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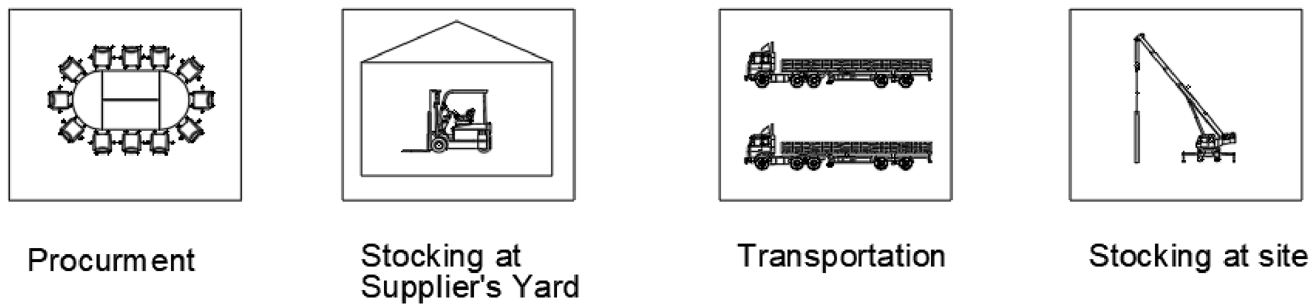

A Measurement of Logistics Performance

Master of Science thesis in the master's Programme Design and Construction Project Management

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Master's Thesis ACEX30

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Abstract

Logistic management within the supply chain network plays a significant role in delivering materials and resources to the construction sites. Logistics operations may be unable to achieve efficient deployment of materials due to several factors such as weak logistical plans, lack of cooperation between different disciplines as well as the congestion of traffic. The term of logistics performance came to analyse the effectiveness and efficiency of logistical tasks such as planning, organizing, coordinating, and controlling the materials flow from the extraction of raw materials to the incorporation into ready-to-deliver end products. Since logistics started gaining valuable importance and becoming more prominent, there is an increasing need to measure the performance of construction logistics. Although several methods investigated the measurements of logistics performance, these methods are still aimed to measure it in the manufacturing industry, and little has shown how that could be implemented in the construction industry. Therefore, this master's thesis has been directed towards introducing variables that could be used as applicable and straightforward measures for logistics performance. Another intention of this work is to show how the combination of measuring the logistics performance and the practices can lead to optimisations of the logistical plan.

In order to achieve the aims of this work, the abductive approach has been followed. The work starts with a literature study on the material flow process and the measures of logistics performance in order to provide preconceptions. Thenceforward, a set of interviews have been carried out to collect the needed data qualitatively. Ultimately, but not last, an estimated case has been generated to show how the logistics performance can be measured according to the proposed framework. In addition, the estimated case has been limited to for prefabricated concrete project since this type of projects is the dominant type nowadays.

As expected, the proposed framework is able to measure logistics performance when the needed data are available. Measures such as cost and time have, to an extent, the ability to present the logistics performance. Furthermore, the results displayed that poor logistical plan could lead to cost overrun. On the other hand, various challenges in the construction industry prevent it from achieving a good logistics performance. Therefore, a simple change in the transportation schedule has been conducted in the purpose of optimising the logistical plan. The results of this change exhibited a significant reduction in the logistics cost. Moreover, the interviews showed that several philosophies such as Just-In-Time and Lean should be applied to make the construction industry able to dispose of its logistics poorness.

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Keywords: Logistics performance, Performance measurement, Activity-based costing (ABC) theory, Prefabricated concrete flow process, Just-In-Time.

Preface

This work has been inspired by the importance of logistics nowadays. Since the world is growing with different types of construction projects, logistics is gaining high importance in the flow process of any construction project. Several logistical plans can exist in the construction industry, but the critical point of determining whether the logistical plan is efficient or not, is to measure logistics performance. Therefore, our intention has been directed towards suggesting an applicable and simple tool that can show the performance of the logistical plan and help the decision-maker in detecting the optimal logistical plan.

The report includes a suggested method that can be followed to give the project manager an indication of how the performance of logistics is. Additionally, it shows how some current logistics method can improve the logistical plan and hence, enhance the logistics performance. This master's thesis was carried out between January 2020 to June 2020, at the Department of Civil and Environmental Engineering, Division of Construction Management.

We would like to acknowledge the endless support of Christian Koch. His support was the driving force behind the completion of this master's thesis.

Moreover, we appreciate the efforts of Dimosthenis Kifokeris, who shared the process of improving and enhancing this work with professor Christian. For both, please, accept our sincerest thanks.

In addition, we cannot forget our families who are not beside us physically, but they are in our hearts. Our families were other support by their loving words and enthusiastic encouragement.

Ahmad Arafat has again dedicated this work to Björn Engström's soul, the professor who taught engineering with passion.

Ahmad Arafat and Hassan Salha, Gothenburg, June 2020

Contents

1 Introduction

1.1 Background

The term of logistics has been used for the first time several decades earlier, in the era of the Napoleonic wars. This use was in purpose of understanding the business of war such as equipping armies process and supply mechanisms. Later, the term of logistics started being in use for various industries such as manufacturing and infrastructures industries. In early 1980s, logistics term was used in the UK as a reserve meaning for the construction management in the construction industry. With the development of industries around the world, the logistics management and supply chain management terms are used as fundamental synonymous terms in order to manage the flow process of materials and information (Sullivan, et al., 2011). Thenceforward, in 2008, Chartered institute of logistics and transport provided a definition as ‘‘*the process of designing, improving such supply chains, which might include purchasing, manufacturing, storage and, of course, transport*’’. During the evolution of logistics, the term of logistics performance came as a fundamental term to evaluate the logistics. (Kearney, 1984) defined the logistics performance as the ratio of actual output to standard output. (Mentzer & Konrad, 1991) gave a broader view of logistics where the efficiency and effectiveness in completing a given task are the foundation for the logistics performance. As accompanying development to the logistics development, the logistics performance in the construction industry has been evolved to investigate the flow process of materials and information in the logistics process and describe how that could achieve the clients requirements as well as the strategic intentions (Wegelius-Lehtonen, 2001). However, measuring the logistics became a challenge for the researchers, since it has a multidimensional nature (Chow, et al., 1994), which means that it is dependent on several variables such as cost, time and quality. Therefore, several research papers have been directed towards suggesting measurements for logistics performance. (Read & Miller, 1991) chose the quality as a measurement for the logistics performance, where various measures were considered such as customer satisfaction, zero defects as well as reduction of the cost of quality. Furthermore, (Rhea & Shrock, 1987) measured the performance based on the distribution effectiveness, where measures such as adequacy, consistency as well as accuracy were selected. On the other hand, (Harrington, et al., 1991) suggested that the logistics performance is based on the vendor performance, which could lead to using measures such as lead-time variability and total purchases. As it is obvious, researchers suggested several measures for logistics performance, but gathering the needed data could complicate or ease the measurement process. Therefore, (Chow, et al., 1994) characterized the measures whether they are hard or soft measures based on the data collection method and data source.

This thesis is suggesting a conceptual framework that could detect the logistics performance and enhance the ability of project managers to improve and optimise the logistical plans.

1.2 Aim and research questions

The logistical plans are essential to execute any construction project efficiently by eliminating the activities lead time and mitigating the different types of costs related to these activities in the logistics flow processes. Implementing efficient logistical plans in construction projects plays a decisive role in the projects' success. Furthermore, measuring logistics performance can be the critical factor to decide whether the logistical plan is efficient or not. On the other hand, the nature of logistics performance can be a multidimensional indicator for controlling the construction projects. The nature of logistics performance creates an intricacy that stems from the fact that logistics performance is dependent on several variables.

This fact shows that the construction sector needs a simple procedure that can be followed to investigate logistics performance.

In order to provide an applicable and straightforward procedure for measuring the logistics performance, the aim of this thesis will be directed towards suggesting a conceptual framework that is applicable and effective for measuring the logistics performance

In order to achieve the intention of this thesis, the following research questions have been identified:

- How to choose adequate measured variables in order to present a full picture of logistics performance?
- To what extent are the measures applicable and straightforward to use?
- What is the ability of the suggested framework to give improvements to the logistics performance?
- Which activities can impact the logistical concrete flow process in terms of the measured variables?

1.3 Methodology

Studying logistics as a scientific topic started in the 1960s (Kovács & Spens, 2005). The nature of logistics research can be described as a compound nature since it has two origins. One of them is the business origin where logistics research is affected by economics, marketing as well as management (Arlbjørn & Halldorsson, 2002), (Mentzer & Kahn, 1995). The second origin is the engineering origin where mathematical simulations and models are used (Mentzer & Kahn, 1995). This nature of logistics research resulted in the fact that researchers in logistics combined different approaches and methods in order to conduct their research (Kovács & Spens, 2005). Various approaches have been used and combined to conduct logistics research. In order to determine the suitable approach for a logistics study, deductive, inductive and abductive have been used in the logistics field. Whereas, in order to collect the needed data, qualitative and quantitative are common approaches in the purpose of performing interviews for logistics research. In the following subchapters, the used approaches and methods are discussed in detail.

1.3.1 Method selection

As stated before, the approaches for conducting logistics research varies between deductive, inductive and abductive. The deductive approach gives the researcher the ability to apply a general law on a specific case (Andreewsky & Bourcier, 2000). In contrast to the deductive approach, the inductive approach gives the researcher a reserve path, where the researcher can generalize a law based on several cases or observations. In other words, the researcher can observe facts to build up a theory (Taylor, et al., 2002), (Danermark, et al., 2019). According to (Arlbjørn & Halldorsson, 2002), the deductive approach is dominant in the logistics research field, where the researcher can examine the present theories for a specific case. On the other hand, the abductive approach is an approach that stems from different disciplines such as computer science, where it is used in neural networks as well as artificial intelligence (Eiter & Gottlob, 1995). This origin leads to an iterative behaviour of abductive approach, which could lead to intuitive creativity. However, the abductive approach gives the researcher the opportunity to figure out whether a general law can be applied on a specific case or not. This means that the abductive approach is a specialized approach for particular cases (Kovács & Spens, 2005).

Since this master's thesis aims to determine applicable and adequate measures for logistics performance, a set of interviews shall be conducted. The approach of conducting these interviews needs to be specified earlier. As aforementioned, in order to collect data and perform interviews, two approaches are common, qualitative and quantitative approaches.
The qualitative approach can be considered as a non-linear path of collecting data (Bernard & Bernard, 2013), where its behaviour is flexible and can be adapted to different situations (Sreejesh, et al., 2014). Following this approach can stimulate the subconscious of the respondent to reach the needed data and provide additional data that could contribute to the research object (Sreejesh, et al., 2014). On the other hand, the quantitative approach is predictable in terms of results, where it has a predesign and the respondent is limited to the choices that the researcher provides (Sreejesh, et al., 2014). The decisive factor for determining which approach can be followed in a research is the nature of the needed data. If the needed data is soft data as words, sentences, opinions and graphs, the qualitative approach is a suitable approach. Whereas, in case of numbers and big data, which is described as hard data, quantitative approach could be the appropriate one (Creswell & Creswell, 2017).
For this work and based on the literature review of the previous approaches, the method that has been followed to conduct this logistics research is the abductive method. Moreover, this research has an intention of performing interviews as a foundation for observations. In order to achieve this intention, the interviews have been performed by following the qualitative approach.

1.3.2 Application of selected methods

The method of this research is based on the abductive approach. The first step to conduct this approach is to start out with some pre-perceptions and theoretical knowledge which can be based on literature study and previous study cases. According to (Dubois & Gadde, 2002) an conceptual framework needs to provide the so-called ''articulated preconceptions'' in advance. These articulated preconceptions which can be considered as theoretical knowledge cannot be understood without empirical data. Therefore, for this research, the literature study has been directed towards investigating the following areas:

- Logistics performance
- Measurement of several variables such as cost and time
- Common theories for the measured variables
- Concrete flow process
- Challenges that confront the flow process of concrete

Thenceforward, in order to combine the application of qualitative approach and abductive approach, the authors decided to perform a set of interviews, where interviews could ease the

process of collecting real-life observations. The real-life observations are fundamental pillars for building up the conceptual framework (Dubois & Gadde, 2002), (Kovács & Spens, 2005).
In order to conduct the interviews, the structure of these interviews shall be defined in advance. (Patton, 1990) suggests three categories of interviews, which are conversational interviews, semi-structured interviews as well as standardised interviews.
Based on the definition of these categories, the most suitable interviews category for this research is the semi-structured category. Performing the interviews based on the semi-structured category is beneficial in terms of achieving the systematic nature of the conceptual framework as well as adding a broader view to the authors.
Therefore, a set of semi-structured interviews have been carried out with several respondents (Table 1). Moreover, the interviews have been taken as a foundation to build up the estimated case study.

Table 1: *Interviewees*

Respondents role	***Current Company***
Regional Logistics Manager	Dayspring Göteborg AB
Head Sales Manager	UBAB Ulricehamns Betong AB
Regional Purchasing manager	JM AB
Area Manager	JM AB

The next step of applying the abductive approach is to sieve the theoretical knowledge to achieve a good matching between the real-life observations and the theoretical knowledge (Kovács & Spens, 2005). The matching process for this work was an iterative process, where the theoretical framework could not be able to explain the abnormalities of the observations. Therefore, the so-called ‘‘matching theory’’ is executed to find a new matching framework or to extend the theory used prior to the real-life observations. The used matching theory can be simplified by carrying out several trials and going back and forth to achieve the thesis’s aim. The process of the abductive approach is depicted in the figure below (Figure 1).

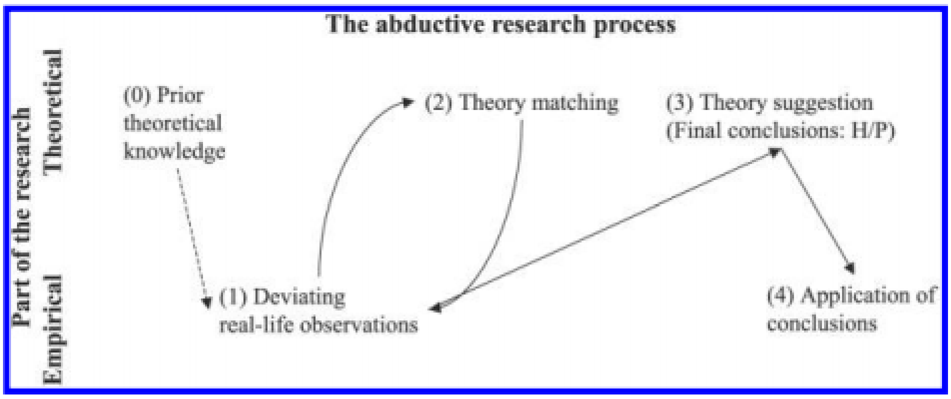

Figure 1: *Abductive approach process, (Kovács & Spens, 2005)*

1.4 Limitations

The flow process of concrete is a complex process. This means that it has a huge amount of activities, where some of these activities are major activities, whereas some are minor. Including all the activities in this work, could lead to several complications. Therefore, the presented flow process of concrete in this work is limited to only include the major activities in the flow process, which have the most influence on the logistics process.

In order to apply the suggested conceptual framework, an estimated case has been generated. The estimated case is based on interviews and previous case studies. Since the projects of prefabricated concrete elements are the dominant projects in Sweden and Europe generally, generating an estimated case for cast-in-place concrete projects was hard. Therefore, the suggested conceptual framework was limited to be applied on a project of prefabricated concrete elements. This does not mean that the suggested conceptual framework cannot be applied on cast-in-place concrete projects.

In this work, an optimised case has been presented. The optimisation is not ideal and further optimisation can be achieved. Therefore, this thesis does not provide a clear procedure to minimise the logistics cost. Alternatively, some production and logistics methods are presented, which could lead to a reduction of the logistics cost.

It has been observed in this master's thesis that increasing the transportation rate could lead to a reduction in the logistics cost. This observation can be a logistical improvement but applying it could lead to a negative impact on the environment. Hence, environmental impacts are not considered in any suggested improvement.

2 Literature review

In the following chapters, the gathered literature study and theories will be presented.

2.1 Construction logistics performance measurements

Construction logistics is the planning process of supply and site activities in order to achieve a rational reduction in the total cost of materials management. This reduction needs an understanding of the interdependencies of these activities (Said & El-Rayes, 2014). The construction field is a well-known field that suffers from fragmentation, which results in lack of coordination and communication (Othman & Voon, 2018). Moreover, the construction industry presents a poor information flow, where there is a lack of sharing information between the different disciplines (Azambuja & O'Brien, 2008). Furthermore, in the construction industry every project is an unique project, which means that the construction industry misses the ability to standardize the production (Azambuja & O'Brien, 2008). However, these issues such as fragmentation, lack of sharing and standardization, does not only have an impact on communication and coordination, but it also has a huge impact on performance, which could result in cost and time overruns, low-grade quality as well as unsafe environment (Ying, et al., 2015). Therefore, the construction industry started recognizing the importance of logistics performance. The term of logistics performance came as a term to describe the efficiency and effectiveness of the logistical plans. (Mentzer & Konrad, 1991) defines the effectiveness as *''the extent to which goals are accomplished*'', whereas the efficiency is defined as '' *how well the resources expended are utilised* ''. These definitions can be seen as general definitions since there is no clear procedure for how to achieve these efficiency and effectiveness. Therefore, in order to enhance the understanding of logistics performance, an understanding of the activities behaviour as well as the challenges is needed.

The construction activities differ from the manufacturing activities in terms of several things, but the most distinctive difference is that the construction activities are independent (Azambuja & O'Brien, 2008). This quality of construction activities combined with the construction industry defects, results in poor logistics performance.

In order to investigate the logistics performance several studies (Wegelius-Lehtonen, 2001), (AbouRizk, et al., 2011), have been directed towards measuring the logistics performance. However, measuring the performance is not a simple process since this process could confront several difficulties. One of the most common challenges that could be faced is which variable shall be measured. In other words, what is the capability of the variable to present the real logistics performance since measuring the inputs and outputs costs could result in underestimating the logistics performance (Mentzer & Konrad, 1991). However, It has been proposed different manners of measuring the logistics performance, where some of them (AbouRizk, et al., 2011), (Vidalakis, et al., 2011) proposed simulation models and others (Wegelius-Lehtonen, 2001), (Fang & Ng, 2011) proposed frameworks The simulation models have this development simultaneously with the development of computer and mathematics science, where some mathematical algorithms are utilised such as the stochastic optimisation algorithm. These models are still of limited use, which could be attributed to the fact the construction industry is conservative and slow industry (Stewart, et al., 2004).

On the other hand, the construction industry tends to use more applicable procedures for measuring the logistics performance. Therefore, measuring the logistics performance by frameworks is still the dominant manner.

In order to achieve the aim of this master's thesis, the authors opined that presenting an conceptual framework can be more practical and simpler in use for the construction industry.

2.2 Materials flow process

The construction process could vary depending on materials included in the flow process as each material is unique in its flow process. The matching between materials and their locations on the construction site is necessary before the installation occurs, in order to avoid any kind of delays and uncertainties to supply the needed materials and complete the required work on time. This kind of challenge could lead to restrain the productivity on the construction site (Tommelein, 1998).

According to (Agapiou, et al., 1998), most of the materials are purchased and delivered under an ad hoc basis in the traditional construction industry. This does not view the whole picture of the project and can hinder the work schedule due to some delivery delays or not needed materials on site for days. (Enshassi, 1996) emphasised that this basis may lead to two problems when considering the materials' wastage. The first related to the materials' production needed for the project as it is produced in large quantities without considering the required need at the work site. This could cause materials' waste during the logistics activities such as transportation and handling of the materials, The second problem is to purchase some materials directly upon request, and this may lead to interruptions and delays in the work schedule, which leads to waste that everyone bears responsibility for.

To improve the logistics performance in the construction industry, the materials flow should be developed by conducting comprehensive analysis of the existing logistics processes in construction projects, as there are many factors that will improve the material flow process performance, such as planning and production, accuracy in requirements, warehousing and inventory reduction, transportation, and sustainable development of the work structure (Ekeskär & Rudberg, 2016). Another difficult aspect that faces the material flow process is the lack of a precise coordination of Just-In-Time production and delivery to the customer and understanding the risk factors for efficient material's flow process such as the concrete flow process (Khan & Afzal, 2018).

2.2.1 Concrete flow process

Concrete can be viewed as a fluid in its fresh state, given a certain degree of flow can be achieved and the mix is quasi-homogeneous with regularly spaced aggregate parts (in volume and size). Modelling concrete rheology and flow process is a very difficult process, because each type of concrete behaves differently depending on its composition and method of mixing (Dufour & Pijaudier-Cabot, 2005). Even though the fresh concrete can be manufactured on the site where it is to be used. The construction industry depends on cast-in-place fresh concrete manufactured at a close mixing factory and then transported by truck mixers to the location. Moreover, for the large-scale engineering construction, the transport of fresh concrete is especially important, because the nature of fresh concrete is connected to its mechanical efficiency, essentially the subsequent design and construction life in order to preserve continuity and avoid separation during the transport cycle. In a truck mixer the fresh concrete should be mixed further. However, the effect of motion parameters on fresh concrete uniformity is not clear and mostly relies on empirical estimation because people do not know much about the mechanism of mixing (Feng, et al., 2015). Variables and uncertainties clutter concrete processes, if these are considered in the early stages of preparation, many may result in needless practices that have begun to be difficult to handle. To define and control these uncertainties, it may be possible to introduce lean construction principles (Dunlop & Smith, 2004). First, the process at the concrete batching plant and construction site is a sequence of flows and conversions. Conversion activities are those processes conducted that add value to the material or knowledge converted into a product. Flow processes reflect inspection ,moving and waiting activities (Koskela, 2000), (Dunlop & Smith, 2004). Some heuristic concepts have developed in lean thinking in construction, many of which relate to concrete operations and may well minimise and control the amount of waste found in flow processes, take into account the common concepts regarding to predict and minimise variability and minimise cycle time (Koskela, 2000), (Dunlop & Smith, 2004). The chart below declares the flow of concrete operations from the batching plant to the site in lean construction projects. Lean construction means that the implementation of a new philosophy of production leading to 'lean production'. In other words, minor space, less efforts and shorter production time which lead to transforming almost every business and providing drastic changes in the structure of work (Alarcón, 1997). Furthermore, the emphasis is on optimising the value generated by using the value added to construction delivery across all the work processes from concepts. Reliability of the workflow and labour flow are claimed to be key determinants of the efficiency of the building. To achieve a successful lean project, the delivery framework must meet the three objectives, transformation, flow and adding value (Salem, et al., 2006).There are two common concepts in the construction industry about what the principles of lean construction can do and support. The first concerns the application of the process of lean production to the building industry. The Second is the basis of a modern way of thinking within the construction industry. Continuous flow pulls out output and continuous improvement have been the main objectives of implementation up to date (Bertelsen, 2002). The construction industry consists of one-of-a-kind development that has no set sequences that can be standardised and has thus been based on. The processes of lean construction are considered understandable and straightforward in their essence to be regarded as a lean process, also some features of the conventional practice tend to be part of the lean (Sarhan & Fox, 2013). According to (Koskela, et al., 2002) the key difference between lean construction and conventional view of operating a construction project is that lean views all activities as part of something larger than individual activities, by combining the emphasis of activity engagement with job execution. It is claimed that lean will produce higher efficiency. Furthermore, another important distinction between conventional and lean construction is that the latter considers the relationship between the building phases and their participants (Paez, et al., 2005).

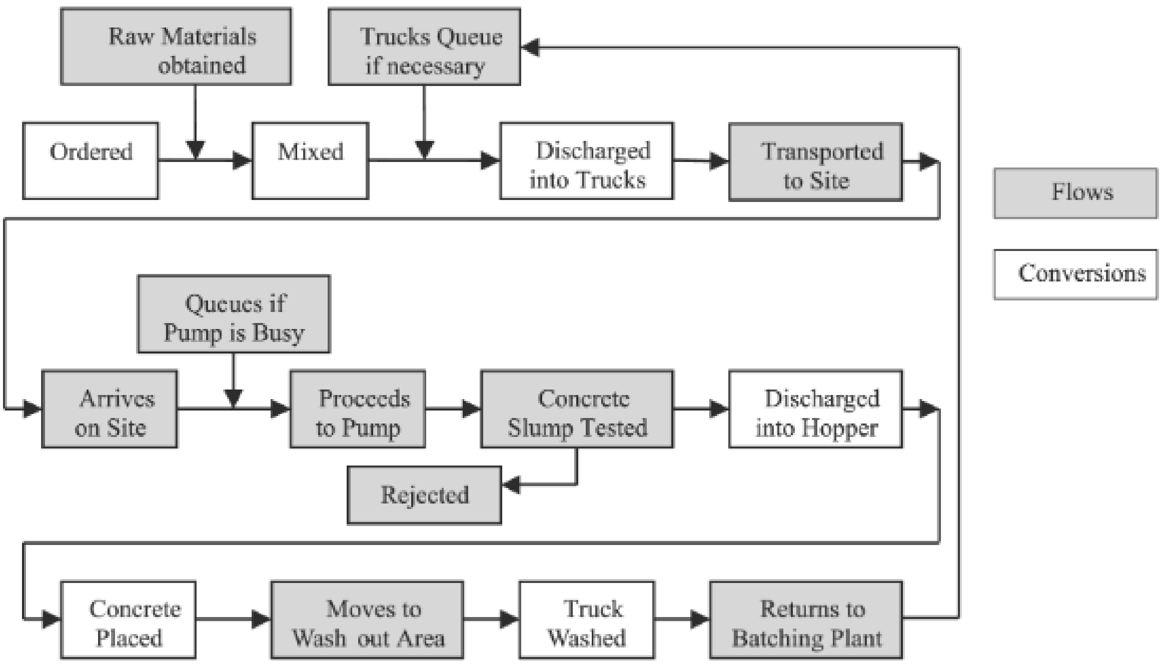

Figure 2: *Logistics process and activities in cast-in-place concrete projects, (Dunlop & Smith, 2004)*

In addition, massive job orders are moved across the supply chain and on-site, generating high stock rates and long lead times. In contrast, the pitching strategy divides job orders into small lots of the same size allowing for a decrease in lead time and inventory rates, and a reduction in real-time for preparation and monitoring construction projects, which allows development to be prioritized according to the demands and delays of the various construction sites (Dallasega & Sarkis, 2018). Lead time is the period of time that goes from the start of a phase to its completion, including pre-production, production, post-processing periods. Enterprises analyse lead time in manufacturing, supply chain management, and project management for its importance and effect on these fields (Ballard, et al., 2003). In order to boost the efficiency of the demand chain, it is best for the supply chain parties to focus first on reducing lead time (De Treville, et al., 2004). According to (Tersine & Hummingbird, 1995), (Li, et al., 2014) the efficient ways of softening the effect of supply chain uncertainty, either demand uncertainty or supply uncertainty, or even both, were called operational hedging strategies such as maintaining safety lead time, minimising lead time differences and retaining safety stock. While all mentioned strategies are commonly used, researchers found out that if the lead-time is long, eliminating lead-time could improve the performance of safety stock strategy in terms of minimising uncertainties (Schmitt & Singh, 2012), (Sullivan, et al., 2011), (Heydari, 2014)). lead-time hedging stems from the principle of reserving lead-time protection to protect against upstream risks such as machine breakdown, bad weather, etc (Hariharan & Zipkin, 1995).

The word 'Just-In-Time', used for example to illustrate the delivery of materials to the construction site, implies that materials will be delivered to their places for final installation and installed immediately upon arrival without delay due to a laydown processing or storage area, Just-In-Time is a term introduced by the Japanese who produced the Toyota Production Method, which was later translated into English as a lean production system, the main aim of Just-In-Time production is to supply the right materials at the right moment and at every phase of the operation. By introducing a pull method using 'Kanban,' loosely translated from Japanese as 'cards,' Toyota achieves Just-In-Time efficiency, Kanban is built in reverse order to avoid overproduction and to insure that pieces are removed from operation to operation, Therefore, they introduce a supplementation program designed to regulate the quantities of output, Parts are only taken and replenished when necessary and in the appropriate quantity (Tommelein, 1998).The product pull from upstream is demonstrated by means of a Kanban withdrawal, the consumer process removes pieces from a store, which is a place of limited product storage capacity generated by the supply process. If inventory is too small, the supermarket is replenished by issuing a production Kanban (Tommelein, 1998).

The Kanban production therefore directs the supplying method of producing more goods, the supplying system only produces enough goods to substitute what has been removed. This approach avoids overproduction but makes a close-knit inventory between supplier and the consumer process (Spearman & Hopp, 1996).In general way, a pull device can include a station downstream feedback mechanism to inform a station upstream and the need for more stuff, material is then assembled and delivered to meet this particular need. This approach intentionally limits the amount of process work in the system, which helps to minimise the time of the product cycle. The alternative is to manufacture product in anticipation of a need, i.e. based on a predicted need, as it is the case for push systems, product forced into the manufacturing cycle is more likely to sit idle, thus not only tying up resources but also increasing cycle time (Tommelein, 1998).The delivery and installation of the construction elements such as pipe wire on the construction worksite is subject to various uncertainties using pull and push scheduling approaches. Push schemes tends to rise the amount of waste (e.g., long turnaround times, overly large inventories) as they are calculated guided and contain fudge factors to mitigate expected uncertainties, during project implementation uncertainty may or may not manifest itself, if so, push systems do not have the resources to adapt rapidly to evolve system requirements while pull systems do (Tommelein, 1998). To understand the concrete flow process, according to (Popescu, et al., 2016) there are two common processes of concrete flow. The first one is cast-in-place which the concrete mixed in the batching plant and casted in place, while the second one is the prefabricated concrete elements where the elements are produced and casted in the factory then delivered to the site.

2.2.2 Cast-in-place concrete

The process of cast-in-place consists of several activities. It starts with the process of mixing materials in the factory, followed by the process of transporting these materials, then the process of delivery. Lastly, the process of pouring concrete in the project through pumps (Jabbar, 2016).

2.2.2.1 Mixing and transporting process

Effective concrete installation relies on careful mixing, proper equipment and good transport. This site will identify, evaluate, and illustrate each significance in the overall concrete placement phase. Mixing concrete is clearly described as the "complete mixing of the materials required to make a homogeneous concrete" (Jabbar, 2016),it can range from manual to machine mixing, the most popular being computer mixing. But without proper batching of all components, no effective mixture can be achieved, Batching is "the method of weighing or volumetrically calculating the ingredients for a batch of concrete and inserting them into the mixer" (Kosmatka, et al., 2002),quality control, appropriate materials and equipment configuration, and proper measuring of the materials are the necessary measures that must be performed before all the mixing happens. There are several mixing components which need to be addressed to ensure a consistent concrete mixture can be achieved. The position, shape and angle of the mixing blades, mixing chamber form, rotational speed and horsepower must all be taken into consideration. It is of utmost importance that each batch is regularly mixed to standards so that the final strength of the concrete does not weaken (Dobrowolski, 1998). There are essentially three classifications of mixers: the drum mixer, pan mixer, and continuous mixer. If the appropriate mixer has been picked, the mixing time must be calculated. It is the length of the concrete mix, until the mixture is completely filled with all the materials. Charging is a significant move as it offers an opportunity to pre-blend the materials. The mixer's form and conditions such as rotation speed, load size, and material nature all decide the correct mixing time. For each, the mixing time is not normal. For instance, a tiny-diameter drum mixer produces a greater velocity than a large-diameter drum mixer, and the mixing time will be reduced (Dobrowolski, 1998), (Jabbar, 2016).There are many elements of transporting that need to be considered in order to ensure that a mix does not change its state as specified in the contract. The two key goals when transporting concrete from the mixing plant to the construction site are to prevent segregation and to not reduce the workability of the mix. This transportation process must be well thought out and organised efficiently. As a general rule of thumb, thirty to sixty minutes of transportation are acceptable on small jobs. At a central or portable ready-mix plant, concrete should be discharged from a truck mixer or agitator truck within two hours. If non-agitating transporting equipment is used, this time is reduced to one hour. All delays must be avoided in order to prevent honeycombing, as shown in or cold joints. Many factors determine which type of transportation is most suitable. Type and constituents of the concrete mix, size and type of construction, topography, weather conditions (i.e. temperature, humidity, wind speed), location of the batch plant, and cost are all taken into consideration when choosing a mode of transport for your concrete. If you choose the wrong mode of transportation, your concrete could be segregated, which would in effect, make it useless. Therefore it is essential that adequate thought be given to the type of transportation you actually need (Dobrowolski, 1998), (Jabbar, 2016).Concrete batching plant is used to combine and mix cement, water, sand, and aggregates to form value concrete without which it is difficult to create any building project. To finish a construction project as quickly as possible, it is important that the concrete batching plant be productive and speedy so that will save the time to get the ready concrete to the project (Ferraris, 2001). These are the methods of transporting: Wheelbarrow or motorized buggy, Truck mixer, Bucket or steel skip, Chute, Belt conveyor Concrete pump and Pneumatic placer. An efficient concrete transport process should lead to guarantee that the water-cement rate, slump or strength, air quality, and homogeneity are not altered from their expected conditions. As a general rule, concrete must be discharged from a truck mixer or agitator truck within two hours at a standard or portable ready-mix plant (Lu, 2006).

2.2.2.2 Delivery process from the batching plant to the worksite

Delays at the construction site are most encountered issues. They may have negative implications, such as higher costs, loss of production and sales, disputes between the main actors of the contract (Owolabi, et al., 2014) Construction firms in the concrete business face an issue with work schedule and planning on a daily basis. Concrete manufactured at multiple plants must be transported to the worksites of consumers using a diverse vehicle fleet and this is considered to be a major issue for the time and cost-related delivery process (Schmid, et al., 2009). Mixed concrete is the main building material used in large amounts all over the world for construction purposes, mixed Concrete is efficient only when it is delivered to the customers in time-long roads, delays due to congestion or queues commonly impact delivery (Afzal & Khan, 2018). the high quality concrete which produced in batching plants so this standard concrete has to be shipped to the location for finished use, but a major problem also occurs during ,Concrete delivery: long road and delays involved in the transportation of concrete mixtures that can minimise the working ability of concrete that needs to be preserved before pumping (Afzal & Khan, 2018).About concrete companies in the industry and their question of scheduling which they face daily. In addition, he concentrated integers multiple commodity flow by focusing on possible solutions like hybrid approach and factor neighboured search, their results that show development in mixed concrete production, all these solutions were addressed and they concentrated on a feature of distance travel, traffic effect and demand, volume-based promotions, late delivery fees and mix-spoilage costs (Schmid, et al., 2009).The Concrete Delivery Problem is a mixture of a scheduling and a logistics issue, and route issue encompassing the shipment of concrete to a variety of worksites, each worksite often refers to as consumer, The concrete is shipped by a non-homogeneous group of vehicles, each able to deliver concrete ones (Kinable, et al., 2014).

In large and crowded cities, cement shipping operations from the factory to the worksite are the most common operations that lead to a delay in cement delivery, and this is due to the lack of alternative secondary roads or the driver's lack of knowledge of the existence of these roads, but this delay process is also financially costly given that it is from The cement can be damaged due to its sensitivity, and some logistic operations have been proposed that can be offered to reduce this, such as using the Global Positioning System (Lu, 2006).

2.2.2.3 Casting and installation at site

After the concrete arrives from the factory to the site, the cars loaded with concrete must wait their turn to advance to the pump and put their loads in the pump this period if they need a long time the concrete will lose its qualities and become inappropriate and it can affect the barrel of the car carrying it, which means the need to maintain it as well as the capacity The concrete transport vehicle is preferably sufficient to transfer the required quantity to the customer from the factory in one batch because there are time intervals between concrete deliveries that lead to a partial hardening of the concrete at the construction site before the arrival of subsequent supplies the Scheduling or directing vehicles carrying concrete is a complex process and one of the logistical problems where it is necessary to determine the dates, times and arrival of vehicles to the site throughout the day and to ensure that there are no significant time intervals in time and to ensure the effectiveness of the pump in the project and its ability (Asbach, et al., 2009).Pumping is a method used to transport fresh concrete which makes it possible to put fresh concrete in the site without using concrete buckets or conveyor belts. Concrete pumping technology has existed for nearly 70 years. Concrete pumps where the concrete moves by metal pipes have been used in the U.S. since 1933,Pumping technology has seen significant growth, and many adjustments have been created, especially to pumps (Kaplan, et al., 2005).Blockage is the most common issue with pumping concrete, if the pump is mechanically sound, concrete failure is called blockage it happened the end of the pipeline, the rise in the pressure indicated by the pump pressure Geiger shows the blockage of the pipeline and these issues have led to delays in the casting of concrete and some time these technical difficulties have caused the concrete to spoil (Tam, et al., 2004).After the vehicles empty their concrete load in the pump, they should go for cleaning and bring in another quantity of concrete if the site requires this and that the site is not equipped with equipment and a special place to wash these vehicles or there is crowding in the workplace that leads to a delay in the work of these vehicles and may harden Cement residue in these compounds which leads to technical breakdowns that lead to material costs, A specified location shall be given by the contractor at the construction site Where such rinsing operation can take place, this is sometimes inconvenient and inefficient, particularly if the rinsing stations is located at a site away from the location of the concrete discharge (Barry, 2000).

2.2.2.4 Challenges of cast-in-place

Construction projects keep running over time and over budget, so the industry needs a shift. The approach endorsed is lean construction, with Just-In-Time and autonomy can be the solution for that (Ferrer Ramells, 2013). It is difficult to achieve a completely lean process because it would need a specific product without waste or storage in zero time (Koskela, et al., 2002).It is easy to change the processes involved in lean projects, but the difficulty lies in understanding the time of the whole process from start to finish by the obstacles in the project (Koskela, et al., 2002).People working on major projects each focus on a specific point without having a complete understanding of the plan and the process in the project (Picchi & Granja, 2004). Unlike the manufacturing industry, the construction industry carries out unique projects without a fixed and uniform task order and therefore cannot standardize the operation, which can lead to logistical challenges and delays to the lead time of the activities involved in the process (Paez, et al., 2005).

2.2.3 Prefabricated concrete elements

Prefabricated concrete elements are a very well-known building and civil engineering product. Prefabricated components are used to build homes, roads, or bored passages for years (De la Varga & Graybeal, 2015).
The regulated production cycle, rapid erection and strong repetition render planning of this material very exciting technologically and financially. While looking for a fast execution time of the design and the likelihood of high duplication of elements, prefabricated concrete begins to be a fascinating substitute to casting concrete in-site because of the streamlined use of materials. Prefabricated concrete has a great potential to be inexpensive and robust compared to the cast in place concrete. In a plant, prefabricated elements are manufactured in good conditions and with great control of quality. Usually, permanent factories are used to produce items of a tiny size in large quantities (De la Varga & Graybeal, 2015). The prefabricated concrete elements that are installed in the laboratory are transferred to the work site when needed.
Most of the significant aspects that make prefabricated concrete elements more preferable than cast-in-place and also describe the features of prefabricated elements clearly. The construction time for prefabricated elements is going to be less than cast-in-place concrete. While the construction process consists of several processes such as logistics and production activities. The lead time of these activities can differ from a process to another. Planning and drawing phase lead time for the prefabricated elements is longer than the ready-mixed concrete due to the design complication where the delivery date, equations and sketches of the elements have to be done in the preliminary stage. Whereas, considering the entire construction process lead time a significant decrease will be observed (Chen & Riley, 2010). Problems related to the material storage on site when cast-in-place, especially in dense cities, is the project area might be too small and it is not possible to find a warehouse or a yard nearby. It is better to use prefabricated elements where they can be installed immediately in their locations after unloading from vehicles (Jaillon & Poon, 2014).
The concrete quality of the prefabricated elements is better than the cast in place concrete at the construction site because precast concrete is subject to stronger and more effective control

during the manufacturing process and this means that the design was made more precisely (Van Casteren, 2015). Another important aspect is the flexibility, prefabricated concrete facilitates the construction process for complex structures that require special moulds, because the design, moulds can be used in various and complex shapes while casting on site is difficult to do (Eigenraam, 2013). An environmental aspect to mention for its import, is the lifecycle of prefabricated concrete where these elements can be used again after demolition, and the demolition by itself is easier than cast-in-place structures (Van Casteren, 2015). Prefabricated elements have its own characteristics with the ability to do repetitions and duplications of the same element. A considerable to choose prefabricated concrete is cost. Since the repetition of the elements is considered in the precast concrete as one of the most important reasons for economic profit. The cost in this type of concrete is based on the cost of building the formwork. In other words, repeating the same design of the elements gives more economic solutions (Hack, et al., 2013).

Design rules, the prefabricated concrete aims to apply the details of the accurate designs because one of the most important features of the precast concrete is that it can guarantee the delicate designs following several rules, to make the designs as simple as possible and pay attention to the design time to ensure the greatest degree of repetition. Usually, designers try to get the biggest possible size of the elements to keep the transportation rate as low as possible and not exceeding the crane capacity on the construction site. Another important design rule to pay attention for, is to limit the connections, joints and nodes as much as possible. Transportation is very important in the process of the arrival of the prefabricated intact to the work site. It is important to know the capabilities, advantages and disadvantages of precast concrete before starting the design of the structure in order to ensure the integrity of the structure during the service life, in order to reach a result as a ready-made concrete design (Van Casteren, 2015). The stability, to achieve a high speed erection, it is preferable to use the connections that are simple. Therefore, using fixed connections is a common solution. The elements must be installed in a way that ensures the transfer of shear forces in a correct form. If the connections are wet, the concrete needs time to harden and this leads to project delays. Another aspect to be considered is the progressive collapse, which could lead to a failure of the structure and causes great damage. It can even lead to a total collapse of the building in critical situations. Thus, this kind of collapses risks should be mitigated during the design phase (Van Casteren, 2015). Tolerances, the prefabricated concrete manufacturing involves some relatively small deviations, so designers have to take into account that a slight change in the dimensions could occur, so the design must be made on the basis of a safety factor provided that is also economically acceptable and practically reasonable (Van Casteren, 2015). Lastly, Connections and joints are important factors for the transfer of forces between the prefabricated elements in order to obtain the interaction and complementarity of the elements of the structure. These connections must secure the structure’s behaviour that should be followed and carefully examined the path of forces between these elements through these connections. Therefore, several aspects should be taken into account when designing, customizing, transporting and installing hydraulic links. These aspects should revised and included in the design process, prefabricated elements production, transportation, storing and handling prefabricated elements, the Structural behaviour for the different types of loads and finally the performance and constitution of the structure (Van Casteren, 2015).

The process of making prefabricated concrete elements needs a lot of planning, coordination and careful monitoring of the product flow process, also a knowledge of the process is necessary to complete it from production into transportation and delivery to the site.

Assembling and installing the elements at the appropriate time and cost as this process must follow the logistical development to enhance its performance (Liu, et al., 2020).

2.2.3.1 Transportation of prefabricated concrete elements and the crane capacity

According to (Van Casteren, 2015) the prefabricated concrete elements that are produced at the factory must be moved from the storage place to the project site, and this process of transportation often results in additional costs and an increase in time compared to the process of cast-in-place. The process of transportation is carried out for the precast concrete elements by large trucks, but the transport process must follow the restrictions of the set transportation but there is a certain weight that is permitted for the truck to be loaded. In case of greater weight than 30 tons trailers will be installed to the trucks to carry out large transport operations. The biggest trickle down in the transportation process is that designers must from their outset link their designs to the permitted conditions for transportation and the ability of trucks to transport items. The cost of transportation from the factory to the site in Sweden is calculated proportional to the distance between the plant and the working site, since the cost of transportation time of the truck is the highest (Håkansson & Waluszewski, 2007).
The determination of the elements' size is not only limited to the restrictions imposed by the transportation process, although the crane's cost as the prefabricated elements should be lifted from the truck to the site through the cranes in the site. Each crane has a certain ability to lift a weight or size and also a specific height or lifting distance. The capacity of the crane must be taken into account when designing the elements as well as the number of cranes in the site. It may be cheaper to use two hydraulic cranes instead of using one large and heavy crane, but this requires a broader and more comprehensive concept of terrain and experience in managing the lifting process. Columns, cables, trees, channels, and adjacent buildings affect the lifting process, especially in crowded cities (Van Casteren, 2015).

2.2.3.2 Design input of prefabricated concrete elements

According to (Englekirk, 2003) a well-organised design routines as well as serious organization of the project team are essential elements in prefabricated concrete, all important information about the design must be available. The architect, consultant engineer, service engineer and all other disciplines should participate in the design process considering the customer requirements by working as a team to give a complete design. The optimal design for prefabricated concrete elements is those projects which are prefabricated projects from the start. The design philosophy in projects that rely on prefabricated concrete elements depends on large extensions, structural integrity and some specific stability systems. In order to obtain a design that contains all the details and procedures the difference in the dimensions specified in the plan and the actual dimensions in the work ground must be taken into account. It is preferable that very severe or weak details should be avoided with consideration that there are some deviations and errors that must be permitted and set during the design process. In terms to reduce and minimise these deviations and differences, following the prefabricated concrete method for building design is a feature that affects all stages of the design of the building and that leads to a rapid production and the inclusion of all details within the designs. It must be emphasised that the design and planning have been put in great accuracy to ensure that no errors would occur. Changing the design or edit it in later stages of the process could cause remarkable delays in time and increase in cost to make new designs.

2.2.3.3 Challenges of using prefabricated concrete elements

According to (Chen & Riley, 2010) by using the prefabricated concrete elements the lead time will be longer because the period to do the designs and the plans is longer than other activities (Pheng & Chuan, 2001). The installation of prefabricated elements should be carried out immediately from the carrier vehicles to reduce the risk of damage during storage. The process of making prefabricated elements needs a stronger and more effective control during the manufacturing process and this means that the design was made more accurately (Van Casteren, 2015). According to (Eigenraam, 2013), the prefabricated process needs special moulds because moulds can be used in various and complex shapes. It has to be a repetition of the elements that will be designed which in some cases is a challenge for it might take longer time to design it (Van Casteren, 2015). Transport is very important in the process of the arrival of the prefabricated to the work site as it should be at right timing. Damages during transport will make the elements not capable to use. In addition, the capacity of the crane at the construction site and the size of the vehicles carrying the prefabricated elements are limited to a certain weight which should be followed when uploading and unloading the elements (Van Casteren, 2015).

2.3 Conceptual framework

The construction enterprises often try to compete by achieving cost efficiency, but nowadays the development of the construction raised the competition to a new level by also achieving time efficiency (Wegelius-Lehtonen, 2001). moreover, the accessibility to time and cost data is obtainable in the construction industry, despite the fact that this data is fragmented. Since this data could contribute robustly to the logistics performance, it has been intended in this master's thesis to measure the cost and time as indicators for the logistics performance. Measuring these variables requires tools that are applicable in the construction industry. Performing the literature study shows that the most common tool for measuring the logistics cost is the theory of activity based-costing (ABC). Whereas for measuring the time, one common tool is the controllability engineering theory (CE). These tools are the basis for the suggested conceptual framework, where two analyses are intended to be performed. The first analysis is the activity and cost analysis, while the second one is the accuracy and delivery time analysis. This chapter introduces the suggested conceptual framework for this study and in the following subchapters the two aforementioned analyses are illustrated in detail.

2.3.1 Activity and cost analysis

The foundation of this activity and cost analysis based on the theory of activity-based costing (ABC). The operations are described as separated activities to understand the cost allocation for each one of these activities. Therefore, a pair of objectives were in focus by this theory. The first objective is to detect the activities and costs of the material flow, and the second objective is to show the costs of unnecessary work in the delivery chain (Wegelius-Lehtonen, 2001). Since the ABC theory is more business/management-related theory, adjustments are needed to be applicable for the construction industry (Baker, 1998). These adjustments shall add efficiency to the cost computation to present a clear picture of the logistics performance. Therefore, several studies (Gooley, 1995), (Henricks, 1999), (Fang & Ng, 2008) have been directed towards adjusting ABC to be more effective in the construction industry. This effectivity has been achieved by considering several aspects in calculating the logistics costs such as; characterizing the activities inside the logistics chain, pointing out the main consumed resources in the logistics chain, calculating the costs of the activities which are included in the chain and figuring out the main factors that impact the logistics cost. Moreover, (Fang & Ng, 2011) suggests additional adjustments that can be implemented for ABC to be more adequate for projects of prefabricated concrete elements. One of the major adjustments is to define the main activities in the prefabricated concrete flow process. Additionally, the main costs in the construction logistics chain have been considered in this paper by adapting the cost equations to be applicable for this type of projects.

In order to perform the activity and cost analysis, the so-called ''activity analysis'' shall be implemented. To initiate this analysis, it is required to identify the consumed resources as well as the cost components. (Brimson, New York, NY), (Kaplan & Cooper, 1998) characterized the resources in five different categories, which include labour, materials, equipment, facilities, property and capital. (Fang & Ng, 2008) investigated the flow process of prefabricated concrete elements that have been used in residential projects and identified several observed activities as depicted in Figure 3. This flow process includes several phases; procurement phase, stocking at supplier's yard phase, transportation phase as well as stocking at site phase. In these phases, it has been described various activities, where the flow process begins with the activities of the procurement phase and ends when the elements are installed.

Moreover, (Dunlop & Smith, 2004) identified the activities of the flow process of cast in place concrete projects and characterized the activities in two categories Figure 2. The first category is the conversion activities, which are the activities that add value to the material or transform information to a product. The second category is the flow activities which represents activities such as moving and waiting, inspection. More elaboration about the cast-in-place activities can be found in chapter 2.2.

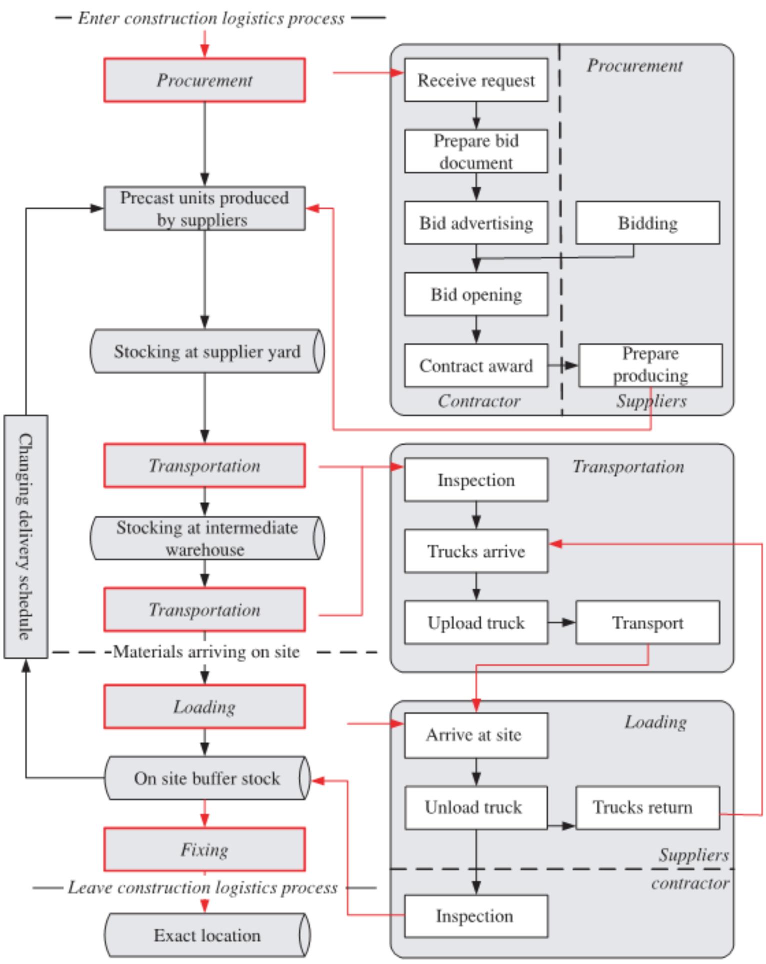

Figure 3: *Logistics process and activities for prefabricated concrete projects, (Fang & Ng, 2011)*

By identifying all activities that the logistics chain contains from the beginning to the end, the step of calculating the cost of activities can be implemented in an accurate way. Furthermore, Identifying the critical activities is an essential base for the cost calculation. Any missing activities in the process of identifying the activities will result in excluding some costs from the logistics cost calculation, which means underestimating the cost calculation.

However, in order to avoid any cost miscalculation, the adjusted ABC theory in (Fang & Ng, 2011) proposes five types of costs that can be measured and calculated to apply the ABC theory. These five types of costs cover all critical activities. Additionally, each cost of these costs represents the cost of one phase in the flow process. For instance, the inventory cost represents the cost of the stocking at the supplier's yard phase. However, these costs are elaborated more in the following subchapters.

2.3.1.1 Inventory cost

In order to enhance the concept of inventory cost, various papers (Waters, 2003), (Fang & Ng, 2011) emphasised that the nature of the inventory cost can vary from industry to industry, resulting in different definitions of this cost. (Gürmann & Schreiber, 1990) defined the inventory cost as the cost of keeping materials in the warehouse and maintaining the warehouse. In case of construction materials, the inventory cost can be considered as the cost of stocking at the suppliers' factory or intermediate location. Moreover, (Waters, 2003) included the holding, shortage and re-order costs in the inventory cost.
This cost according to (Waters, 2003) shall include the cost of storage space cost, losses due to damage, handling cost as well as administration cost. As more related-definition to the prefabricated concrete projects, (Fang & Ng, 2011)clarifies inventory cost at the supplier's yard as It includes handling, administration and capital frozen costs. The utilization of many resources such as labour, equipment and materials could be the main costs for the handling, administration costs. In case the material is standard (prefabricated concrete elements) the handling cost can be constant if the quantity is determined, whereas the administration and frozen capital costs depend on the quantity and how long the material will be stocked. Another cost could be included in the inventory cost is when the supplier uses an intermediate warehouse during the stocking phase. The cost at the internal warehouse is composed of the opportunity cost as well as the rental cost. This case does not occur often unless the quantity is huge and cannot be stocked at the supplier's yard or the supplier is an international supplier.
Moreover, it's beneficial to mention that the inventory cost is a related cost to the transportation capacity. In other words, there is an inverse relationship between the transportation capacity and the inventory cost (Vidalakis, et al., 2011). However, several factors can affect the inventory cost and one of these factors is the level of demand, where high demand could result in high inventory cost if the logistical plan is not able to reduce the stocked materials.

2.3.1.2 Transportation cost

The transportation cost is a well-known cost and several studies have been directed toward investigating it. (Burns, et al., 1985) built a model that can analyse the transportation cost and according to this model the transportation cost is dependent on several factors such as travel distance as well as size of component. For precast concrete units, the required components are picked up from the factory or intermediate warehouse and transported to the construction site according to the delivery schedule. The transportation cost of any component does not only mean the cost of driver's salaries, fuel and employed equipment, but, in many cases such as precast concrete projects, it can also include the cost of utilised materials during the transportation process. Moreover, delays can happen during the site installation phase and the cost of this delay can be included in the transportation cost as well. Additionally, defects due to transportation can be potential, therefore, the transportation cost shall include the costs of handling these defects (Fang & Ng, 2011).
On the other hand, it has been seen in the previous subchapter how the transportation capacity could affect the inventory cost positively. Nevertheless, high capacity of transportation could lead to high transportation cost (Vidalakis, et al., 2011). However, the transportation cost in the construction industry is higher than other industries since the construction products are high in volume and low in value. In other words, one delivery can transport low-value product to

the construction site. Therefore, the transportation cost could be a significant cost in the logistics cost (Vidalakis, et al., 2011).

2.3.1.3 Stocking at site cost

In the past several studies such as (Ferguson, 2000), believed that the logistics chain ends when the materials arrive at the construction site. Later on, it has been revealed that this belief could not be accurate, where stocking at site cost and fixing cost shall be included in the logistics cost. In case of prefabricated concrete elements, the elements are prone to be stocked at the construction site. This implies that costs of renting equipment, labours as well as materials shall be included in the logistics cost. For instance, resources such labours, cranes, iron materials can be utilised during the lifting and fixing process, whereas resources such as stow-wood can be utilised in the stocking process. However, the use of these resources could add opportunity and depreciation costs to the stocking at site cost (Fang & Ng, 2011). This cost is related to the site capacity and other costs. Since all costs in the logistics chain are related to each other, this cost is related to the inventory cost and transportation cost. Low inventory cost could lead to high stocking at site cost in case the site has low capacity (Pheng & Hui, 1999). However, reducing this cost needs a high collaboration between the supplier and the contractor as well as application of some logistical philosophies.

2.3.1.4 Procurement cost

According to (Fang & Ng, 2011)the procurement cost is defined as: ‘‘ *the expenses associated with the sourcing of suitable suppliers for the project which involves identifying appropriate suppliers, seeking quotations from the suppliers, negotiating the contractual terms with the suppliers, etc.* ’’. The construction industry experiences in the procurement process inefficiency, where the construction materials need to be under long period of quantity take-off revisions and cost estimation, which leads to additional costs (Castro-Lacouture, 2007). Several strategies such as utilizing e-commerce have been proposed to ease the process of choosing the appropriate construction materials. Therefore, based on the aforementioned definition of procurement cost as well as the inefficacy, the procurement cost shall be considered.

However, the construction logistics research still suffers from not providing a clear procedure for calculating the procurement cost, but some studies such as (Fang & Ng, 2011)provide a simple procedure for procurement calculation. It is worth to mention that this procedure calculates the procurement cost based working hours as well as the utilised equipment.

2.3.2 Accuracy and delivery time analysis

The foundation of accuracy and delivery time analysis is the theory of controllability engineering (CA), which has been suggested by (Eloranta, 1987). The application of this theory in the construction industry aims to figure out whether the logistical plan has the capability to achieve its intention or not (Lehtonen & Seppala, 1997). Another intention of applying this theory is to provide the logistical plan with potential improvements by detecting the distorted activities. In less rigorous words, it aims to detect the activities that does not achieve the optimal logistical plan in terms of cost and time. However, (Wegelius-Lehtonen, 2001) suggests the CE theory aims as well to build up a whole picture of the structure of delivery times. By knowing this structure, the accuracy of these delivery times can be detected. (Lehtonen & Seppala, 1997) suggests that the so-called ‘‘Zooming-Focusing’’ technique can be combined with the CE theory. This technique allows the project manager to detect the issue of the followed logistical plan. This technique starts by identifying the components of the logistical plan. Next, zooming on the largest process of the logistical plan such as the inventory process. Thence, focusing on the components of the largest process. The combination between CE theory and zooming-focusing technique could give the project management several benefits such as detecting the delays in the delivery process as well as presenting some potential refinements. Several papers (Wegelius-Lehtonen, 1995), (Lehtonen & Seppala, 1997), (Wegelius-Lehtonen, 2001) discussed how the results shall be presented in order to achieve the benefit of this theory and almost most of them they agreed on presenting them graphically, but the type of the graph differs between them. One (Lehtonen, 1997) suggested that the area graphs the suitable presentation, whereas the other (Wegelius-Lehtonen, 1995), (Wegelius-Lehtonen, 2001) suggested that column and bar graphs are the good way of presenting. However, in order to achieve the aim of this thesis of providing simple measures, the bar graphs such as Figure 4 have been chosen as presentation for the results of this theory. Furthermore, (Wegelius-Lehtonen, 2001) emphasised that collecting the needed data is a fundamental issue to apply the CE theory. Since the construction industry is a fragmented industry, these data could be missing, which means that logistical plan does not perform well. Additionally, according to the definition of qualitative and quantitative approaches, the quantitative approach is the most suitable approach for gathering the needed data, which is indeed data of numbers.

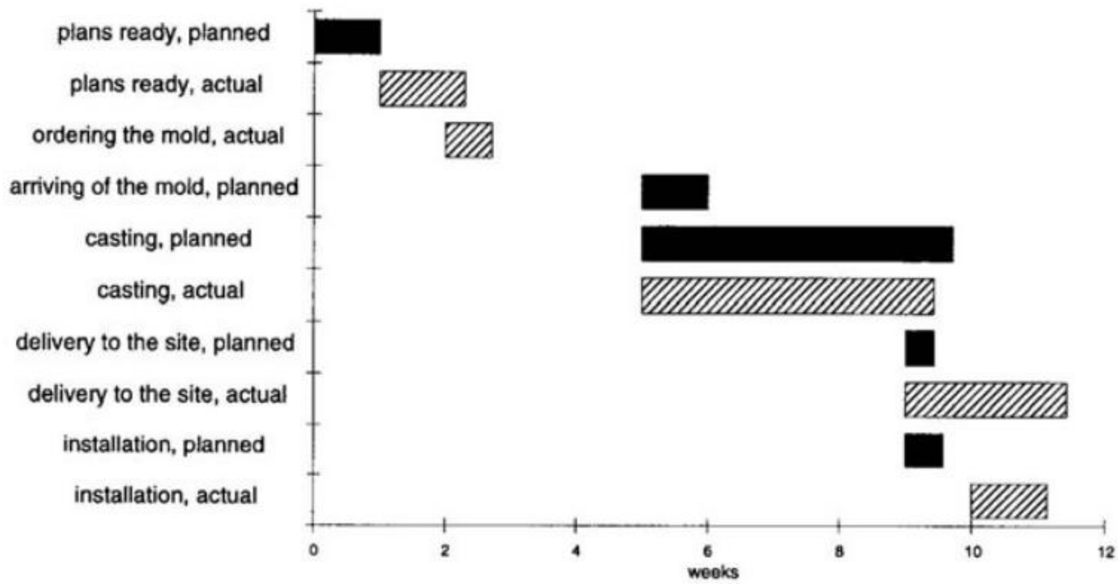

Figure 4: *delivery time structure of concrete elements, (Wegelius-Lehtonen, 1995)*

2.3.3 Application of the conceptual framework

In order to show how the activity and cost and the Accuracy and delivery time analysis can be tool to measure the logistics performance, a case has been generated. This case shows the application of activity and cost as well as accuracy and time analysis in order to optimise and improve the logistics plans in the construction sector.

The estimated case that has been generated is for a prefabricated concrete elements project of 73 apartments. In this project, 420 prefabricated elements have been used. Moreover, three types of prefabricated elements have been considered in this project, and the quantity of these elements as follows:

- 200 type 1 elements
- 170 type 2 elements
- 50 type 3 elements

Furthermore, the corresponding costs for each type per element as stated below:

- 19620 SK for one element type 1
- 24525 SK for one element type 2
- 29430 SK for one element type 3

As suggested by the literature review, the starting point of performing activity and cost analysis is to identify the flow process of this project and the activities that includes. It has been assumed that the main activities that occurred during the flow process are as stated in Table 2, and any minor activities have not been considered.

After defining the activities, the step of calculating the costs, which is the application of ABC, shall be conducted. The starting point of cost calculation is to determine several terms in advance. Some of these terms shall be defined to perform a clear picture of cost calculation.

- Depreciation rate is the rate of decrease of value and it can be calculated simply by using the straight-line method. Hence the annual depreciation rate can be computed according to (Yu & Yanlin, 2016) as follows:

$$Depreciation\ rate = \frac{(1 - Estimated\ net\ risdual\ value\ rate)}{Estimated\ useful\ live} \times 100$$

  Where, in this work, it has been assumed that the estimated useful lives are 5 and 10 years for transportation trucks and handling material equipment, respectively and the estimated net residual value rate is 5%. Hence the depreciation rate for stocking at supplier yard and transportation are 19% and 9.5%, respectively.

  Moreover, due to lack of data about the procurement phase, it has been estimated that the depreciation rate for the procurement process is 7%. Additionally, since the depreciation rate is low for stocking at the site due to high rent rate, it has been estimated that the depreciation rate for stocking at site is 1%.

- Opportunity cost rate is defined according (Buchanan, 1978) as ‘‘ the rate of inducing loss cost due to unrealizing utility from an alternative to an outcome ’’. This cost is usually underestimated in the construction sector, whereas it should be considered properly in the cost computational process. Neglecting this cost can induce unseen cost losses. In the project at hand, no data for alternative are available, therefore, the opportunity cost rates have been assumed based on (Fang & Ng, 2011) research as 10% for stocking at supplier’s yard and 20% for stocking at construction site.
- Contract price is defined in ABT06 (year)General conditions of contract for design and construction contracts for building, civil engineering and installation works as the

payment for contract works and it is paid for the contractor when the project is done. The estimated value for this construction project is 715000 SK.

- Pay rate is the rate of cost that is consumed for labour such as inspectors, workers and drivers. In this estimated project, it has been assumed that the pay rate for handling materials at supplier's and construction site as 3% and 2% of the total quantity cost, respectively. For inspectors at supplier's yard, the pay rate has been considered as 5%. The pay rate for drivers is 190 SK per 100 km and for inspectors after transportation is 600 SK per delivery.
- Rental rate is the rate of cost that is paid for equipment at the phase of stocking at supplier's yard and for trucks at the transportation phase. It has been estimated to 5% and 300 SK per 100 km, respectively.

In order to complete the data for the application of ABC, three assumptions have been conducted. The first one is that all deliveries occur directly from the supplier's yard to the construction site e.g. There is no storage at intermediate warehouse. The second one is that the distance between the supplier's yard and the construction site is 100 km. The third one is that the deliveries conducted in total for 12 weeks and there is a gap between every two weeks. Additionally, all calculations have been performed based on the actual activities. Furthermore, It is also beneficial to calculate the production and transportation rate per day.

Subsequently, all data are determined to ABC theory. Based on the literature review, ABC suggests that the total logistics cost is composed of four types of costs. The application of ABC to calculate these costs are illustrated in the following sub-chapters.

2.3.3.1 Inventory cost

As aforementioned, there are two cases for stocking the material. The first case is when the materials are stocked at the supplier's yard, whereas the second one is when the materials are stocked at an intermediate location.
For the first case the inventory cost consists of the handling administration and capital frozen costs. Since the handling cost is composed of the labour salaries and the hiring cost of trucks, it can be considered as fixed cost. In order to make the handling cost as fixed cost, Material quantity shall be determined in advance. Additionally, in order to achieve the fixity of handling costs, the pay rate for labour as well as the hiring rate for trucks shall be determined as well.
On the other hand, the inconstant costs are the administration cost, which could include administrators' salaries and depreciation cost of stocked material, and the opportunity cost frozen in inventory.
Hence, the inventory cost for the case of materials are stocked at the supplier's yard can be calculated as follows:

$$I = FC_I + \sum_{t=1}^{T} \sum_{w=1}^{W} \left(R_{depreciation} + R_{pay} + R_{opportunity}\right) \times C_{unit} \times Q_{e,w}$$

$$FC_I = \left(R_{pay} + R_{rent}\right) \times Q \times C_{unit}$$

Where, CI is the storage cost at supplier yard, FC_I is the fixed cost in CI, $R_{depreciation}$ is the depreciation rate, R_{Pay} is the pay rate, $R_{opportunity}$ is the opportunity cost rate, R_{rent} is the rental rate, C_{unit} is the unit cost, $Q_{e,w}$ is the storage quantity at supplier yard of e on week w and Q is the total quantity.

2.3.3.2 Transportation cost

The transportation cost consists of two parts, the first part is a fixed part, whereas the second one is a variable part. The fixed cost can include several costs such as employed equipment cost, drivers' salaries, materials depreciation cost and resources cost. The variable part includes the inspection costs as well as the penalty cost and these costs are related to delivery times. The penalty cost could be due to delay in the delivering process such as traffic congestion or shortage of materials and this cost should be paid by the supplier to the contractor. It is beneficial to mention that the supplier who should be responsible for the transportation cost, which can be calculated as follows:

$$CT = FC_T + R_{pay} \times T_{delivery} + R_{penalty.1} \times P_{delay} \times T_{delivery} + \sum_{t=1}^{T} \sum_{w=1}^{W} R_{penalty.2} [N_{e,w} - D_{e,w}]$$

$$FC_T = \left[\left(R_{Pay+} R_{rent} \right) \times D + R_{depreciation} \right] \times Q \times C_{unit}$$

Where, CT is the transportation cost , FC_T is the fixed cost in CT, $N_{e,w}$ is the quantity of e needed on week w and $D_{e,w}$ is the quantity of e delivered on week w. $N_{e,w}$ shall be bigger than $D_{e,w}$.

2.3.3.3 Stocking at site storage

The cost for site storage consists of two parts, fixed and variable costs. If the resource rate and total quantity are specified the fixed cost can be calculated by knowing the pay, rental and depreciation rate. The variable cost represents the cost of depreciation cost of as well as the opportunity cost. Therefore, the total cost of stocking at site can be calculated as follows:

$$FC_S = \left(R_{pay} + R_{rent} + R_{depreciation} \right) \times Q \times C_{unit}$$

$$CS = FC_S + \sum_{t=1}^{T} \sum_{w=1}^{W} \left(R_{depreciation} + R_{opportunity} \right) \times C_{unit} \times Q_{e,w}$$

Where, CS is the cost for site storage and FC_S is the fixed cost in CS.

2.3.3.4 Procurement cost

The procurement cost consists of the staff salary, depreciation of equipment and travelling costs. This cost does not have a clear procedure to calculate since for each project the material could differ which leads to change in the way of calculating the procurement cost. However, for this work it has been chosen to calculate the procurement cost according to as follows:

$$CP = R_{Pay} \times T_{work} + R_{depreciation} \times C_{contract} + R_{traffic} \times C_{contract}$$

Where, CP is the procurement cost, T_{work} is the work time of labor, $C_{contract}$ is the price of contract and $R_{traffic}$ is the travel cost rate.

Appendix A shows how the cost equations can be applied to compute the total costs of logistics.

The second analysis that has been performed on this estimated case is the accuracy and delivery time analysis. The main purpose of performing this analysis is to figure out in which phase of the flow process the lags occur. Moreover, the accuracy and delivery time analysis is a powerful tool that can be used in optimising the logistical plan.

In order to start the analysis of accuracy and delivery time analysis, it is very essential that all activities during the flow process shall be defined in advance. Thence, the step of collecting different documented data shall be conducted. These documented data can be obtained from delivery orders, production plans, construction site diaries and installation plans. Based on these documented data, the duration of planned and actual activities can be clarified. The most useful manner to show these activities is graphically as **Figure 4**. This manner of showing the activities is beneficial for detecting any lag that occurred and predicting any induced lag that could occur later. Furthermore, the graphical presentation is a foundation for optimising the logistics plan, whereby linking the graphical presentation with the cost calculation, the elimination of costly non-adding value activities can be conducted more accurately.

For this estimated case, no data was available since collecting documented data is a hard measure and cannot be obtained only by performing interviews. The process of collection data needs a high collaboration between the supplier and contractor as well as the same level of documented data. Therefore, the planned and actual activities have been estimated to be as clarified in (Figure 5, Figure 6, Figure 7, Figure 8). Table 2 also shows the planned and actual duration of each activity. The duration of each activity refers to the time that is consumed by the activity unconsciously, which means that these weeks are distributed for the whole project period.
For instance, production of prefabricated elements activity was not contentious during the whole period of the project, whereas, it was during 20 separated weeks. Moreover, duration refers to the time between the starting and finishing the activity.

Table 2: *Actual and planned activities for logistics chain activities*

Activities	Planned Duration [weeks]	Actual Duration [weeks]
Receive Request	1	1
Prepare tender document	2	2
Tender advertising	3	3
Tendering	1	1
Tender opening	1	1
Contract reward	1	1
Producing prefabricated elements by supplier	20	20
Stocking at supplier yard	28	28
Inspection at supplier yard	6	6
Trucks arrive	12	8
Upload truck	12	12
Transport	12	12
Arrive at site	12	12
Unload truck	18	24
Trucks return	6	12
Inspection	6	12
Installing	34	36

After performing the aforementioned analyses, the performance of the logistics plan can be determined by detecting whether the drawn logistics plan is efficient in terms of saving costs and efficiency of delivery time or not.

3 Empirical Data

This chapter highlights and summarizes the collected data from interviews that could affect the logistics performance directly. The interviewees were from different disciplines involved with the logistics process. In order to enhance the scope of this conceptual framework, various perspectives have been covered in the following subchapters.

3.1 Planning process

The logistics manager started with the problems related planning and accuracy time. It has been stated by the respondent that cast-in-place processes have many logistical problems, For instance, construction labours usually stick to the specified plan to do the casting even if there is an opportunity to do it earlier. In other words, there is a lack of flexibility to change the scheduled activities. This could result in delays and time overrun to implement the project. According to the logistics manager, this stems from the lack of skills and experience of scheduling and planning rules. Another issue could flow on the surface that in cast-in-place concrete projects, planners often cannot determine the precisely needed quantity. It has been developed that the issue of not ordering the right amount of materials is a well-known issue in the construction industry and has no solutions yet. It springs from the weakness of planning since the construction industry has a structural problem with the way it works to develop plans for projects. Those who make plans are multiple actors such as the contractor and subcontractor, each of whom has their own plan that they want to implement. This creates problems and mayhem in planning the entire construction process. Some of these challenges are linked to the subcontractors, where there is a lack of skills and knowledge about how to lay out the plans that will be implemented. Additionally, it has been emphasised that there is a contrast between the construction and manufacturing industries regarding the way plans are drawn up, where many rules are involved in making decision processes in the construction industry.

Moreover, the logistics manager mentioned that in construction projects, there is a low possibility to use standardised materials since each of these projects is considered as a unique project and has its own conditions. Sometimes, modifications may be made to the materials purchased the project to become appropriate and this could be time consuming and costly which could lead to inefficiency. In other words, the construction industry has difficulties in achieving the standardization. Furthermore, the logistics manager clarified that when lean thinking is applied in construction projects, it is preferable to use prefabricated concrete elements than cast-in-place concrete.

The sales manager addressed that the manufacturing process of prefabricated concrete elements is divided into five departments; design department, production department, transportation department, assembly department and project management department. The latter department is responsible for allocating the activities and tasks among all departments. Furthermore, the purchasing manager clarified that at the design stage, it is necessary to ensure that methods of casting, calculations for openings, and number of electrical boxes are included in the design where designers should obtain information from electricians, plumper and ventilation contractors. Moreover, it has been stated that suppliers cannot start the production too early, where the final version of the documents and designs shall be finished.

The sales manager added that the design phase should perform well in order to optimise the production rate. It is a main task for the project management department to make sure that they offer an optimal cost-effective and required product, also to keep in mind that the product should fit with the design of the architect. Moreover, the area manager emphasised that the optimisation should be well made during the planning process is crucial to minimise the obstacles and challenges during the execution. Transportation, material delivery and task-distributing should be planned in advance, especially when there is a project of a size of 100 workers or more.

Regarding the procurement process, the purchasing manager mentioned that construction companies will sign a contract that includes the details of the activities cost and delivery time. Likewise, the execution of the project will be negotiated and the possibility of implementing the required designs. It has been declared that the company will always make new designs since each project differs from the other in terms of the required conditions. Furthermore, it has been stated that the procurement cost is dependent on the number of labours involved in selling, management, administrating processes, and this cost presents usually around three percent of the logistics cost.

Regarding the storage and inventory cost, the purchasing manager said that there is no storage or inventory cost as the supplier has to make internal calculations and estimate that cost of the total price. It has been added that production is dependent on whether the Just-In-Time method is implemented or not. When using JUST-IN-TIME, prefabricated elements are produced in a good time according to the project delivery plan that is provided by the contractor to explain where and when the elements are needed, then it's up to the supplier to make them ready before the scheduled time.

3.2 Transportation process

The logistics manager stated that the transportation for prefabricated elements has many problems. The prefabricated concrete elements are somewhat fragile, as they must be placed carefully in the transporting trucks and adjusted in the right position. The vehicles usually are subjected to dynamic load (vibrations). This load should not exceed the designed threshold but if it does, the dynamic load could lead to sabotage of the prefabricated elements. Moreover, there is an issue with the size of the prefabricated elements. For instance, if the element has a large size and has a complicated design, it can lead to difficulties through the existing transportation mechanisms. Therefore, it must be divided into several components, and this will increase the transportation cost.

The sales manager mentioned that some issues could stem from the use of prefabricated concrete elements since the designs in factories should be linked to the conditions of transportation, storage, and handling. Regarding the responsibility of the transportation process from the factory to the construction site, it can be divided into several parts. The supplier is responsible for the elements until loading them on the trucks. Thenceforth, the transportation firm will take over the responsibility. Ultimately, upon arrival at the site, it is the contractor’s responsibility during the storage time or the installation process. Risks can be transferred sometimes to the supplier, but this will lead to a significant increase in the total cost of transportation since the cost of potential damage risks during the transportation process will be added to the transportation cost.

Similarly, the purchasing manager mentioned that transportation cost is the cost for fuel, trucks rent as well as drivers and it includes the cost of any damages that might happen to the materials

during the transport. Moreover, it has been emphasised that the risk allocation for the prefabricated elements is allocated among the supplier, transport firm and the contractor. Usually, the supplier bears the responsibility only for producing the elements and risks for damage at the factory's yard. The transportation services will be purchased from a transportation firm to deliver the materials to the workplace and insure any damages during the transport to the construction site. After that, the responsibility will be borne by the entrepreneur or the contractor. It was assured that the contractor will pay any additional costs for any delays related to the contractor decision during the transportation time.
The sales manager also said that the transportation costs depend on distance, not time, and it can be estimated for 10 percent of the total logistics cost. Time and Accuracy are very important aspects to build trust with customers, therefore the delivery time should be scheduled precisely, and alternative plans should be prepared in case of any delays during transportation.

Moreover, according to the purchasing manager, the relationship between production and transportation processes is a critical point to predict what can be dealt with at site in a later stage.
On other hand, it has been stated that the cost varies greatly depending on the location of storage warehouses and construction. In some cases, specific prefabricated elements are imported from overseas and that results in an increase in the transportation cost.

3.3 Delivery process

The purchasing manager stated that there is a specified delivery time when the contractor needs the elements. Additionally, the crane needs to be booked, which could be challenging to get trucks at that time. The crane has been described as the bottleneck of the unloading process. There is always a long discussion with suppliers about what kind and how many elements can be produced and ensure that they can be delivered on time. Delays could occur for hours sometimes, but usually there is no additional cost for that. Additionally, if cancelling or shifting times have no significant impact on the construction site even if the contractor rescheduled the delivery in a good time there is no need to pay additional cost as well. Nevertheless, receiving wrong deliveries or damaged elements caused by the supplier could lead to additional costs to the suppliers.
Most of the problems usually occur due to the weather conditions, staff shortages at site and these issues should be taken into consideration in the calculations. The site location is the most important part of carrying out the planned activities in a timely manner. For construction companies, the lead time is critical to follow and indicates how efficient the construction companies are.
On the other hand, the sales manager emphasised that efficient labour productivity could lead to a reduction in time and cost and keeping a high-quality level. It has been stated that the delivery process should be traced and done properly where the elements should be lifted immediately from the transporting vehicles to its pre-designed locations by using the fixed or mobile crane, then installing it without making any modifications to the element. In other words, lifting the element more than once could lead to overusing the crane and that means extra time and cost. The most difficult and dangerous stage is the stage of connecting the prefabricated elements with the prebuilt foundation, where there is a risk of mismatching between the prefabricated elements and the prebuilt foundation.
Moreover, the area manager declared that remarkable cost can stem from delays in delivery such as not getting the material in the right place or time. It has been added that disruptions that can be confronted during the execution of a project can result in waste of time and additional costs. The main focus is delivery on time, where the area manager stated a sentence

that summarizes the importance of time “We count days not money”. The biggest part of the cost takes place in the last fifteen to seventeen months of the project. Moreover, Efficiency can be reached by planning in advance and acting quickly in order to mitigate the consequences of unforeseen events. Furthermore, it has been stated that choosing the right partners such as suppliers and subcontractors are very important to optimise the logistical plan in terms of delivery time. It has been concluded by the area manager that building good relationships to create trust and obtain quality should be the main objective for any construction company.

4 Result

In chapter 2.3, it has been shown how the conceptual framework can be applied for this case study. Two different logistical plans have been considered in this master’s thesis in order to determine the activities’ costs and show which activities have a critical impact on the cost of construction logistics. In the following subchapters, results for both plans have been presented.

4.1 First logistical Plan

This logistical plan lasted for 52 weeks, and it has the main phases of the logistics chain, as mentioned before. The accuracy and delivery time analysis results show that the logistical activities of stocking at supplier’s yard and transportation phases repeatedly occurred among the process time period. These phases started in week 10 and finished in week 28 (Figure 6, Figure 7). Thence, these phases started again in week 29 and finished in week 47. While, stocking at site phase started in week 17 and finished in week 52 (Figure 8). Moreover, the same activities took place between week 10 to week 28 and week 29 to week 47. Therefore, it has been suggested in this estimated case to present the stocking at supplier’s yard and transportation phases only from week 10 to week 28 (Figure 6, Figure 7), where the project was intended to be finished in week 50, but due to delays issues at the delivery activities, it was finished in week 52.

The phase of stocking at the supplier's yard lasted for 28 weeks in total (Figure 8). During those weeks, several activities occurred such as production, montage, stocking and inspection. The phase of transportation lasted in total for 30 weeks. During these weeks, the activities of trucks arrive, upload trucks, arrive at site, unload trucks and trucks return occurred and considered in the delivery time analysis (Figure 7).

The duration of stocking at site lasted for 36 weeks. During these weeks, storage and installation are the main activities where the crane and its capacity have a significant role to determine the actual time of this phase.

The procurement started in the initial phase of this logistical process and lasted for nine weeks (Figure 5). In addition, this phase included several activities, such as tendering activities.

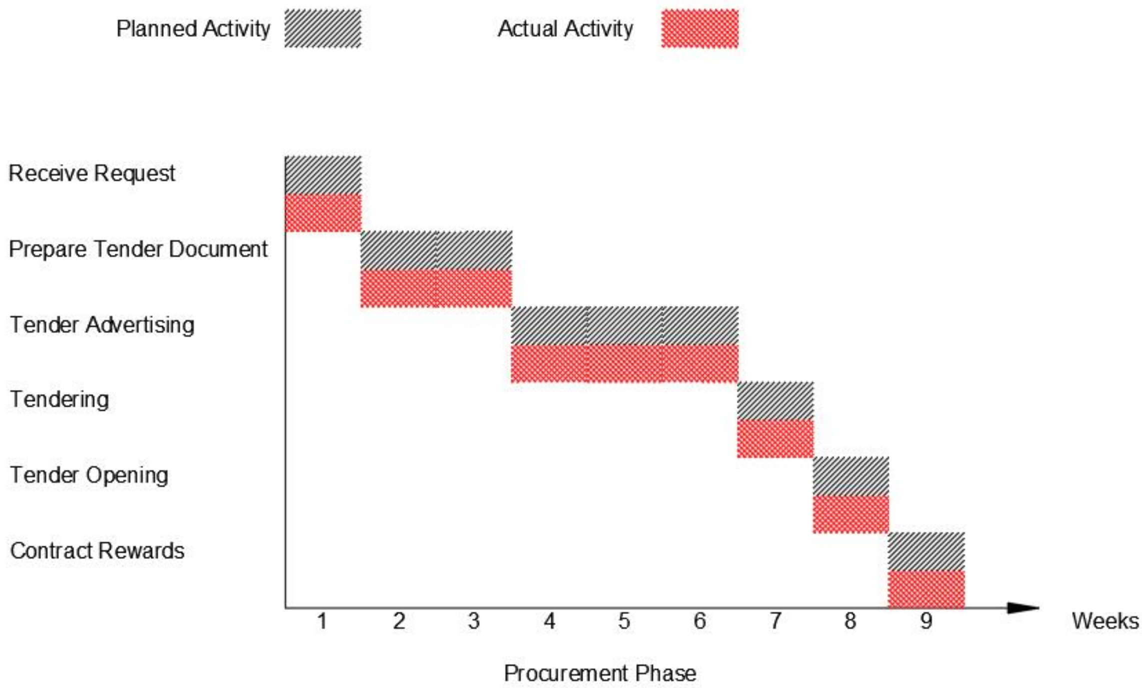

Figure 5: *Time schedule for procurement phase, (Created by authors)*

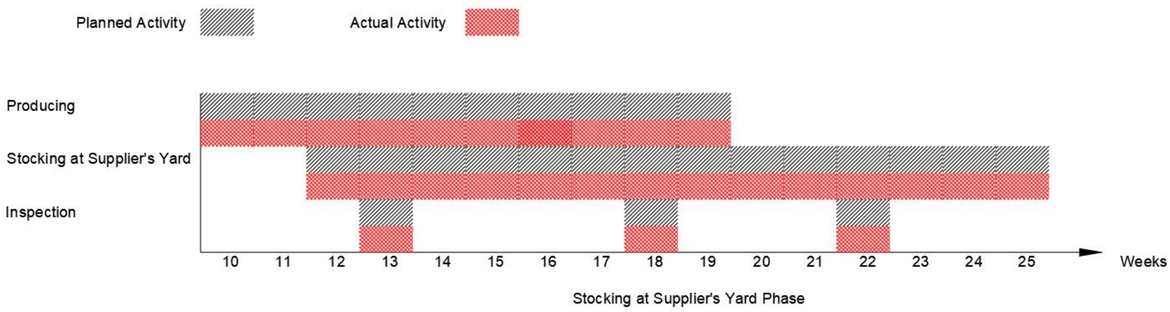

Figure 6: *Time schedule for stocking at supplier's yard phase, (Created by authors)*

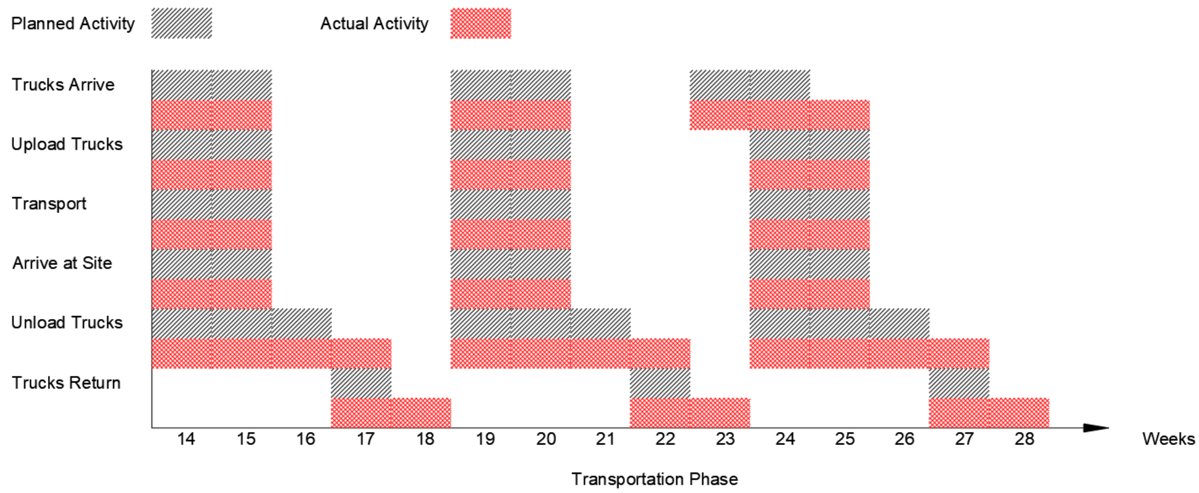

Figure 7: *Time schedule for transportation phase, (Created by authors)*

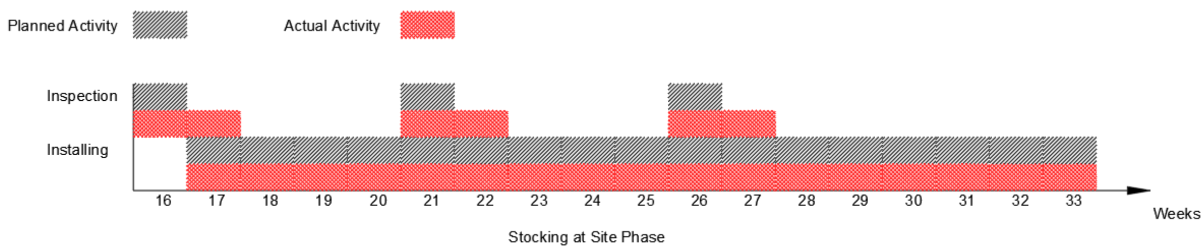

Figure 8: *Time schedule for stocking at site phase, (Created by authors)*

The activity and cost analysis show that the total logistics cost is around 20MSEK for this plan. It has been noticed from the calculation of logistics cost that the inventory cost is the critical proportion of the logistics cost. The value of the inventory cost is around 15.8MSEK, which represents 79 per cent of the total logistics cost (Figure 9). The inventory cost represents the cost of stocking at the supplier's yard. The calculations include both types of inventory cost, the fixed and variable costs. The results show that the fixed cost is 960TSEK, and the variable cost is 14.8MSEK, which represents 6 per cent and 94 per cent of the inventory cost, respectively.

ABC application shows that the transportation cost is 980TSEK which represents 5 per cent of the total logistics cost (Figure 9). For this plan, results exhibit that the transportation variable cost is much less than the fixed one, where the variable cost is 38TSEK and the fixed cost is 940 TSEK, which represents 4 per cent and 96 per cent of transportation cost, respectively.

Furthermore, the results display that stocking at site cost is 3.1 MSEK which is 15.5 per cent of the logistics cost (Figure 9). This cost also consists of fixed and variable costs. Furthermore, cost computations exhibit higher variable cost than the fixed, where the variable cost is 2.4 MSEK, and the fixed one is 765 TSEK. The percentage of the variable cost is 75.5 per cent of the stocking at site cost, whereas the percentage for the fixed cost is 24.5 per cent.

Finally, according to the ABC theory application, the results display low procurement cost, which is 200 TSEK (Figure 9). This value represents almost 1 per cent of the total logistics cost.

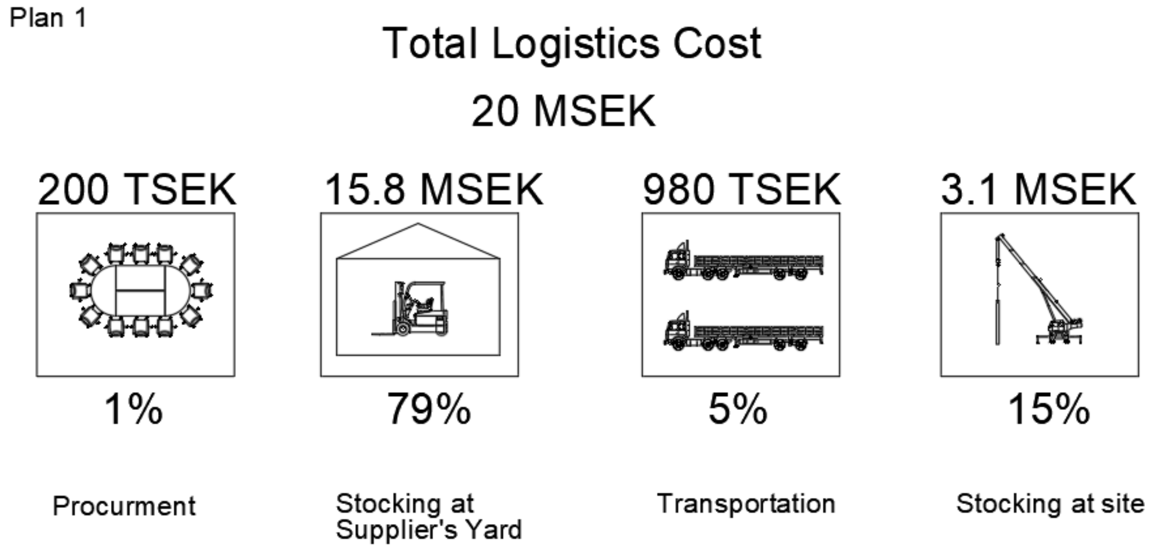

Figure 9: Logistics cost for plan 1, (Created by authors)

4.2 Second logistical plan

This logistical plan has been optimised to reduce the rate of stocking at the supplier's yard, which means decreasing the inventory. This optimisation is not the best alternative. Based on the literature research, an optimal solution can be achieved by implementing Just-In-Time and lean methods for this project. However, the intention of presenting a second logistical plan is to show how changing only the schedule of transportation could result in reducing the logistics cost.

In this plan, it has been considered that the transportation activities start four weeks after the production begins, and the transportation continues regularly until transferring all the prefabricated elements from supplier's yard to the construction site. In other words, this plan tries to transport all the elements to the site and keep the rate of stocking at the supplier's yard at the lowest rate while keeping the transportation rate at the same level. This operational change does not include the scheduled time of procurement, stocking at supplier's yard and stocking at site phase.

The results of applying the ABC theory on this logistical plan display that the total logistics cost lowered to 11.1MSEK, which means there is a reduction of 44.5 per cent in comparison to the first logistical plan (Figure 10). Furthermore, a remarkable reduction occurred in the inventory cost, where it is reduced from 15.8MSEK to 6.6MSEK. It is important to note that the fixed part of the inventory cost remains as it is in the first logistical plan, whereas the change occurred in the variable cost.

Moreover, a slight increase in the transportation cost has been observed due to adding more deliveries to the second logistical plan (Figure 10).

Another slight rise has been detected in the stocking at site cost (Figure 10). The presence of this rise is logical since trying to keep the stocking at the supplier's yard at the lowest rate could result in increasing the stocking at site cost. It is beneficial to mention that this increase occurred only in the variable cost of the stocking at site cost.

Ultimately, the procurement cost did not change since there were no changes in the logistical plan for the procurement phase (Figure 10).

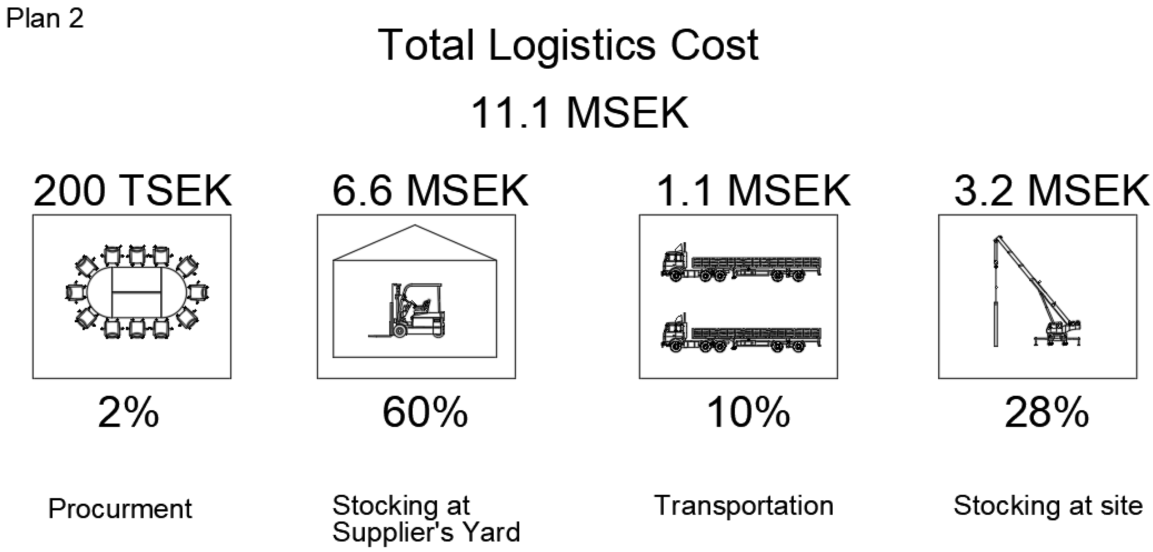

Figure 10: Logistics cost for plan 2, (Created by authors)

5 Discussion and analysis

In purpose of investigating the application of the suggested conceptual framework, discussion and analysis have been performed. The intention of providing this chapter is to understand the behaviour of the critical activities that have a great effect on the logistics performance. Moreover, the results of applying the framework are also analysed and discussed paralleled with the collected data. Furthermore, this chapter also shows how the collected data can contribute to an improvement of the logistics process performance.

5.1 Challenges of logistics activities

In this subchapter, the challenges of planning, transportation and delivery activities will be analysed and discussed since these activities are major aspects of logistics performance efficiency.
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5.1.1 Challenges of planning and design activities

(Paez, et al., 2005) stated that the construction industry is unlike the manufacturing industry, as it carries out unique projects without a fixed and uniform task order. Therefore, operations are enabled to be standardised, and there is a need for more efforts to achieve an accurate plan. This fact has been illustrated by the logistical manager that the weakness in planning phase stems from miscommunication. Many actors such as contractors, subcontractors often attempt to implement their own plans. Therefore, this issue should be raised in order to avoid delays and longer lead times that occur in most of the construction projects, rather than creating problems and mayhem during the construction process.
Moreover, (Owolabi, et al., 2014) stated that delays are the most encountered issue due to the imprecise work schedule and planning on a daily basis. This was supported by the sales manager as it has been declared that the lack of knowledge of the entire process activities by scheduling the work activities where each discipline focuses on their own task with limited skills to handle challenges related to other departments.
The head sales manager declared that inaccurate planning could lead to an overproduction where the needed materials are overestimated. Consequently, this could indicate an inefficient planned strategy and inaccurate process in these construction firms and also affect the total logistics cost.

Design is one of the challenging phases. The purchasing manager declared that the design phase is considered as the most complicated phase where the activities that occur are difficult to be organised. It has been added that the coordination between the different disciplines is not that easy to handle and ensure the working integrity, where many actors from the construction company and the supplier's sides are involved in this process. (Van Casteren, 2015) highlighted this issue about miscommunication between the disciplines that could lead to miscalculation and wrong design. Additionally, regarding the prefabricated elements process, the sales manager clarified the necessity of obtaining all the detailed information about the designs. These details shall be described in advance. For instance, the electrical, plumbing and structural engineers should clarify the number of electrical boxes, ventilation pipes in each prefabricated element and the precise amount of the needed elements for each project. In agreement with what mentioned above, (Englekirk, 2003) stated that changing the design or editing it in later stages of the process could cause remarkable delays in time and increase in cost to make new designs. In addition, (Van Casteren, 2015) declared that producing elements with the same design is very efficient, but some certain designs are difficult to duplicate or repeat according to its unique form which consumes more time and resources. The sales manager confirmed this statement by describing how the uniqueness is considered as an obstacle in front of achieving time efficiency.

On the other hand, (Van Casteren, 2015) declared that Connections and joints are important factors for transferring forces between the prefabricated elements in order to avoid any kind of collapses in critical situations and ensure the interaction and complementarity of the structure. This issue was raised by both the purchasing manager, and sales manager as the connections should be designed to make the necessary matching between the foundation slabs and the prefabricated elements to give stability and also avoid any significant delays in terms of the need for new designs.

These observations show the importance of the planning process and how the design phase influences the performance of the whole process. These issues can be applied not only for the concrete process but although for similar material processes. It indicates that cooperation between the different disciplines such as the architects, consultants, structural engineers and many others has a significant effect on performance and can be developed by always working as an integrated team to fulfil the customers required design.

5.1.2 Challenges of transportation and delivery activities

According to the sales manager, transport and delivery are major activities in the logistics process, and these activities should occur with high accuracy to avoid any critical delays during the process. This statement has been emphasised by (Van Casteren, 2015) that the prefabricated elements arrival process should be executed in a correct time and with no damages. Another point can be mentioned is the sales manager declared that the transportation of prefabricated elements process firstly depends on the distance between the supplier warehouse and the site location, but it usually takes up to two hours more to unload the elements.

Another type of projects has been mentioned by the purchasing manager, where it has been stated that the main intention that should be considered during the transporting of cast-in-place concrete is the mixing process. This process shall guarantee that the cement and aggregates are well mixed, and the concrete is not hardened. According to the sales manager, the transportation of ready-mixed concrete is usually by a rider truck while the trailer trucks are used to transport the prefabricated elements and could carry about three times of the ready-mixed vehicles. The area manager added that sometimes when ready-mixed is used, the transportation rate is higher where there is often a need for daily transport.

Moreover, the head sales manager has demonstrated that the prefabricated concrete elements are exposed to many movements during the transportation process as it is considered as a risky process for damages. Therefore, the company responsible for transportation or drivers must be well skilled and they should be careful to not take longer time to arrive at the site.

Head sales manager declared that there might be obstacles and delays like accidents, traffic, or truck Problems, and these should be calculated when doing the calculation for delivery time.

On the other hand, the crane is a key factor in the delivery process, where the capacity of the crane and the vehicle size are critical factors to determine the frequency of transport and delivery. Additionally, the sales manager described it as a “bottleneck” for delivery and transportation at the site.

According to (Pheng & Chuan, 2001), the installation of prefabricated elements should be carried out immediately when they are delivered to the site from the carrier vehicles in order to reduce the risk of damage during storage. Furthermore, the regional purchasing manager emphasised the importance of transport and delivery time and stated that the measurement of performance has three indications the first one is the cost of the process, the second is the time of the process and lastly is the delivery for the service or the project. Similarly, all of these indicators have been mentioned in the literature study which can contribute to developing a measurement for the logistics performance in the construction industry in Sweden.

It has been perceived that the transportation and delivery time are the main components toward efficiency on the working site and to keep the cooperation at a high level between suppliers and contractors. Transportation time is a decisive factor in measuring the performance of the logistics process. It should be carefully planned in coordination with all actors involved in the transportation process to prevent any risks for delays.

5.2 Performance of logistics activities

This subchapter is intended to analyse and discuss the results of the conceptual framework application.

5.2.1 Inventory cost

Regarding the prefabricated concrete projects, the inventory cost can be defined briefly as the cost of handling, administering and maintaining the supplier's yard during the stocking phase (Waters, 2003). It has been mentioned in the literature study that the inventory cost is composed of two costs (Fang & Ng, 2011). One of them is fixed, whereas the other is a variable cost. The Fixed cost represents the cost of labour salaries and renting equipment. On the other hand, the variable cost represents the opportunity, depreciation as well as inspectors' costs. It is beneficial to mention that the variable cost is dependent on the number of stocked elements per week and it can be lowered by optimising the logistical plan, whereas the fixed cost is dependent on the total number of produced elements. As results of two logistical plans show, between 60 per cent to 79 per cent of the total logistics cost is the cost of inventory. The variable cost represents between 85 per cent to 90 per cent of the inventory cost. Whereas the fixed cost represents the residual cost.
The percentage of the inventory cost is very dependent on the logistical plan and how the implementation of the logistical plan can keep the number of stocked elements at the lowest rate. In other words, keeping the supplier's yard at the lowest rate of stocking could result in lowering the inventory cost, hence, improving the logistics performance.

Contrarily, the sales manager declared the opposite, where it has been mentioned during the interview that the manger's company has an advantage of keeping the stocking rate higher than the production rate, which means that the inventory cost does always exist. Additionally, during the interview, it has been pointed out that the cost of keeping elements at the factory's yard is not calculated since it is negligible. This contradiction could be attributed to several reasons. One of these reasons is that the mentioned stocking rate at the factory's yard is not high, and the stocking time is not long. Low stocking rate and short stocking time could lead to a negligible inventory cost, but that does not gainsay that there is no elements stocking process. Another reason could be the inclusivity of inventory cost, which means that calculating the inventory cost needs to consider several costs such as depreciation cost as well as opportunity cost and some of these costs could be missing in the calculation. However, it has been mentioned by the sales manager that the manager's company tries to follow Just-In-Time theory in producing prefabricated elements, which could confirm that stocking rate is low, and the stocking time is short at this company.

Moreover, the purchasing manager stated that this contractor has an agreement with a supplier, which means that all projects have been done with the same supplier. The regional purchasing manager stated that the Just-In-Time method is implemented in their projects. That displays a high collaboration between times results in lowering the inventory cost, minimising the stocking rate at the supplier's rate and improving the logistics performance.

5.2.2 Transportation cost

As many logistical costs, the transportation cost is composed of fixed cost as well as a variable cost. The fixed cost is dependent on pay rate, rental rate, depreciation rate, distance, as well as the total quantity (Yu & Yanlin, 2016). Whereas, the variable cost is dependent on the pay rate for inspectors, delivery times and delays (Burns, et al., 1985). The results of the transportation cost between two logistical plans show that there is a slight change between the transportation costs. That can be attributed to the fact that there is no major change in the transportation schedule, but the change was more applied to the distribution of the delivery times to be more intensive. Optimising the transportation schedule could play a significant role in lowering the logistics price.

According to the sales manager, it has been emphasised that distance is one factor that the transportation cost is dependent on. Moreover, it has been stated that the cost of transportation is on the supplier or it can be as a cost for the transportation company. Additionally, it has been mentioned that the manufacturing company prefers to deliver all elements after production, which put more responsibility on the contractor to decide whether the supplier should start producing or not.

Both regional purchasing manager and the logistics manager confirmed that the distance is the main role in determining the transportation cost. Furthermore, it has been stated that the transportation cost could be 10 per cent of the logistics cost, which validates the calculation of transportation cost for the optimised logistical plan (Second logistical plan). Moreover, the interviewee talked about the probability of delays and mentioned that this probability could be lowered by building trust between the supplier and the contractor. However, according to this interviewee, the costs of damages are covered by insurance.

5.2.3 Stocking at site cost

Several studies (Lambert, et al., 1998), (Ferguson, 2000) considered that the logistics chain finishes when the elements could arrive at the construction site, whereas in reality the logistics chain cannot be considered as finished. (Fang & Ng, 2011) emphasised that the stocking at the site is part of the logistics chain, and the cost shall be included in the logistics cost. Hence, the stocking at the site can be defined briefly as the cost of handling, administrating and fixing the material at the construction site.

The calculation of stocking at site cost exhibits that it can vary between a logistical plan and another, where it increased from 15 to 28 per cent due to increasing the transportation and making it more continuous. This cost is directly dependent on the delivery times and indirectly on the stocking rate at the supplier's yard. In other words, producing too many elements could lead to stocking more elements in the construction site, which results in increasing the stocking at site cost. Additionally, several factors can control the stocking at site cost such as pay rate, renal rate, depreciation rate, opportunity rate as well as the number of stocked elements.

Furthermore, stocking at the site process includes even minor activities that are rarely taken into consideration as the purchasing manager stated. In other words, the cost of these activities could be missing in the calculation of stocking at site cost. All in all, it can be understood that the transportation and stocking at site phases are interacted since as aforementioned, there are mutual activities among both phases.

5.2.4 Procurement cost

The procurement cost can be defined simply as the costs of the process of making decisions regarding choosing the appropriate suppliers. This cost can include the process of determining different suppliers, preparing and suggesting quotations as well as the process of negotiation the contractual forms and conditions with the supplier (Zeng & Rossetti, 2003). However, the procurement cost is not simple to be determined since the variety of materials between project to project can impact the methods of calculating the procurement cost.
(Fang & Ng, 2011) suggested a method of calculating the procurement cost in the prefabricated concrete projects, which could be the most relevant to the purpose of this work.
The suggested method is dependent on pay rate, depreciation rate, number of hours as well as travel costs. This method considers the procurement cost as a percentage of the contract price. The application of ABC theory on two logistical plans exhibits that the procurement cost varied between 1 to 2 per cent, where this could be between 2.5 to 5 per cent the manufacturing industry (Heinrich & Jüngst, 1991). This variation in the results is not because of changing the logistical plan, but it is more attributed to the fact that the logistics cost has been reduced.
The quality of the procurement process could play a significant role in reducing or increasing transportation cost. For instance, the logistics manager declared that some elements have the probability of being damaged or have a failure during transportation due to the bad geometry of the elements. These geometric problems can be solved by increasing the corporation between the supplier and the contractor. This cooperation could reinforce the decision to choose the appropriate suppliers. This could imply a reduction in the procurement cost. Moreover, the purchasing manager stated strongly that the procurement cost is almost negligible since the company has an agreement with a specific supplier. This kind of agreement can be considered as an advantage in reducing the procurement cost and subsequently the logistics cost.

5.3 Optimisation of logistics performance

In this subchapter, some practices for optimising the logistics performance are discussed and analysed.

Several practices can be indeed utilised to improve logistics performance. Optimal performance streams from an efficient planning strategy and the accuracy of implementing these plans. The sales manager supported this statement and added that there are several errors still come about in the construction industry and need to be eliminated to reach the desired performance.

Regarding the efficiency of the prefabricated concrete flow process, (Van Casteren, 2015) stated that enhancing the efficiency could be achieved by implementing effective control and providing the logistical plan with the flexibility to change the design in later phases in order to meet the required conditions. Furthermore, for cast-in-place concrete flow process, the estimated quantity is the dominant factor for an accurate execution and optimal performance.

It has been declared by the purchasing manager that delays at site during wrong estimations and planning are common issues related to these aspects. In order to compare the lead time of these processes, (Chenet.al, 2010) mentioned that by using the prefabricated concrete elements, the lead time would be longer because the period to do the designs and plans is longer than cast-in-place concrete. Additionally, it has been developed by the sales manager that the design phase is longer for prefabricated elements, but considering the entire project lead time, then it is going to be shorter. On the other hand, there are several methods to reduce the activities lead time and cost to the suppliers with adding value to the customers such as Just-In-Time and lean construction method. (Enshassi, 1996) stated that purchasing some materials directly upon request may lead to interruptions and delays in the work schedule. In contrast, (Tommelein, 1998) mentioned that Just-In-Time production method tends to ameliorate the delivery and transportation activities where materials will be delivered to their places and installed immediately upon arrival without delays due to a laydown processing or storage area. This statement has been emphasised by the purchasing manager that using Just-In-Time production method can eliminate the overproduction and make a balance between the supplier and the contractor. Moreover, During the interview with the sales manager, it has been clarified that the production of prefabricated concrete elements in Sweden mostly based on Just-In-Time method to remain the efficiency of the activities lead time, and to eliminate the inventory cost for the supplier and stocking at site cost for the contractor.

Regarding the lean construction project (Koskela, et al., 2002) stated that it is difficult to achieve a completely lean process to reduce the lead time because it would need a specific product without waste or storage in zero time. This has been supported by the logistics manager and declared that lean method in the construction industry is of limited reach and does not spread widely among construction companies as the company that follows this method will limit their options and material choices. In lean construction projects, prefabricated concrete elements are often used as it will affect the lead time of the entire project. Additionally, it was clarified by the area manager that following the planned activities' lead time strictly would result in less disruption, waste of time and additional costs as it was clearly stated: ”We count days not money”.

Moreover, it has been recognised that using Just-In-Time method would boost the efficiency and optimise the lead time of the included activities in the process. This implies that Just-In-Time method would improve the logistics performance and minimise the time waste. Moreover, it has been cleared that applying lean projects would improve the logistics performance by co-creating value to the entire process.

Finally, these observations pointed out the significance of activities' lead time to achieve optimal logistics performance.

6 Conclusion

The main intention of carrying out this work was to provide a conceptual framework for measuring the logistics performance as well as presenting some practices that could lead to achieving high logistical performance. Therefore, part of the literature study has been directed towards exploring the measured variables for the suggested framework. The literature study revealed that cost and time as measures could provide to an extent a clear picture of the logistics performance.

This framework is composed of two analyses; accuracy and time analysis as well as activity and cost analysis.

In order to be able to conduct these analyses, the interviews carried out as basis for two intentions. The first intention is to understand the behaviour of activities that impact the logistics performance. Whereas, the second intention is to build a foundation for the estimated case.

One conclusion from these interviews could be that the inventory cost is negligible in the Swedish construction industry. This observation could be ascribed to whether there is a lack of knowledge about the cost in the industry or the applied logistical practices are very efficient to the degree where the inventory cost is eliminated. However, this study showed that achieving a logistical plan with high performance demands very high cooperation between the project managers and costs divisions.

Considering the complexity of the logistical plans, the authors found from the interviews and the literature study that the planning process in the construction industry is a complex process and difficult to develop since it depends on several aspects. Additionally, it has been observed that the development of the logistical process is based on the integrity of all activities.

During the collecting data process, it was expected that the construction industry has a bit of ability to standardize the material, but the interviews emphasised strongly that the standardization is hard to achieve in the construction industry since each project is a unique project. Furthermore, it has been stated in the interviews that the transportation process of prefabricated concrete elements is a critical process, and it should be taken into consideration carefully.

The last conclusion that springs from the interviews is that in terms of cost and time applying the current philosophies such as Just-In-Time and Lean can lead to eliminating the stocking cost as well as decreasing the lead time; hence, improving the logistics performance.

Thenceforward, the proposed framework has been applied to the estimated case that has been generated based on finding from the collected data. The outcome of this application showed that performing accuracy and time analysis needs to gather documented data of the delivery times and then present the time schedule of the activities graphically. Furthermore, the literature study showed that in order to perform an activity and cost analysis, it is an essential step to accurately identify the activities that the logistics chain includes. Thence, ABC theory shall be followed to calculate the costs of the identified activities. The literature study displayed that the ABC theory could be a suitable tool to calculate the costs of activities.

For the purpose of showing to what extent the aforementioned analyses can be simple and applicable, an estimated case of prefabricated concrete project has been generated.

The results of this estimated case showed that the inventory and stocking at site costs represent most of the logistics cost, whereas the procurement cost is the least. Hence, it can be concluded that lowering the most critical costs is an intention to enhance the performance of any construction logistics chain.

Furthermore, in order to show to what extent this framework can provide improvements to the logistical plan, an optimised estimated case has also been generated. From the results of this optimised case, it has been observed that small changes in the transportation schedule could result in reducing the stocking at supplier's yard rate. Hence, a significant reduction in logistics cost. In addition, the worst scenario according to our results, is that stocking prefabricated elements in the supplier's yard for a long time could lead to a significant increase in the stocking cost. Whereas stocking the whole number of elements at the construction site is not an optimal solution but still have less impact on the logistics cost. However, a successful accuracy and time analysis could assist the project manager to achieve the optimal logistical plan by detecting the delays in the activities as well as the costly activities.

Another part of this study was performing qualitative interviews to get a better understanding of the logistics performance in the construction industry.

7 Future Suggestions

In this master's thesis, the application of the presented conceptual framework was limited to be applied on prefabricated concrete projects. It would be valuable to apply this framework on projects of cast-in-place concrete and investigate how the performance measurement could differ by adapting a specific project data instead of estimated data. The necessity for optimisation requires a development of this framework to make it applicable for other materials flow processes.

Furthermore, the concrete flow process is one of most important processes as concrete is the most used material in the construction industry. It will be interesting to expand this framework by covering more complicated transportation routes, with greater projects to inspire the enterprises how measuring the performance and improving it would lead toward greater efficiency and effectiveness on a daily basis work.

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Appendix A

Assumed Data

Cost of prefabricated element per type (SEK):

$C_{element.1} := 19620$ (Cost of elements type1)

$C_{element.2} := 24525$ (Cost of elements type1)

$C_{element.3} := 29430$ (Cost of elements type1)

Total quantity:

$Q_{element.1} := 200$ (Quantity of elements

$Q_{element.2} := 170$ (Quantity of elements

$Q_{element.3} := 50$ (Quantity of elements

$$Q := Q_{element.1} + Q_{element.2} + Q_{element.3} = 420$$

Opportunity cost rate:

$R_{opportunity.S} := 10\%$ For stocking at supplier's yard

$R_{opportunity.C} := 20\%$ For stocking at construction site

Depreciation rate:

$R_{depreciation.S} := 19\%$ For stocking at supplier's yard

$R_{depreciation.C} := 1\%$ For stocking at construction site

$R_{depreciation.T} := 9.5\%$ For transportation

$R_{depreciation.P} := 7\%$ For procurement

Pay rate:

$R_{pay.I} := 5\%$ For inspection at supplier's yard

$R_{pay.T.1} := 400$ (SEK per 100km)

$R_{pay.T.2} := 600$ (SEK per Delivery)

$R_{pay.HS} := 3\%$ For handling at supplier's yard

$R_{pay.HC} := 2\%$ For handling at construction yard

$R_{pay.P} := 400$ (SEK Per Hour) For procurement work

Rental rate:

$R_{rent} := 5\%$

$R_{rent.T} := 300$ (SEK per 100km)

Travel cost rate:

$R_{travel} := 2\%$

Price of contract (SEK):

$C_{contract} := 715000$

Production rate:

$\#days := 5$ Number of working days Per week

$WP := 20$ Weeks of production

$R_p := \frac{Q}{WP \cdot \#days} = 4.2$ Elements per day for 20 weeks

Transportation rate:

$WT := 12$ Weeks of transportation

$R_T := \frac{Q}{WT \cdot \#days} = 7$ Elements per day for 12 weeks

$Delivery_w := 2$ Deliveries per week

Application of ABC:

Inventory cost (SEK):

Fixed cost:

Total quantity of stocked elements per week:

$$Q_{S.12} := 3 \cdot R_p \cdot \#days = 63$$

$$Q_{S.13} := Q_{S.12} + \left(R_p \cdot \#days\right)$$

$$Q_{S.14} := \left\| \begin{array}{l} \text{if } Q_{S.13} + \left(R_p \cdot \#days\right) - \left(R_T \cdot \#days\right) \geq 0 \\ \quad \left\| Q_{S.13} + \left(R_p \cdot \#days\right) - \left(R_T \cdot \#days\right) \right. \\ \text{else} \\ \quad \left\| 0 \right. \end{array} \right| = 70$$

$$Q_{S.15} := \left\| \begin{array}{l} \text{if } Q_{S.14} + \left(R_p \cdot \#days\right) - \left(R_T \cdot \#days\right) \geq 0 \\ \quad \left\| Q_{S.14} + \left(R_p \cdot \#days\right) - \left(R_T \cdot \#days\right) \right. \\ \text{else} \\ \quad \left\| 0 \right. \end{array} \right| = 56$$

$$Q_{S.16} := Q_{S.15} + R_p \cdot \#days = 77$$

$$Q_{S.17} := Q_{S.16} + R_p \cdot \#days = 98$$

$$Q_{S.18} := Q_{S.17} + R_p \cdot \#days = 119$$

$$Q_{S.19} := \begin{Vmatrix} \text{if } Q_{S.18} + R_p \cdot \#days - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.18} + R_p \cdot \#days - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{Vmatrix} = 105$$

$$Q_{S.20} := \begin{Vmatrix} \text{if } Q_{S.19} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.19} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{Vmatrix} = 70$$

$$Q_{S.21} := Q_{S.20} = 70$$

$$Q_{S.22} := Q_{S.21} = 70$$

$$Q_{S.23} := Q_{S.22} = 70$$

$$Q_{S.24} := \begin{Vmatrix} \text{if } Q_{S.23} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.23} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{Vmatrix} = 35$$

$$Q_{S.25} := \begin{Vmatrix} \text{if } Q_{S.24} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.24} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{Vmatrix} = 0$$

$$Q_{S.26} := Q_{S.25} = 0$$

$$Q_{S.27} := Q_{S.26} = 0$$

$$Q_{S.28} := Q_{S.27} = 0$$

$$Q_{S.29} := Q_{S.28} + R_p \cdot \#days = 21$$

$$Q_{S.30} := Q_{S.29} + R_p \cdot \#days = 42$$

$$Q_{S.31} := Q_{S.30} + R_p \cdot \#days = 63$$

$$Q_{S.32} := Q_{S.31} + R_p \cdot \#days = 84$$

$$Q_{S.33} := \left\| \begin{array}{l} \text{if } Q_{S.32} + R_p \cdot \#days - \left(R_T \cdot \#days\right) \geq 0 \\ \quad \left\| Q_{S.32} + R_p \cdot \#days - \left(R_T \cdot \#days\right) \right. \\ \text{else} \\ \quad \left\| 0 \right. \end{array} \right\| = 70$$

$$Q_{S.34} := \left\| \begin{array}{l} \text{if } Q_{S.33} + R_p \cdot \#days - \left(R_T \cdot \#days\right) \geq 0 \\ \quad \left\| Q_{S.33} + R_p \cdot \#days - \left(R_T \cdot \#days\right) \right. \\ \text{else} \\ \quad \left\| 0 \right. \end{array} \right\| = 56$$

$$Q_{S.35} := Q_{S.34} + R_p \cdot \#days = 77$$

$$Q_{S.36} := Q_{S.35} + R_p \cdot \#days = 98$$

$$Q_{S.37} := Q_{S.36} + R_p \cdot \#days = 119$$

$$Q_{S.38} := \left\| \begin{array}{l} \text{if } Q_{S.37} + R_p \cdot \#days - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.37} + R_p \cdot \#days - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{array} \right| = 105$$

$$Q_{S.39} := \left\| \begin{array}{l} \text{if } Q_{S.38} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.38} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{array} \right| = 70$$

$$Q_{S.40} := Q_{S.39} = 70$$

$$Q_{S.41} := Q_{S.40} = 70$$

$$Q_{S.42} := Q_{S.41} = 70$$

$$Q_{S.43} := \left\| \begin{array}{l} \text{if } Q_{S.42} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.42} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{array} \right| = 35$$

$$Q_{S.44} := \left\| \begin{array}{l} \text{if } Q_{S.43} - (R_T \cdot \#days) \geq 0 \\ \quad \| Q_{S.43} - (R_T \cdot \#days) \\ \text{else} \\ \quad \| 0 \end{array} \right| = 0$$

It has been assume that stocked elements are divided as 50% elements type 1, 35% elements type 2 and 15% elements type 3.

$$T_{delivery} := WT \cdot Delivery_w = 24$$

$$FC_I := \left(R_{pay.I} + R_{rent}\right) \cdot \left(C_{element.1} \cdot Q_{element.1} + C_{element.2} \cdot Q_{element.2} + C_{element.3} \cdot Q_{element.3}\right)$$

$$FC_I = 9.565 \cdot 10^5$$

Variable cost:

$$i := \begin{bmatrix} 12 \\ 13 \\ 14 \\ \vdots \end{bmatrix} \qquad Q_{S.} := \begin{bmatrix} Q_{S.12} \\ Q_{S.13} \\ Q_{S.14} \\ Q_{S.15} \\ \vdots \end{bmatrix}$$

$$VC_I := \left(R_{depreciation.S} + R_{pay.HS} + R_{opportunity.S}\right) \cdot \left(\sum Q_{S.}\right) \cdot \left(C_{element.1} \cdot 0.5 + C_{element.2} \cdot 0.35 + C_{element.3} \cdot 0.15\right)$$

$$VC_I = 1.487 \cdot 10^7$$

$$CI := FC_I + VC_I = 1.582 \cdot 10^7$$

$$Inventory.Variable.Cost.Percentage := \frac{VC_I}{CI} \cdot 100 = 93.955$$

$$Inventory.Fixed.Cost.Percentage := \frac{FC_I}{CI} \cdot 100 = 6.045$$

Transportation cost (SEK):

$D := 4800$ (km)

Fixed cost:

$$FC_T := \left(\left(R_{pay.T.1} + R_{rent.T} \right) \cdot \frac{D}{100} + R_{depreciation.T} \cdot \left(C_{element.1} \cdot Q_{element.1} + C_{element.2} \cdot Q_{element.2} + C_{element.3} \cdot Q_{element.3} \right) \right)$$

$$FC_T = 9.423 \cdot 10^5$$

Variable cost:

It has been assumed that there is 5% probability of delay .

$R_{penalty} := 20000$ (SEK per Week)

$$P_{delay} := 5\%$$

$$T_{delivery} := WT \cdot Delivery_w = 24$$

$$VC_T := R_{pay.T.2} \cdot T_{delivery} + R_{penalty} \cdot P_{delay} \cdot T_{delivery} = 3.84 \cdot 10^4$$

$$CT := FC_T + VC_T = 9.807 \cdot 10^5$$

$$Transportation.Variable.Cost.Percentage := \frac{VC_T}{CT} \cdot 100 = 3.916$$

$$Transportation.Fixed.Cost.Percentage := \frac{FC_T}{CT} \cdot 100 = 96.084$$

Stocking at site cost (SEK):

Fixed cost:

$$FC_S := \left(R_{pay.HC} + R_{rent} + R_{depreciation.C}\right) \cdot \left(C_{element.1} \cdot Q_{element.1} + C_{element.2} \cdot Q_{element.2} + C_{element.3} \cdot Q_{element.3}\right)$$

$$FC_S = 7.652 \cdot 10^5$$

Variable cost:

$\#W14 := 29$ Number of weeks of having 14 elements as stocked elements att site

$\#W2 := 7$ Number of weeks of having 2 elements as stocked elements att site

It has been assumed that when there are 14 elements stocked, the percentage of types is: 50% elements type 1, 35% elements type 2 and 15% elements type 3.
Whereas, when there are 2 elements stocked, the elements type is 3.

$$VC_S := \left(R_{depreciation.C} + R_{opportunity.C}\right) \cdot \left(C_{element.1} \cdot 0.5 + C_{element.2} \cdot 0.35 + C_{element.3} \cdot 0.15\right) \cdot \left(\#W14 \cdot 14\right) + C_{element.3} \cdot \left(\#W2 \cdot 2\right)$$

$$VC_S = 2.357 \cdot 10^6$$

$$CS := FC_S + VC_S = 3.122 \cdot 10^6$$

$$Stocking.Site.Variable.Cost.Percentage := \frac{VC_S}{CS} \cdot 100 = 75.489$$

$$Stocking.Site.Fixed.Cost.Percentage := \frac{FC_S}{CS} \cdot 100 = 24.511$$

Procurement cost (SEK):

$T_{work} := 360$ (Hours)

$$CP := R_{pay.P} \cdot T_{work} + R_{depreciation.P} \cdot C_{contract} + R_{travel} \cdot C_{contract}$$

$$CP = 2.084 \cdot 10$$

Total fixed cost (SEK):

$$FC := FC_I + FC_T + FC_S = 2.664 \cdot 10^6$$

Total variable costs (SEK):

$$VC := VC_I + VC_T + VC_S = 1.726 \cdot 10^7$$

Total cost (SEK):

$$C := CP + CT + CS + CI = 2.013 \cdot$$

$$Inventory.Cost.Percentage := \frac{CI}{C} \cdot 100 = 78.59$$

$$Transportation.Cost.Percentage := \frac{CT}{C} \cdot 100 = 4.87$$

$$Site.Stocking.Cost.Percentage := \frac{CS}{C} \cdot 100 = 15.505$$

$$Procurment.Cost.Percentage := \frac{CP}{C} \cdot 100 = 1.035$$