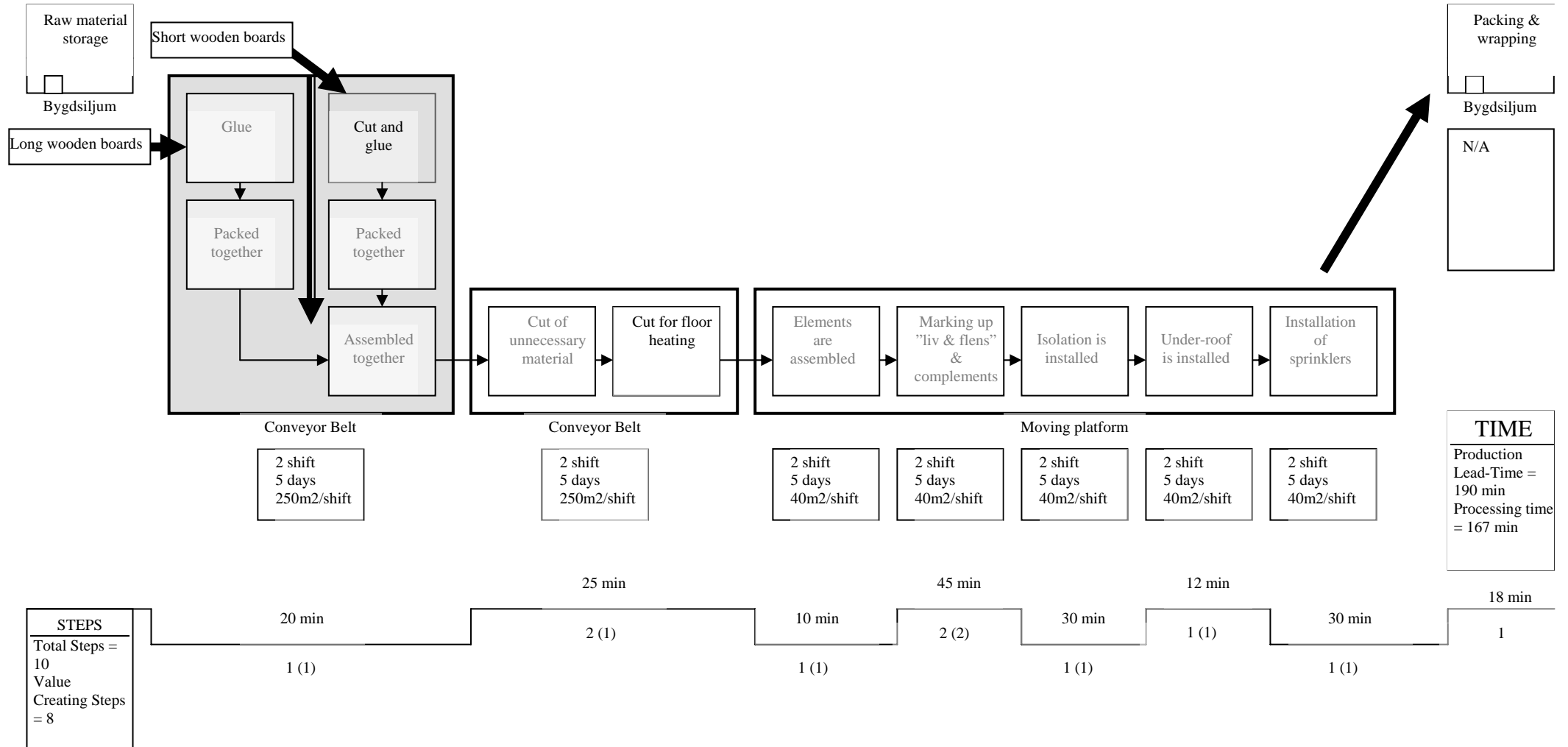
Distance 1239 km over 2 transport links

APPENDIX XVIII – PHYSICAL ACTIONS REQUIRED TO CREATE, DELIVER AND INSTALL 1
FLOOR ELEMENT

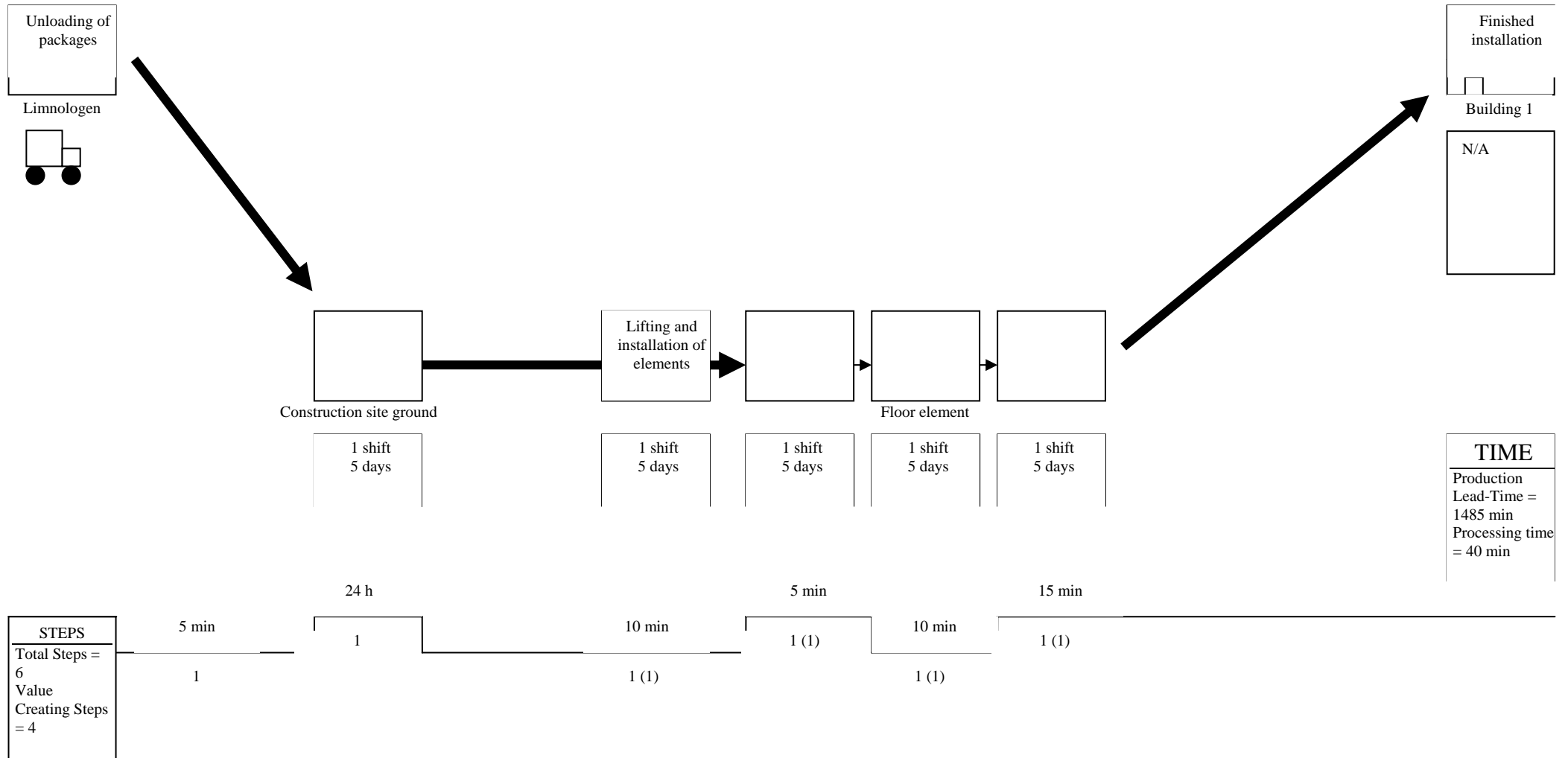
	Physical actions required to create, deliver and install 1 floor element	
	Total steps	Total time
	Sawmill Kroksjön (long boards)	
1.	Loading Sawmill Kroksjön	15min
		Total 15min
	Transport Link 1	
2.	Shipping Kroksjön-Bygdsiljum (70km)	90min
3.	Unloading of boards at facility	15min
4.	Quality check	2min
		Total 107min
	Martinssons facility Bygdsiljum	
	<u>Preassembly of blocks</u>	
5.	Glue and packing (long boards and short boards)	20min
6.	Cut off unnecessary material and cut for floor heating	20min
7.	Transport overhead crane to new conveyor belt	5min
		Total 45min
	<u>Assembly of elements</u>	
8.	Assembly of two blocks into an element	10min
9.	Marking up web and flange	30min
10.	Various complements are installed	15min
11.	Insulation is installed	30min
12.	Under-roof is installed	12min
13.	Installation of sprinklers	30min
14.	Packaging and wrapping	18min
		Total 145min (2,42h)
	Transport Link 2	
15.	Storage at facility	3 days
16.	Shipping Bygdsiljum-Limnologen (1169km)	2 days
		Total 5 days
	Limnologen jobsite	
17.	Unloading of packages	5min
18.	Storage of packages	24h
19.	Installation of elements	10min
20.	Preparation for next element	5min
21.	Sylodynes are applied on the element	10min
22.	Plywoodstrips are applied	15min

		Total 24,75h (incl. 24h storage)
Summary of physical actions		
Steps	22	
Distance	1239 km over 2 transport links	

APPENDIX XIX – VSM FOR MARTINSONS BYGGSYSTEM AB



APPENDIX XX – VSM FOR LIMNOLOGEN



APPENDIX XXI – VSMM FOR THE STUDIED SUPPLY CHAIN

