A Total Cost Analysis Model of Construction Logistics Solutions

Comparing Direct Delivery and Delivery via a Construction Logistics Center at JM

Master's Thesis in the Master Programme in Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

The construction industry has challenges in increasing productivity and at the same time keeping production costs down in comparison to other industries. The construction industry also entails a high environmental footprint due to choices of materials and the many materials deliveries necessary for building completion. Rearrangements of construction logistics and implementing supply chain management (SCM) provide possible solutions to these issues. As part of gaining control of the supply chain and reducing the number of deliveries to the site, Construction Logistics Centers (CLCs) are increasingly being used. The aim of this study is to develop a total cost analysis (TCA) model to evaluate two logistics processes of materials delivery to construction site: *Direct Delivery* or *Delivery via a CLC*. A reference project at the Swedish construction company JM provides data to the TCA model.

The TCA model examines costs in relation to logistics activities from the point of materials leaving the supplier to being placed at the assembly area at the site. The cost data in the TCA are gathered from JM's framework agreements with suppliers and the CLC-operator. The activities identified in each logistics process are gathered from observations as well as the framework agreements and information from involved parties. The study contributes with a TCA model for different logistics solutions and batch sizes where the TCA itself provides insights of how logistics operations are organized and the costs they entail.

The study shows that JM through the implementation of a CLC and the subsidiary JM Supply (responsible for on-site logistics) has taken successive steps towards more efficient SCM. The study contributes to the understanding of the effects of implementing a CLC. The results from the TCA model shows that due to the present supplier agreements and logic of batch sizes, the most cost advantageous logistics solution at JM is the direct delivery to site. However, it should be noted that costs differ significantly in relation to various material types. The TCA model also illustrates that the number of transportations to site decreases with the implementation of a CLC, which is considered a benefit. Thus, to reach the full potential of a CLC solution, JM needs to align purchasing, production, and logistics processes further by taking a holistic perspective of value creation. The research results support JM's future decision making about the design of their construction logistics solutions as to increase productivity and improve market competitiveness.

Keywords: Construction Logistics, Construction Logistics Centers, Total Cost Analysis, Construction Supply Chain Management, Lean Construction, Logistics Cost Management

En totalkostnadsanalysmodell för bygglogistiklösningar: En jämförelse mellan direktleverans och leverans via ett bygglogistikcenter hos JM

Examensarbete inom mastersprogrammet: *Organisering och ledning i bygg och fastighetssektorn*

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SAMMANFATTNING

Byggbranschen har, i jämförelse med andra branscher, inte lyckats öka produktiviteten och samtidigt hålla nere produktionskostnaderna. Byggbranschen medför även stor miljöpåverkan då byggprojekt i regel kräver mycket material som även behöver levereras till byggprojekten. Att omorganisera bygglogistiken och implementera Supply Chain Management (SCM), erbjuder möjliga lösningar på några av dessa utmaningar. Som ett led i att få kontroll över leveranskedjan och minska antalet transporter till byggarbetsplatserna så ökar användandet av bygglogistikcenter. Syftet med denna studie är att utveckla en totalkostnadsanalys-modell för att validera två olika logistikalternativ för leverans av material till byggarbetsplatserna: *Direktleverans* eller *leverans via ett Bygglogistikcenter*. Ett referensprojekt hos det svenska byggföretaget JM används för att få ut data till totalkostnadsanalys-modellen.

Totalkostnadsanalys-modellen undersöker kostnader i relation till logistikaktiviteter, från det att materialet lämnar leverantör tills dess att det placeras på monteringsplats i projektet. Kostnadsdata i totalkostnadsanalys-modellen är hämtad från JM:s ramavtal med deras leverantörer och logistikföretaget som driver bygglogistikcentret. Aktiviteterna i varje process är identifierade genom observationer men även via information i ramavtalen med de involverade aktörerna. Studien bidrar med en totalkostnadsanalys-modell över olika logistiklösningar och leveransstorlekar. Totalkostnadsanalys-modellen ger insikter i hur logistikaktiviteterna är organiserade och vilka kostnader de medför.

Studien visar att genom implementering av ett bygglogistikcenter och dotterbolaget JM Supply (som ansvarar för logistiken på byggarbetsplatsen) har JM successivt tagit flera steg mot en mer effektiv leveranskedja. Studien bidrar till förståelse för effekterna av att implementera ett bygglogistikcenter. Resultaten från totalkostnadsanalys-modellen visar att direktleveranser till byggarbetsplatsen i nuläget är den mest fördelaktiga logistiklösningen ur ett kostnadsperspektiv. Resultatet förklaras genom utformningen av ramavtalen med leverantörerna som anpassats för den mer traditionella logistiklösningen med direktleveranser. Kostnaderna varierar dock mellan olika materialtyper. Det finns således ingen enhetlig lösning som är bäst för samtliga materialslag utan materialen bör studeras individuellt efter respektive förutsättningar. Totalkostnadsanalys-modellen illustrerar även att antalet transporter till byggarbetsplatserna minskar när ett bygglogistikcenter används vilket anses fördelaktigt för såväl ekologisk som social hållbarhet. Studien visar att för att nå en full potential av en lösning med bygglogistikcenter behöver JM få ett holistiskt perspektiv på hela logistikprocessen. Det är eftersträvansvärt att uppnå en tätare sammanlänkning av funktionerna för inköp, produktion och logistik.

Nyckelord: Bygglogistik, Bygglogistikcenter, Totalkostnadsanalys, Supply Chain Management, kostnadsstyrning av logistik.

Contents

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Gothenburg, June 2021

Filip Ossiansson

Elin Åström

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1 Introduction

This chapter introduces the phenomenon of the study including arguments for why it is important and interesting to study. This provides the background and thereafter, the aim of the study is presented, followed by the research questions under investigation. Also, limitations are described, and finally, the structure of the thesis is outlined.

1.1 Background

Productivity statistics from Statistics Sweden (2020) show that in the construction industry productivity has barely increased at all in the last two decades at the same time as other industries show significant improvements in productivity ratios (SCB, 2020). Other industries have, due to the increased internationalization and competition, been forced to develop their business to save time and money in production while the construction industry instead has increased the price tags. The prices for residence in Sweden have increased by 357 % since 2000 and no change is yet seen (Mäklarstatistik, 2021; SvD, 2021). The increased pricing instead of productivity improvements may cause problems for society and all involved actors. The construction companies lose opportunities for higher profitability margins, fewer projects will be built and invested in as it is too expensive, and it will be a great challenge for the individual resident to enter the residential market.

The construction industry is known to have low productivity and have high costs due to its complexity and the fact that the industry is project-based (Vrijhoef and Koskela, 2000). The projects are often unique, situated in many different locations, and in need of many different materials that all need to be delivered to and handled on-site. These sometimes complex, fragile, and expensive materials and the different locations make logistics in the construction industry a key issue. Construction logistics faces many problems; materials that are stored on-site risk being damaged or need to be moved around frequently. Other issues are deliveries that are late or arrive with damaged goods, which hampers production on-site (Agapiou et al., 1997).

The construction industry has in recent years developed within the area of logistics (Ekeskär and Rudberg, 2016). New solutions and companies have entered the market and provide solutions and new ways of organizing construction logistics, for example, third-party logistics (TPL) companies, which handles logistics with everything from the handling of materials and disturbance of logistics centers to digital platforms (Ekeskär and Rudberg, 2016). Other initiatives are just-in-time (JIT) deliveries to avoid material storage on-site which can entail extra movements and damaged materials. The JIT-delivery can also reduce waste and lower the material usage since the projects only order the amount needed for the moment (Koskela, 1997). Another solution is Construction Logistics Centers (CLC), also called construction consolidation centers (CCC). A CLC is a type of warehouse where some or all the materials going to the construction sites are stored before a consolidated transportation delivers the goods to the sites (Dubois et al., 2019; Janne and Fredriksson, 2019).

Another aspect that relates to the increased attention to logistics improvements is the growing environmental problems the world must contend with. A reduced number of transportations will improve both ecological sustainability through fewer emissions and social sustainability through less noise and disturbance to the surroundings (Lundesjö, 2015). Reducing the carbon footprint in the construction industry is a direct necessity in order to meet Sweden's commitments in the Paris Agreement (Regeringenkansliet, 2017). The reduced number of transportations will also be an important factor from a safety point of view, reducing accident risk both on the construction site and in nearby surroundings (Lindholm & Browne, 2015).

The Swedish housing construction company, JM, Sweden's 5th largest construction company (Byggföretagen, 2020), has a large market share of Sweden's new production of residential buildings. As one strategy of increasing their profit margins and competitiveness, JM has identified the need to shorten lead times in production and increase efficiency. According to the logistics manager at JM, the company has set a goal of reducing their standardized lead times by 25% by 2025, and without increasing the cost. To achieve this, JM has identified that the deliveries from suppliers to the construction sites are a key factor. By improving the flow of material, including fewer steps, and getting materials to the right place at the right time, JM will increase the value-creating time for the workers on-site.

In recent years, the company JM has initiated a Logistics Department in Stockholm that has grown rapidly. The manager at the Logistics Department states that the company has taken inspiration and expertise from other industries, such as the automobile industry. In 2017 JM launched a logistics company, called JM Supply, that carries out the on-site materials handling. In 2020 a procurement of a TPL that owns and operates a CLC was made to gain better control of the deliveries to sites. Three pilot projects have been using the CLC for the deliveries of some commonly used interior materials from JM’s suppliers. The pilot projects have been completed successfully, and the solution has been documented to provide positive outcomes. As an example, the number of transportations to site has been reduced by 83 % (JM, 2020). JM has the vision to expand this solution with a CLC and to implement it to a greater extent in the future to encompass more projects.

An obstacle for the future implementation of the CLC logistics solution is that JM does not yet know what the costs connected to the different delivery alternatives stem from and entail. Calculations need to be carried out to investigate what the different solutions actually cost and how costs are allocated to different material types to evaluate which types of materials that are favorable for transportation via the CLC. For example, what is the cost to deliver all the doors from one supplier via the CLC, and then co-load smaller batches of doors together with other types of material to the site? This should be compared to the traditional alternative, transporting directly from the supplier factory to the construction site. A total cost analysis (TCA) model thus needs to be created that can illustrate the costs of the delivery alternatives. In addition, in relation to which delivery alternatives that are most cost advantageous, the cost for a one-piece flow batch size and JM's standard batch size must be considered comparing direct delivery or delivery via the CLC. The study involves the development of a TCA model that will show these different costs connected to different delivery alternatives and batch sizes for 21 material types.

1.2 Aim of the Thesis

The aim of the thesis is to develop a total cost analysis (TCA) model for JM to evaluate two logistics processes of materials delivery to site: *direct delivery* or *delivery via a construction logistics center* (CLC).

The model is based on JM's framework agreements with suppliers and TPL company and a reference project at JM is used to trace prices and quantities as input to the model to enable the analysis. The TCA together with knowledge and observations create a basis for recommendations regarding the material flow for the materials included in the TCA where advantages and disadvantages of various alternatives are highlighted. Price comparisons between the new logistics solution of using a CLC and the traditional logistics logics of direct delivery are visualized to show similarities and differences.

1.3 Research Questions

To fulfill the aim the following research questions are identified:

- What should be included in a TCA to be able to evaluate the cost and identify cost drivers related to direct delivery or delivery via CLC?
- What are the pros and cons of implementing a CLC solution in comparison to direct delivery in residential building projects?
- How can the TCA model support JM's future development and implementation of logistics solutions?

1.4 Limitations

The study considers the material flows from the suppliers to the assembly point at the construction site. Only the materials flow for the selected 21 material types are considered. The study does not involve the delivery and handling of machines and tools to the site. The study is limited to the JM region Stockholm and the relevant framework agreements connected to the materials and services relevant for the case. Other JM regions are not included and, the study is limited to new buildings and not reconstruction or refurbishment.

1.4 Structure of the Thesis

The thesis contains seven chapters, starting with a first chapter introducing the subject, presenting the aim of the study and its research questions. The introduction is followed by chapter 2, the theoretical framework, which gives the reader a deeper understanding of the subject and the theories connected to it. Chapter 3, the methodology chapter, describes how the study has been conducted and how the data are collected for the case study. The quality, ethical, and sustainable conducts are also presented in the third chapter.

Further, the thesis contains chapter 4 with empirical inquiry about JM, the CLC, and how the solution has been perceived, to form a better understanding for the case. The empirical data chapter is followed by chapter 5 describing the structure of the TCA model, the parameters used, and how they relate to each other to form the results of RQ1. The last part of chapter 5 contains the results of the TCA model and interpretations of the results. In chapter 6, data from the theoretical framework, empirical data as well as the TCA model are discussed to answer RQ2 and RQ3 in the thesis. The conclusions of the thesis are then summarized in chapter 7. Finally, the references are presented at the end of the report.

2 Theoretical Framework

This chapter presents the theoretical framework of this thesis. In section 2.1, the construction industry characteristics will be explained in regard to how this affects the supply chain. Four roles of how to view Supply Chain Management (SCM) in construction are presented and within these focus roles, three different levels are presented in how to apply supply chain management. These three levels of SCM form the basis for the subsequent section 2.2 Initial partnership, 2.3 Logistics management, and section 2.4 Genuine SCM. In these sections, the historical and current situation in the construction industry is presented and the specific characteristics and affirmations to have a successful supply process are highlighted. Solutions such as third-party logistics, warehouse management and Construction Logistics Centers are introduced. Section 2.5 deals with the logistics solution Construction Logistics Centers. It presents the purpose of implementing these CLC's and research about lessons learned regarding implementation and operating processes. Finally, in section 2.6, theories are presented on how to conduct cost control of logistics processes.

2.1 Supply Chain Management in Construction

Supply Chain Management (SCM) is by the Council of Supply Chain Management Professionals (CSCMP, 2013, p.187) defined as:
"Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."

Vrijhoef and Koskela (2000) state that in order for the construction industry to incorporate the principles of SCM, adjustments for the typical characteristics of the industry must be adapted. Vrijhoef and Koskela (2000) presents four specific roles in which SCM can be embedded in the construction industry, see *Figure 2.1*.

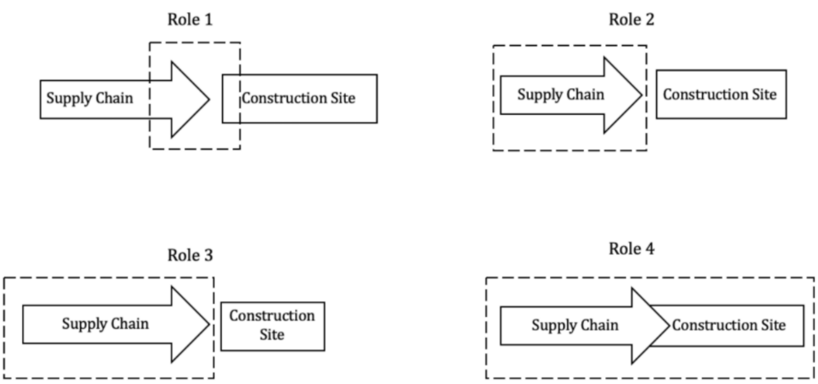

Figure 2.1. The four roles of SCM in construction (Vrijhoef & Koskela, 2000).

The first role focuses on the connection between off-site and on-site logistics and therefore mainly how the supply chain impacts the logistics on-site. Important aspects in this role are that materials and equipment are delivered on time and the goal is to reduce the duration and cost of activities. Vrijhoef and Koskela (2000) state that a way to achieve this is to focus on the cooperation between suppliers and contractors. In the second role, the focus is on the supply chain itself with the aim to reduce cost related to lead-time, logistics and inventory. A way to achieve this is according to Ekeskär and Rudberg (2016) by customizing deliveries with specific labeling and specific packing of materials according to e.g., apartment and floor plans. Vrijhoef and Koskela (2000) state that in depth cost and time analysis should be performed in order to be able to develop the supply chain.

The third role focuses on a transfer of activities from site to the supply chain and Vrijhoef and Koskela (2000) state that this should be adopted by both suppliers and contractors. Examples of this step are to use prefabricated building elements in production or to move certain assembly activities from on-site to earlier stages off-site. In the fourth and final step, the goal is to combine and integrate the off-site activities with the on-site activities (Vrijhoef & Koskela, 2000). Ekeskär and Rudberg (2016) state that the fourth role is realized when the supply chain is totally integrated with the construction site.

Construction is a project-based industry where the contractors are organized in projects, where they gain their profit. Most contractors have more than one project at the time and the different projects can be viewed as different entities in the company (Gadde & Dubois, 2002a; Frödell et al., 2013). Contractors have a central organization that consists of different departments such as purchasing, top management, human resources, and overall economy, among others. The projects function as stand-alone entities that have their own financial management and the right to make decisions that are appropriate for the project. The projects have a predetermined timespan and a budget that is set before the project starts. The construction industry is reliant on competitive tendering to assure the lowest price and most effectiveness (Gadde & Dubois, 2002a).

Gadde and Dubois (2002a) define the features of the construction industry to be a loosely coupled system due to the focus on the individual projects and the decentralized financial control and decision making. Contractor companies can be more or less centralized, either the organizations are decentralized and almost all decisions and financial management are made at a project level, or the company is centralized, and decisions have to go through top management. Frödell et al., (2013) state that currently, most companies are a mix between the centralized and the decentralized. According to Gadde and Dubois (2002a), a decentralized contractor company easily adapts to local circumstances and each project has a buffer to unfavorable conditions that may happen somewhere else in the company. They also state that in loosely coupled systems and companies' new solutions and development are easier managed and implemented due to the "freedom" of each project and that fewer people are involved.

Decision making is also easier in decentralized companies, decisions can be taken faster and be founded in knowledge of the local environment (Gadde & Dubois, 2002a).

In centralized companies with tight couplings, decisions take longer time, and development initiatives must go through top management and then be implemented in all projects. In a more centralized company standardization is easier when decisions come from the top management, to procure framework agreements is also easier when a central department can negotiate for the whole company (Frödell et al., 2013). As mentioned before, a mix between centralized and decentralized is most common and the different advantages are depending on the size of the company and how geographically spread the business is.

Which contractor that is to construct the different projects are determined through a tendering process that often are based on lowest price. The tendering can also be based on expertise, knowledge or experience that are valued in a certain project (Waara & Bröchner, 2006). In a construction project there are several subcontractors procured by tender to perform different tasks they are experts at (Gadde & Dubois, 2002a). There are also many different suppliers involved in every construction project due to all the needed materials and equipment. Due to all the involved actors, unique projects, short-term relationships, and different components the settings of a construction project are complex (Gadde & Dubois, 2002a).

There are also different stakeholders connected to the projects, there are the direct stakeholders such as investors, clients, or suppliers but also indirect such as residents in the neighborhood to site, pedestrians and other businesses nearby. For every new project, many if not all, subcontractors and suppliers are exchanged and new relationships must be established (Lindén & Josephson, 2013). The main contractor's role is to coordinate all the involved actors and make sure that the project performs within the budget frame and the time frame. An important part of managing the project is to manage the different supply chains in relation to the involved actors.

Vrijhoef and Koskela (2000) explains that SCM views the entire supply chain and the interdependencies between the actors in the supply chains. They recognize three levels of SCM that are; *initial partnership* that involves the establishment of good relations with suppliers and distributors, *logistics management*, to create a good flow in the chain and controlling it by involving all actors, and *"genuine SCM"* covering continuous improvement of the entire chain and its different actors and components. Vrijhoef and Koskela explain that for every construction project, several new temporary supply chains are established to supply the specific "product" that is to be built. They also state that these supply chains are characterized to be unstable due to their temporary settings.

2.2 Initial Partnership within Construction SCM

The first level of SCM in construction is according to Vrijhoef and Koskela (2000) *initial partnership*. A central part in the performance and design of the supply chain is how many involved actors there are and the relationship between them (Mattson, 2012). Mattson (2012) describes how the company relations traditionally have been dominated by so-called *multiple sourcing* where the company uses several different suppliers of the same product type. This implicates that the suppliers are pitted against each other to reduce prices while reducing the risks of supply problems by spreading the risks to several suppliers. However, research has indicated that this mindset is declining in favor of *single sourcing* and building a stronger partnering relationship (Mattson, 2012). Multiple sourcing helps to create a feeling that both actors are counterparties and compete against each other rather than that they are part of a larger chain that needs to be optimized to make the end customer happy. It is, therefore, said that multiple sourcing contributes to a negative collaborative climate, which is what SCM-theories usually strive to avoid (Mattson, 2012).

Mattson (2012) states that *multiple sourcing* is best suited for standard items that are traded in a well-developed market with many competitive companies. Studies show that *multiple sourcing* is usually cheaper initially, but there are several benefits of single sourcing that make it an advantageous choice in the long run with many benefits that affect the final price (Mattsson, 2012). Since *single sourcing* has fewer suppliers to work with which implies that the administrative work will decrease while opportunities to develop and follow up the work and communications will increase. Single sourcing also entails a more open and efficient exchange of information, and this collaboration can lead to product and production development and new solutions can be created. The long-term perspective and stability that single sourcing provides for the supplier can in turn motivate lower prices both directly as well as giving suppliers security in investing in their production, which also can reduce prices. The increased effort towards lean processes with JIT-deliveries also places higher demands on the partnership making *single*, or possibly *dual sourcing* almost a prerequisite for making JIT-deliveries work (Mattsson, 2012).

In construction projects, where a big focus on price is present, a multiple sourcing approach is traditionally most common. Contractor companies have decentralized decision-making and financial control which means that each project makes their own decision in who to procure the components from (Gadde & Dubois, 2002a). Frödell et al. (2013, p.47) state that "*a trend within the contractors of the construction industry has been to follow the strategic purchasing approaches originally developed for the manufacturing industry by centralising the purchasing function and organisation and forming framework agreements with suppliers in order to reach enhanced efficiency"*. Then a purchasing department in the top management of the company is partly responsible for purchasing and procurement of materials and the projects call-off the deliveries but also purchase a smaller amount of some products (Frödell et al., 2013). This enables companies to do a proper supplier selection, negotiate good prices for all the company's projects and to sign framework agreements to have long-term collaboration. Construction projects apply a mix of single and multiple sourcing depending on the materials that are needed and how the purchasing responsibility is divided. A more centralized purchasing department at a company is in line with SCM theories due to the easier control and influence of the supply chain. Thus, with some materials or locally settings a multiple sourcing or decentralized purchasing is preferred due to the flexibility or local agreements (Frödell et al., 2013).

Mattsson (2012) describes that SCM, in general, advocates a holistic view of the entire supply chain with the end-customer in focus. Christopher et al. (2006, p.278) highlight that without a holistic perspective there is a risk that sub-optimal supply chain decisions may be taken. "*For example, the introduction of "just-in-time" delivery may reduce inventory in the factory but increase it at the supplier whilst also increasing transport costs. What might look like a cost saving to one firm could mean increased costs to the supply chain as a whole"*. This initiative then results in no benefit at all for the end customer, which as previously mentioned should be the ambition in logistics improvement. It has been suggested that "supply chains compete, not companies" (Christopher, 1992). However, Mattson (2012) claims that when working with streamlining processes, a too broad perspective could lack function. This since companies often have very little opportunity to influence more than one link upstream / downstream in the chain to find better new solutions.

2.3 Logistics Management in Construction

The second level of SCM in construction is according to Vrijhoef and Koskela (2000) *logistics management*. This concept is about creating a good flow in the chain and controlling it by involving all actors and applying different managing operations (Vrijhoef & Koskela, 2000).

The Council of Supply Chain Management Professionals (CSCMP, 2013, p.117) defines logistics as:
"The process of planning, implementing and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements." In logistics, one should strive for the fulfillment of the seven R's of logistics, and all relevant parts of the company that enables fulfillment of this should be included in the logistics work. The seven R's of logistics are defined as: Getting the Right product, in the Right quantity, in the Right condition, at the Right place, at the Right time, to the Right customer, at the Right price (CSCMP, 2013). Implementation of these objectives should be done as cheaply as possible without compromising on quality.

According to Lundesjö (2015), logistics in construction has traditionally been connected to the planning of the site; including gates, walkways, canteen, toilets, health and safety facilities, that is, things that are normally found in an area disposition plan (APD plan). Logistics has, over the years, had second priority behind the so-called value-adding activities, for example, the montage of gypsum boards or kitchen counters (Lundesjö, 2015). Lundesjö (2015. p.1) states that "*logistics function is a supporting role to the primary activity of construction*", which indicates that the focus in construction projects has not been planning for a good supply chain for the supplies to the project. Mattsson (2012) adds on to the issue and claims that a general issue regarding logistics management is that there are divided opinions about which scope the logistics include depending on who you ask and who is responsible for each part. There are many opinions about how logistics views and strategies should be implemented in certain companies' supply chains in order to achieve value and/or cost advantages. Oskarsson et al. (2013) point out that a starting point for a modern logistics view is that logistics is something that affects the whole company/project, and not just part of it.

Dubois et al. (2019) identified three different configurations of supply logistics activities that are present in the construction industry. The configurations are *the de-centralised coordination, the on-site coordination* and *the supply network coordination*. The de-centralised coordination configuration is the traditional way that logistics in construction projects are handled. The de-centralised coordination, see *Figure 2.2*, is that materials needed in a project are ordered and handled by the separate receivers of the different materials (Dubois et al., 2019).

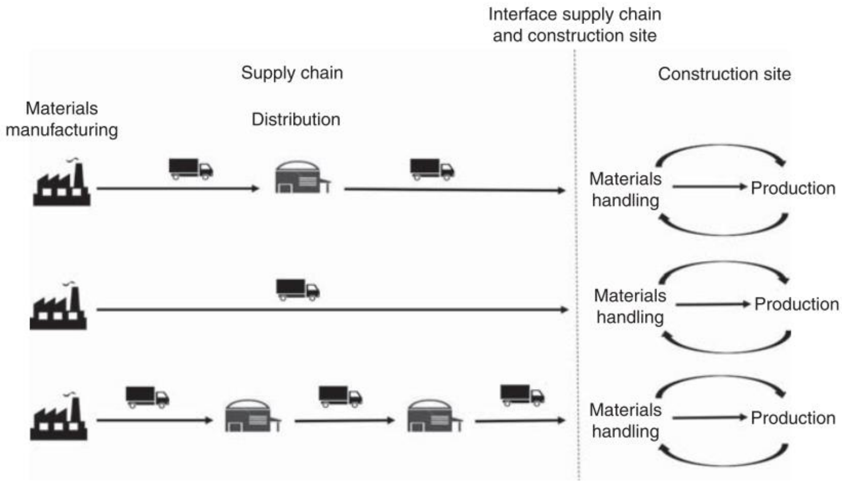

Figure 2.2. The de-centralized coordination configuration. (Dubois et al., 2019).

The on-site coordination configuration, see Figure 2.3, involves controlling the on-site activities and the transportations coming to site. This configuration often involves a third-party logistics company and will be described further in the next section.

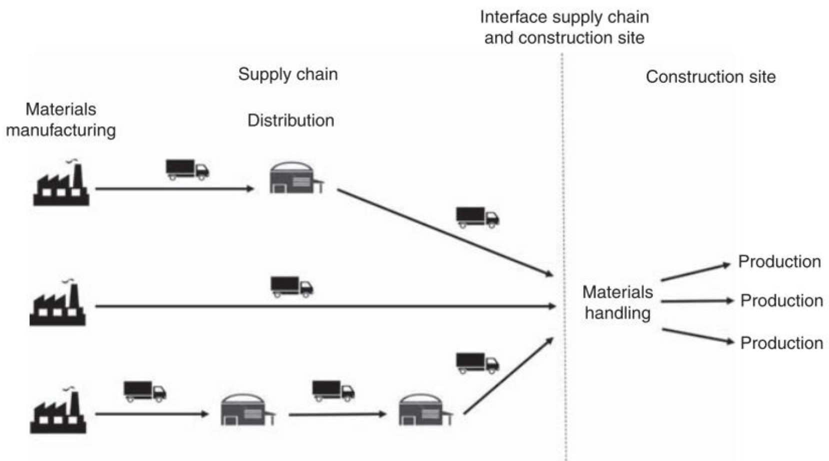

Figure 2.3. The on-site coordination configuration. (Dubois et al., 2019).

The third configuration; the supply network coordination, see *Figure 2.4*, goes beyond site and involves the up-stream supply chains. This third configuration often involves joint coordination of transportations to various extent which can be achieved by adding a CLC to the supply chain.

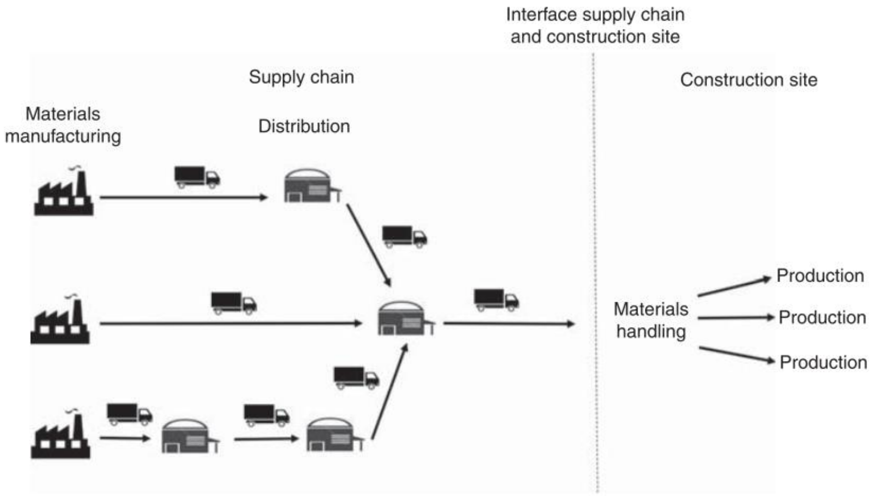

Figure 2.4. The supply network coordination. (Dubois et al., 2019).

Dubois et al. (2019) explain that a reason why the decentralized coordination and traditional way of handling construction logistics is a result of the fragmented structure in the projects and many involved actors, like main contractors and subcontractors, that often order and handle their own materials. These subcontractors are commonly not coordinating with each other which results in many different material deliveries, of varied sizes, arriving to the site (Lindén & Josephson, 2013). The purchases are rarely coordinated and because of the bulk discounts the contractors may order larger amounts to get a lower price. Lundesjö (2015) states that it is also common to order larger amounts of materials "just in case" the materials are lost or damaged. The order procedure to constantly receive few but large deliveries entail that plenty of different materials need to be stored on-site which affects the pass ability, and availability on-site, see *Figure 2.5* (Agapiou et al., 1997; Lundesjö, 2015).

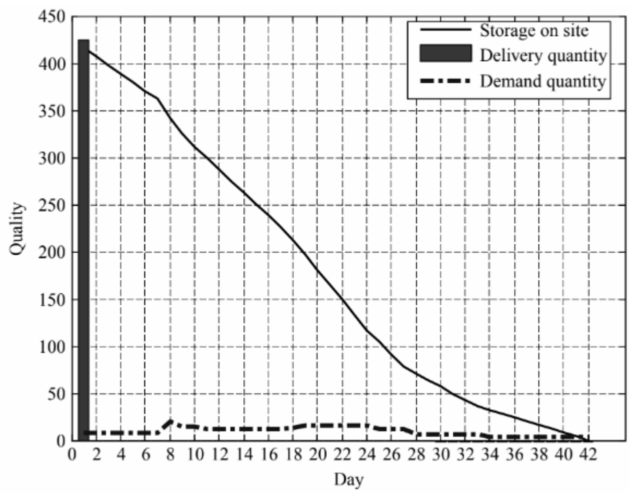

Figure 2.5. Delivery and demand quantity in projects (Fang & Ng, 2011).

Storage of materials on-site is according to Dubois et al. (2019) an even greater challenge in projects located in dense areas, with nearby buildings and other businesses that often affect the site area and where the room for storage is typically not prioritized. When materials are stored on-site, the workspace for craftsmen decreases, and materials may need to be moved around to enable value-adding activities which lowers productivity (Thomas et al., 1989; Agapiou et al., 1998).

The issues described above could be examples of sub-optimizing, where the holistic view of the supply chain is not applied and savings done in one part of the supply chain appear as a cost somewhere else instead (Christopher et al. 2006; Vrijhoef & Koskela, 2000). Vrijhoef and Koskela (2000) found in their case study that the common practice among subcontractors is to purchase materials at the lowest price. That approach resulted in a higher total cost due to the logistics cost on-site generated by the large amounts of materials see *Figure 2.6*. Vrijhoef and Koskela (2000) highlight the importance of involving all actors in the supply chain to control it when practicing SCM.

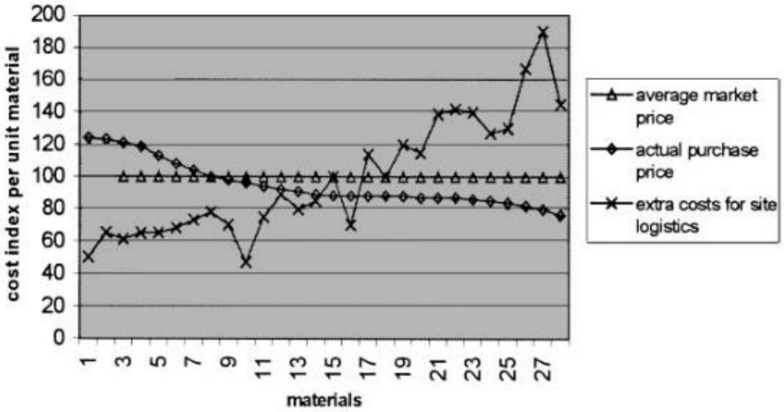

Figure 2.6. Cost and price analysis for building materials (Vrijhoef & Koskela, 2000).

Construction sites located in dense areas are faced with more logistics challenges connected to traffic issues. A study done by Lundesjö (2015) over an 18-month period demonstrated that between 25-275 trucks are received every month at the site, and typically a project receives trucks with materials every day. These deliveries arrive when it is best suited for the supplier and not for the project at the site resulting in disturbances to the production (Lundesjö, 2015). Lundesjö (2015) describes the time frames used to specify the deliveries in construction are ‘morning’ or ‘afternoon’, which affects how specific the planning of the workday can be. The hazard deliveries result in trucks queuing up outside the construction site or circulating waiting for a time slot. This extra waiting and increased traffic outside the site are causing disturbances to third party stakeholders, increased pollution, and safety risks for unprotected road users (Dubois et al., 2019; Lundesjö, 2015). Because of the often-unplanned arrival, the drives call before arriving and the craftsmen meet them at the gate, when there is a queue it results in waiting time, both for the trucks but also for the craftsmen. When materials are unloaded there is also a need for space and tools to move them, if many trucks arrive at the same time there is a waiting time for resources to move the received materials to the assembly or storage area (Lundesjö, 2015).

Agapiou et al. (1997) state that the risk of the materials being damaged by weather or movement increases when being stored at the site. There may also be a risk that all the materials ordered with bulk discounts will not be needed and instead thrown away. Thomas et al. (1989) found out in their case study that the work pace of craftsmen decreases when the material storage is low, or materials are missing. The shortage of materials may be caused by deliveries being late or materials being damaged by weather or during transportation. Weather is a factor that affects the construction industry, since some activities cannot be done in certain weather conditions. These weather issues affect the time plan as such activities might have to be postponed. When activities are moved, the materials that were ordered for a certain day or week instead get stored on the site longer than planned due to the unforeseen conditions. This unplanned storage could entail problems with the available working space and the material itself risks being damaged or lost when moved around (Agapiou et al., 1997; Dubois et al., 2019).

2.3.1 TPL in Construction

The second configuration of supply logistics activities identified by Dubois et al. (2019) is *on-site coordination* and involves joint coordination of site logistics, which can be carried out by a third-party logistics (TPL) company. Since the 90's many of the issues when having a de-centralised coordination of logistics activities have been brought forward and there have been several initiatives to try to solve the problems that logistics (or lack of logistics) cause in construction projects (Lundesjö, 2015). TPL companies have been present in other industries since the early 1990s (Berglund et al., 1999). The concept has in recent decades gained more attention as well in the construction industry in the strive to eliminate some current issues (Ekeskär & Rudberg, 2016). Coyle et al. (2003, p.425) define TPL as ''*an external organization that performs all or part of a company's logistics function*''. It is one way for construction projects to manage parts of the supply chain that traditionally have been handled within the organization by the main contractor or other actors in projects (Lundesjö, 2015). The idea is to outsource the logistics to a company that has special knowledge within logistics instead of having the craftsmen perform these tasks. When someone else takes care of the logistics part, the craftsmen can focus on activities they are experts at, the so-called value-adding activities (Lindén & Josephson, 2013).

Janné (2018, p.13) describes that "*the service offerings must include multiple, bundled services and the relationship between service client and TPL provider should be contractually stipulated over a longer time period for the arrangement to be considered a TPL arrangement*". Ekeskär and Rudberg (2016) describe several services that can be performed by a TPL provider. These services are exemplified as: transportation, storage at distribution centers, handling, and repacking of materials (in a warehouse or at site) and administrate checkpoints at the site gates. Other services that also can be included in a TPL solution are information-related activities such as tracking of materials and planning of the distribution routes to sites but also the design of the supply chain. A TPL can provide one or several of these services depending on the knowledge within the TPL company but also what is needed in a certain project (Janné, 2018). Depending on the kind of project, different services are needed (Lundesjö, 2015).

Avoidance of waste provides for cost efficiency but also the possibility to lower lead times in construction (Ekeskär & Rudberg, 2016). When a TPL is used the logistics costs are visualized which makes them easier to manage, but there is also a risk that logistics seem more expensive since it is visualized (Ekeskär & Rudberg, 2016). A problem with the costs connected to logistics in construction is that the costs are hidden, or some of them included in the purchasing price for materials (Lindén & Josephson, 2013). Janné (2018) describes the fact that materials in construction projects often are stated as "delivered" and then the further logistics connected to that material is not accounted for. Lundesjö (2015) states that a big part of logistics cost in construction are the logistics performed on-site and therefore hidden or hard to see. This since it is included in the activities done by the various actors that are procured on a fixed-price including both the non-value adding activities as well as the value-adding ones. Ekeskär and Rudberg (2016) present a concern about a "*fear of unrealistic fee structures*" connected to this hidden cost for logistics and the lack of knowledge of own internal logistics costs. It is also mentioned by Lindén and Josephson (2013) that contractors can be resistant towards outsourcing their logistics activities due to a lack of consideration regarding some costs connected to their own handling of materials. Since logistics costs in construction are viewed as "included" it can be hard to motivate why resources should be spent on logistics and to motivate the costs of different solutions, a more holistic view must be applied (Janné, 2018; Lundesjö, 2015). The different actors in a project have a habit of just looking at their own supply chain and activities and therefore the broader picture and advantages are missed (Dubois et al., 2019).

2.4 Genuine SCM - Continuous Improvement

The third level of SCM is according to Vrijhoef and Koskela (2000) *"genuine SCM"* which is about continuous improvement of the entire chain and its different actors and components. Ohame (1982) describes how companies become successful and gain competitive advantage by a strategic optimizing of the links between the three C's of The Strategic Triangle; Customers, Company, and Competitor see *Figure 2.7*.

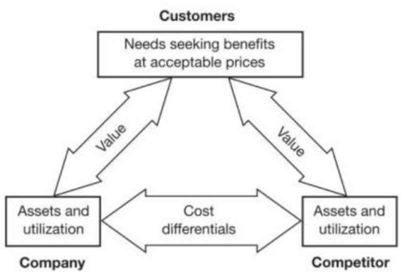

Figure 2.7. The Strategic Triangle (Ohame, 1982).

Simplified, these ideas can be summarized to successful companies work strategically towards either having a cost advantage or a value advantage, or both (Ohame, 1982). Christopher (2004) illustrates the different market fields a company could operate in, see *Figure 2.8*. This is where logistics comes in as a tool to move the company either upwards in the graph, towards a better level of service, or further to the right by becoming more cost-efficient. Preferably, a company wants to succeed in implementing both with the ultimate goal: "Superior customer value at less cost" (Chrisopher, 2004).

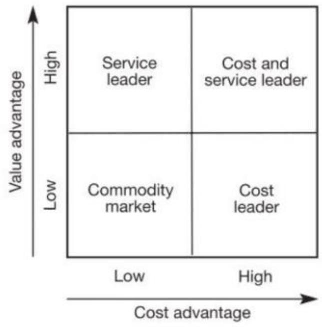

Figure 2.8. Market fields to operate in (Christopher, 2004).

Christopher (2004) claims that it is only in recent decades that business organizations have come to recognize the role logistics can have in creating competitive advantages. One company that has accomplished this by placing great emphasis on continuous improvement and eliminating *waste* is the car manufacturing company Toyota (Liker, 2004). Toyota's, nowadays very well known, production system, *TPS*, has become a precedent for many companies in how to achieve cost efficiency with a lean approach. Liker (2004) states that within the lean philosophy, there is always room for continuous improvement and describes an approach that could be summarized as that nothing is so good that it cannot be improved. The Japanese term for continuous development, *Kaizen*, is an important part of TPS to achieve the desired improvement and customer satisfaction. Liker (2004) describes that *Kaizen* involves all employees and also applies to processes, such as purchasing and logistics, which is reminiscent of the *genuine SCM* vision described by Vrijhoef and Koskela (2000).

2.4.1 Deviations from Optimal Allocation of Resources in Construction

Regarding material treatment in a supply chain, Lean philosophy states three types of deviations from optimal allocation of resources, *Muda* (waste), *Mura* (unevenness), and *Muri* (overburden) (Liker, 2004). Liker (2004) states that companies actively should strive to eliminate these deviations to remain competitive. It is not only in the automotive industry that the reduction theories are applicable. Josephson and Saukkoriipi (2005) show that waste represents around 30–35% of the production costs in construction. In this context, the term waste represents not only garbage that is sent for disposal. TPS refers to *Muda*, and it is defined as an action or step in a process that does not add value to the final customer (Liker, 2004). Originally, TPS refers to seven different wastes, but Liker presents a theory in which an eighth category is added, unused employee creativity. According to Liker (2004), 7+1 types of waste are identified:

- *Overproduction* – production of items not needed.
- *Waiting* – workers waiting for tools, information, materials, etc.
- *Unnecessary transportation or conveyance* – transporting material and finished products.
- *Overprocessing or incorrect processing* – inefficient or unneeded activities due to poor tools or methods. Incorrect processing can also lead to defects.
- *Excessive inventory* – excessive storage of material causing extra costs for transportation and storage. Also risks damaging material when handling it. This phenomenon also hides other problems such as production imbalances or uncontrolled deliveries.
- *Unnecessary movement* – looking for tools or materials, walking around, etc.
- *Defects* – damages on material or products causing rework, repairs, replacements, inspections, etc.
- *Unused employee creativity* – missing good ideas, improvements, or skills due to not engaging or listening to the employees.

Among the 7+1 types of waste, many are found in construction (Josephson & Saukkoriipi, 2005). According to Josephson and Saukkoriipi (2005) construction workers spend 30 % of their time *waiting*. In projects, craftsmen spend time receiving and unloading trucks, they wait for construction hoists or forklifts and other resources to do their job or move their materials (Dubois et al., 2019; Lundesjö, 2015). *Unnecessary movement* is another waste that construction workers spend time on, looking for materials that have been moved around and tools to move the materials, for example, pallet jacks (Lundesjö, 2015). *Excessive inventory* is a problem in many construction projects and is waste due to materials being damaged while being moved or lost at construction sites (Agapiou et al. 1997). Other problems with excessive inventory at sites are the risk that materials are stolen. It is hard to guarantee that unauthorized people do not get past the gates at the site and steal tools or materials (Lundesjö, 2015).

Damages can also be connected to the waste *defects,* mentioned by Liker (2004) which could cause rework, replacement, and more. Vrijhoef and Koskela (2000) state that this defect not only is a factor of logistics but of poor documents and information in the projects. Another example of excessive inventory is uncontrolled deliveries that occur when actors on-site do not communicate, causing unnecessarily traffic jams on-site (Dubois et al, 2019). *Unnecessary transportation or conveyance* is also a waste present in construction projects, large batches of materials stored on-site cause the need to move it around to get to a certain area or to have the materials close to the various assembly areas (Lundesjö, 2015).

2.4.2 JIT as a Tool to Reduce Waste in the Supply Chain

In Lean philosophy, a key concept in the strive toward waste reduction is JIT-deliveries (Liker, 2004). JIT-deliveries means that the right amount of material is delivered at the right place and at the right time which is strongly linked to the seven R's previously presented as the summary purpose of logistics work. JIT-deliveries will help to avoid unnecessary handling of products and create more value-creating time for each producing unit. *Waiting*, *Excessive inventory*, *Unnecessary movement*, are some of the waste categories presented above that JIT-deliveries intends to influence (Linker, 2004).

Cheng and Podolsky (1996) state that the concept of the JIT-deliveries is differentiated from traditional production systems using *push-systems* of production. In the *push-system*, which traditionally has been the dominant character, materials are pushed from one step of production onto the next stage irrespective of whether time and resources are needed at the next level. Organizations adopt a push system where they produce inventory and work in progress, and it could create a lot of inventories at each level of the production flow. In contrast to push, the JIT-delivery concept is built based on the concept of *pull-system*. In the *pull-system* of production, materials are pulled by the next level of the production only when it is required or signaled by the next stage of production.

The benefits from implementing JIT-deliveries are according to Cheng and Podolsky (1996), improved service to customers, more effective operations, and improved working environment. Correctly implemented, JIT-deliveries are also said to reduce costs overall in the process, but Mattson (2012) points out the risk that JIT-deliveries only involves a transfer of problems and costs to an earlier stage in the process. Singh and Singh (2020) state that the cost related to vendor performance (e.g., delivery costs) is increasing when implementing JIT-deliveries.

Cheng and Podolsky (1996) state several obstacles and limitations that must be considered to get the desired effect if implementing JIT-deliveries. JIT-deliveries depends on reliability and consistency of all links in the supply chain and with a JIT-delivery implementation one loses buffering against fluctuations in supply/demand. Cheng and Podolsky (1996) claim that JIT-delivery implementation requires a cultural change, particularly relating to team working and collaboration of companies and corporate departments that previously worked more downpipe-like. Due to the requirements to fit in tightly defined roles and with less autonomy, employee stress could increase. Additionally, there is in human nature a general resistance to change that needs to be managed to achieve a change (Cheng and Podolsky, 1996).

2.4.3 Warehouse Management Affects the Material Flow

An important element in the supply chain flow and the robustness of the system is the buildup of transportation and warehouses since it links together the different activities in the chain (Lundesjö, 2015). Oskarsson et al. (2013) state that the two main reasons for using warehouses in the supply chain are to become more service-friendly and more cost-effective. Warehouses could provide opportunities to benefit from economies of scale when transporting and ordering in larger shares at a time. It also provides security against delivery disruptions and increased opportunity for accurate deliveries which could give a better production flow (Oskarsson et al. 2013). Having warehouses, however, entails costs, and Lundesjö (2015) states that there are three key elements that make up the cost related to warehousing:

- *The physical costs of stockholding:* The cost of building, equipping, and operating warehouses including labor costs.
- *The opportunity cost of holding stock:* The cost of having money tied up in stock or the cost of borrowing money.
- *The costs of 'goods loss' during storage:* Damage to the stock, theft and changes in demand that make the goods unusable.

In recent decades, there has been a major change in the structure of transportation chains towards a higher degree of centralization of warehousing (Mattson, 2012). Mattson (2012) states that there are fewer and larger warehouses currently than 20 years ago and transportations are similarly moving towards fewer and larger suppliers. Mattson (2012) further explains that this change is mainly due to changes in international trade agreements as well as developments to both better infrastructure and vehicles which has made transportation cheaper and safer.

It may seem somewhat contradictory that this change towards decentralization has occurred during the same time that the demand on suppliers has increased towards more JIT-deliveries, shorter delivery routes and a higher degree of customer relationship. Mattson (2012) states that TCA for companies has shown that there are large gains from the centralization of production and distribution that it offsets the increased transportation costs. The decentralization also entails advantages regarding disintermediation, i.e., to have as few intermediaries as possible who treat the product, which has proven to be a cost driver (Lundesjö, 2015).

2.5 CLC Setup and Management

In the sections above, several different solutions to manage and improve the logistics chain have been introduced such as transportation through third-party logistics, warehouse management and JIT-deliveries. A Construction Logistics Center, CLC, is a solution that combines some of these solutions and is said to be a tool to manage and improve construction logistics. The third configuration detected by Dubois et al. (2019): *the supply network coordination* could include a CLC. Logistics centers or distribution centers have been used in other industries for many years and been tested in construction in several pilot projects that have shown some improvements of logistics (Lundesjö, 2015). The initial aim with CLC was to lower the number of transportations to site and by that get less emissions and disturbances in dense areas (Lundesjö, 2015; Janné, 2018). According to Lundesjö (2015) freight transportations to the site can decrease by up to 70 % when a CLC is used compared to the traditional way of receiving deliveries. The solution with a CLC has also been a way to reduce the waste in construction projects, primarily to decrease the storage on-site and to succeed with JIT-deliveries. JIT-deliveries can minimize waiting times for personnel but also the storage on-site and the waste and damages connected to that (Cheng and Podolsky, 1996).

A CLC solution is organized as follows (Janné, 2018; Lundesjö, 2015):

1. The actors on-site or a logistics manager order materials.
2. The materials are delivered to a CLC (warehouse). The warehouse is preferably located nearby or at a strategic location in the outline of an urban area.
3. At arrival to the CLC the goods are controlled for damages and that the right goods are received. Then the goods are labeled and put into an IT system before being put away for storage.
4. When the materials are needed at site the actors call-off materials that are delivered with consolidated loads with other materials to site.
5. At site, a checkpoint is preferably established at the gate to receive the trucks and to make sure there is space to unload.

The punctuality of the trucks to site are according to Lundesjö (2015) around 15 minutes of the time announced. The number of deliveries to site are reduced when the trucks going from the CLC can be fully loaded with different materials. Lundesjö (2015) also describes that when the trucks leave the site they can be loaded with waste and material carriers such as pallets. The waste is handled and sorted at the CLC and then sent for recycling or disposal. The material carriers are sent back to suppliers or sold to other companies for reuse. In *Figure 2.9*, the CLC solution is described. Lundesjö (2015, p.288) describes the CLC's purpose as; *"to receive materials in bulk from suppliers, store them securely and, on order from the site, make up loads for daily deliveries*".

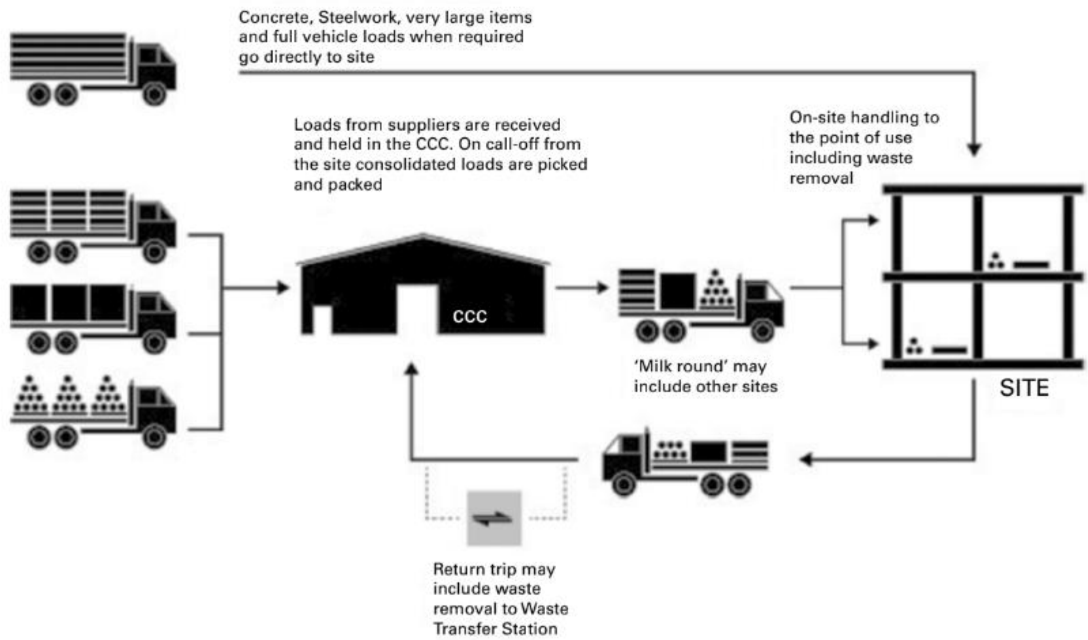

Figure 2.9. How a CLC solution can be designed (Lundesjö, 2015).

A CLC has been used in two projects in Stockholm, one in Hammarby Sjöstad, and one at Stockholm Royal Seaport (SRS) (Lundesjö, 2015; CIVIC, 2018; Janné & Fredriksson, 2018a). The main goals with these CLCs were to lower the number of transportations and environmental impacts. Research connected to these projects detected different benefits. The SRS project estimated an effect of 40-60 % decreased transportations due to consolidated deliveries (Janné & Fredriksson, 2018a). The project in Hammarby Sjöstad reduced the number of small deliveries by 80 % and reduced CO_2 emissions as well as energy consumption (Lundesjö, 2015). In both projects, the demand on lowering the impact of construction on both traffic and environment came from the City of Stockholm that stipulated the requirements.

When a CLC is to be established there are according to Lundesjö (2015) some resources that are needed. These resources are a warehouse with at least an open floor but preferably with pallet racking and shelving areas combined with an open floor. The warehouse should entirely or partly be inside with protection from weather. It needs an area to offload and onload vehicles, this aera should preferably be indoor as well. The warehouse should also have an area for waste and recycling of the materials that are received from the site(s). Other resources needed are one or several trucks to deliver the materials to site. Personnel are also required at the warehouse to do the operative job with handling of the materials but also someone(s) to administer the information and IT systems. Drivers to the trucks are also an essential resource. A warehouse management system (WMS) is a resource that is needed to keep track of the materials stored at the warehouse, also to call-off materials to site. These services are in most cases currently operated and offered by a TPL provider which business is to provide these resources. This know-how and competence segmentation in the industry is a reason why actors in construction procure such a company because they do not possess these resources themselves.

2.5.1 Operating Learnings at CLC

When a CLC is used there are some things that are important to include. Lundesjö (2015) describes activities and steps included in a process of implementing and operating a CLC and states things that are important not to forget for a successful outcome.

Ordering and receiving materials

As in a traditional construction project the contractor, subcontractors or other actors at site order their own materials. When ordering to the CLC, the timespan is important. Materials needed in two months are preferably not called off for transportation to the CLC until around two or three weeks in advance. The time materials are stored in the CLC depends on the storage cost, how unique the product is and how long the time is between the order to the delivery for that supplier. When the trucks arrive at the CLC they are unloaded and the personnel at the warehouse control the load compared to the delivery note. Personnel should also check for visible damage without opening the package. The materials arriving get labelled and (if not needed at once), put away for storage.

The labelling of the materials is very important to know the final destination and to sort them and keep track in the CLC. When the materials are ordered from the supplier the right information needs to be demanded on the goods. As well as when the materials are delivered at the CLC, the personnel need to label the materials for their own information.

Storage in the CLC

In construction projects there are many different actors with different materials and packaging. The materials can vary from big, bulky materials on specially built load carriers to small packages which in some cases do not need to be delivered on pallets at all. Therefore, the warehouse needs to be adjusted to store different goods carriers. The warehouse needs to have space for bulky or large materials that have alternative goods carriers such as steel stands or big pallets and also space for normal pallets. The warehouse should also have an open space to arrange the goods but also if something does not fit into the regular spaces. The warehouse should, as previously mentioned, also be protected from weather conditions, both in the storage area but also in the delivery and loading area.

A warehouse can vary greatly, both in size and inflow and outflow of material. When there are several projects, contractors/companies, and many different goods in the warehouse, a Warehouse Management System (WMS) could be needed to keep track of the goods. The system should be able to register materials, show to whom they belong, quantities of the material, when they were delivered to the CLC, when they are expected to be delivered to site and the location in the warehouse.

Value-adding processes in CLC

A CLC may be an opportunity for a relocation of activities in the supply chain. Some activities that could be done at the CLC to lower storage on-site and decrease the handling of materials on-site are *kitting* and *sequencing*. These are described as value-adding processes since they create a value for production on-site. Oskarsson et al. (2013) state that kitting and sequencing materials optimize deliveries to production. Kitting is defined as when parts are delivered and presented to assembly operations in pre-sorted kits, with each kit containing parts for one assembly object (Hanson & Brolin, 2013). Hanson and Brolin (2013) state that this method reduces the man-hour consumption of assemblers and benefits product quality but also highlights that man hours and costs are increasing in other parts of the chain, in this case at the CLC. The results of a study conducted by Hansson and Brolin (2013) indicate that kitting reduced storage in production and man-hour consumption in assembly but increased man-hour consumption overall because of additional handling time associated with kit preparation.

Sequencing is another well-used method in especially assembly line production with different variants where it is important to match the right component with the right product (Oskarsson et al. 2013). To make the production effective despite challenges with flexibility and great variety products, Oskarsson et al. (2013) states that the automobile industry works early in the process with specific identity definitions and article numeration of articles and products. Silf (2020) defines sequencing as: "*planning of production sequences in production groups, i.e., determining in which sequence different orders are to be served in a production group to* *optimize a certain execution measure, for example minimizing the total lead time or minimizing the average delay relative to planned completion times*".

Since construction materials often are delivered on pallets the materials can be stored on-site for a long period of time since just a small amount of materials are needed at once. When using a CLC, Lundesjö (2015) mentions opportunities to kit mixture pallets with different materials that are needed in the same assembly area. The CLC needs to prepare a workspace to do the kitting and sequencing there instead of doing it at site (Lundesjö, 2015).

Delivery to site

When the stored materials are needed at site, they should be called off according to a JIT-delivery pull system, which means that they should not be delivered before they are needed. A rule of thumb according to Lundesjö (2015) is that materials that are needed in the upcoming one to three days should be ordered from the CLC to avoid materials being stored at site for several days.

The CLC operator must have some vehicles that are destined to deliver to the sites. The vehicles should preferably have GPS-trackers to facilitate the receiving of the trucks at site since the reserves can keep track of their delivery. When materials arrive at the site, the subcontractors can handle their own materials or a logistics team can do all the materials handling on-site.

In a case study by Ekeskär and Rudberg (2016) it is recognized that a checkpoint at the construction sites has an important function in the receiving of goods. The personnel at the checkpoint are responsible for the contacts with the drivers but also to make sure that there is no queuing up outside the site. At the checkpoint materials are inspected and the receiver is notified.

2.6 Cost Modelling Regarding Construction Logistics

Construction business is a cost-oriented industry with a constant focus on reducing costs and increasing profits (Janné and Fredriksson, 2018b). Construction logistics and treatment of material can amount to a big percentage of the total cost for construction. Despite this, Janné and Fredriksson (2018b) state that historically there has been very little focus in the industry on trying to assimilate these costs and look at them in detail. Fang and Ng (2011) describe how logistics costs are to some extent intangible and material is quoted "as delivered" which under these circumstances can make it seem natural to not know what goes into these logistics costs. Janné and Fredriksson (2018b) argue that not knowing what goes into logistics cost implies a risk for sub-optimizing by cutting the wrong logistics cost or e.g., raise the storage cost due to purchasing more materials than needed.

2.6.1 ABC Methodology for CLC

Cost modeling has been a vital part for corporate decision-making for centuries and Miquela (2001, p.133) states that a cost model is "*The tool that companies use in order to have a proper understanding about how to run their business*". One of the main purposes of a cost model is to gather and analyze data generated in the company which will provide useful information and form the basis for decision making (Miquela, 2001). An approach to make logistics cost tangible is Activity-based-costing (ABC) which has been a widely used method in various industries since the 90s (Miquela, 2001). Janné and Fredriksson (2018b) describe ABC as a cost accounting technique that highlights the relationship between activities and resource consumption. A general definition of ABC methodology is made by Hicks (1992) as "*In Activity-based costing, systems are designed so that any cost that cannot be attributed directly to a product, flow into the activities that make them necessary. The cost of each activity then flows to the product(s) that make the activity necessary based on their respective consumption of that activity".*

Miquela (2001) states that ABC is considered invented by Johnson and Kaplan in the early 1990s as a result of the need for improvement in visualization of cost relationships in industries. Back then, direct labor was no longer the principal component of manufacturing cost and there was a need to differentiate overheads. In contradiction to more conventional methods, the ABC approach relates overheads to specific activities to avoid distortions in service and product costs. Another difference between ABC approach and conventional approaches is the treatment of unused capacity. While conventional accounts describe resources that are supplied, the ABC describes recourses that are used by deliveries. The difference between these two is excess capacity. Miquela (2001) states that companies should be aware of which cost their customers really generate and not allocate the excess of capacity to avoid a risk of overpricing its products or services.

Previous research states that a cost model should be developed by using a spreadsheet (Miquela, 2001). The spreadsheet fulfills the needs of the company and is considered a very powerful tool but still very user-friendly. Janné and Fredriksson (2018b) provide a case study with an economic review of economics linked to the use of a CLC in a construction project. The study specifically examines three different projects within Stockholm Royal Seaport and present a process-template for how to implement ABC modeling of a logistics solution. The presented seven-step process to perform an ABC analysis in construction logistics is outlined below (Janné & Fredriksson, 2018b):

1. *Determine the process of interest and set system boundaries:*

In this first step, one should make a first overview of how the current system is structured and what to examine. In their cost model for construction logistics solutions, Janné and Fredriksson (2018b) divide the model into four subprocesses: direct delivery to site, delivery to CLC, operations within the CLC, and transportation from the CLC to site.

2. Break down the chosen processes into activities:

Once the different process boundaries are identified, one should summarize which activities that take place within the different process areas. It could be helpful to use information from the TPL company or perform studies on-site to get an understanding and identify the different steps that need to be accounted for in the model.

3. Identify the resources consumed in these activities:

In a similar way as in step two, in step three one should look at which resources are linked to each activity that is carried out. This could, for example, be a lorry and a lorry driver or a storage cost.

4. Identify cost drivers for the activities:

In the fourth step, one looks at the costs related to each activity and what drives them. Miquela (2001) states three key factors to account for when for selecting cost drivers: How easy is it to obtain the data required by the cost driver? How does the actual consumption of the activity correlate with the consumption implied by the cost driver? What behavior does the cost driver induce? Janné and Fredriksson (2018b) state that the identified cost drivers are deemed to be the ones with the greatest impacts of the logistics cost of the different subprocesses. Examples of cost drivers from Janne's model are drive time/distance, number of relocations, storage time, etc.

5. Gather cost data:

In step 5 of the process according to Janné and Fredriksson (2018b), *Gather cost data,* one should strive to collect as much current information for the project as possible. This data could, for example, be invoice data from completed projects or current contracts agreements or price lists (Janné and Fredriksson, 2018b).

6. Allocate costs to the activities:

In step 6, costs and activities are put together based on the data that has been measured, alternatively is planned for if it has not yet been completed.

7. Analyze the cost information from a total cost perspective:

Janné and Fredriksson (2018b) claim that the output of a cost model will be of managerial contribution and help divide the main processes into part activities which make them visible. It is important to remember that each ABC model developed only is valid for the specific construction logistics setup studied (Janné and Fredriksson, 2018b). Another important factor to affirm regarding the outcome is to keep in mind that certain costs that were previously "hidden" are now more individually visible, which can make it seem that some processes have become more expensive without this being the case. Cooper and Kaplan (1991) highlight that results from ABC should be used as a guide to reprice customer transactions or products or to perform activities more efficiently. Managers should not use the information from ABC naively to close plants, eliminate products or drop customers. Janné and Fredriksson (2018b) state that it should be remembered that the cost model shows hard data concerning the company and may not capture softer parameters that are beyond the company's control. In the case of construction logistics, this can be exemplified by the fact that a cost model of a CLC can visualize cost for transportations but does not include measured improvement. One example of societal improvements is when a reduced number of transportations to the site improves air quality and reduces risk of traffic accidents.

3 Methodology

In this chapter, the chosen method of the thesis will be described. In section 3.1 the research design and used research approach are presented. Section 3.2 describes the research process and what have been done to get the result that the study has achieved. In the final parts, section 3.3 and section 3.4, a discussion regarding ethical and sustainable conduct are presented.

3.1 Research Design

This study is based on an abductive approach. This approach is suitable since the study consists of an iterative process of systematic combination between the empirical findings and the theoretical framework. This research approach is described by Dubois and Gadde (2002b) as a combination between an inductive and a deductive approach and is visualized in *Figure 3.1*.

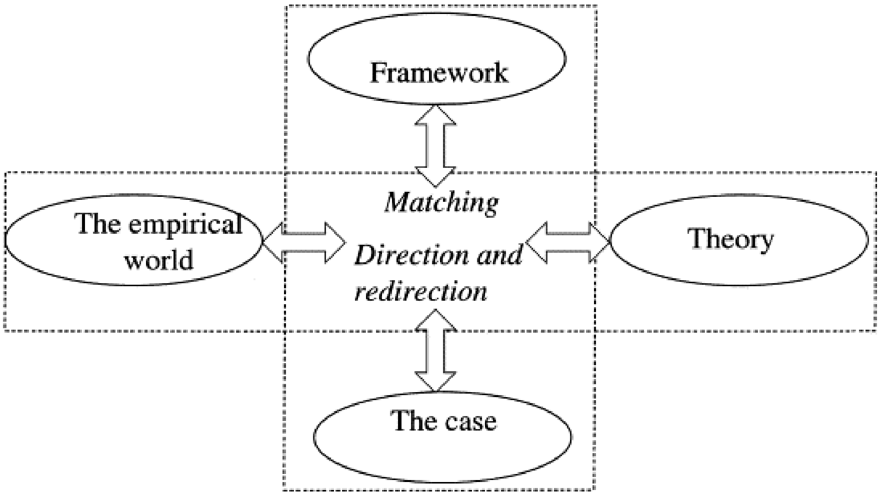

Figure 3.1. The process of Systematic combining (Dubois & Gadde, 2002b).

Dubois & Gadde (2002b) state that "*Matching*" is about going back and forth between framework, data sources, and analysis. It is said that this process does not have any obvious patterns; that the efforts to match theory and reality can take different directions and there is no single way of matching. "*Direction and redirection*", the second component of systematic combining according to Dubois & Gadde (2002b), is stated to be an important feature to be able to achieve matching. *Direction and redirection* are about the importance of different sources and data, together with the methods of data collection. Multiple sources can according to Dubois & Gadde (2002b) contribute to the discovery of new aspects and dimensions of the research problem.

The thesis consists of a theoretical framework that is built on previous research and a case study with empirical data collection. Therefore, an abductive approach is considered to be the most suited research reasoning for this thesis. An abductive approach also provides the opportunity to change the research questions afterward whether interesting insights emerge along with the implementation of the work. During the process, several occasions occurred were interesting new aspects emerged that at first had not been intended to be accounted for. For example, when collecting data from the case, it was found that the contract design and the relationship between supplier and customer were of great importance for both the numerical data as well as it provided a clear framework for future changes. At the beginning of the research process in this study, this was not considered to be a focus area. Due to these insights, it was decided to make a more detailed theoretical review in the subject area concerning supply chain relationships and different sourcing options. Another example can be found in the scope of TCA modeling. At the initiation of the project, the idea was to only analyze the logistics process until the material was unloaded at the site. However, as the study was carried out, it was realized that the material reception on-site was too significantly intertwined in the process to be excluded from the TCA. Systematic combining allows this process to occur, that the direction of study can change during the process.

In this thesis, the aim was to deeply analyze a phenomenon in a certain context in a specific project. This makes the study best suited to be conducted as a qualitative study. Qualitative research uses fewer but deep empirical answers and Bryman & Bell (2015) state that observations, interviews, and reviewing of documents are the most common methods in qualitative research.

3.2 Research Process

The research process started with the framing of the case and the theoretical framework. This thesis work is based on a case study that aims to examine the costs for two logistics processes of material delivery to site; one with a Construction Logistics Center and another with direct delivery to site. To achieve a TCA-model, a reference project has been analyzed. The project is referred to as the All-In project. The project is a “typical” JM housing project, located in a new development area at Lidingö Dalénum. The first step in the process was to execute a literature study. The literature study made it possible to create a theoretical framework that contributed with the knowledge to be able to answer the research questions and to perform the empirical data collection. Further, an empirical data collection was made, based on framework agreements, interviews, observations, and discussions. The empirical data consists of the designing of the TCA model and the data required to be able to do an analyze of the costs. The TCA model results was then analyzed by using the theoretical framework. Analysis of the cohering of empirical data and the theory led to conclusions where the research questions were answered.

3.2.1 Literature Study

A literature study was initiated at the beginning of the process to build a base of knowledge around the chosen subject. Search platforms such as Chalmers Library and Google Scholar were used to find appropriate reports, journals, and books. Some keywords were identified while searching for literature. These keywords were: *Construction supply chain management, Construction logistics, Construction Logistics Center, Third-party logistics in construction, Construction logistics cost management,* and *Total cost analysis.*

A selection of the literature was made to find appropriate articles that could contribute with relevant information for the theoretical framework of the thesis. The research involved characteristics of the supply chain in the construction industry, construction logistics currently, and logistics solutions and methods to improve the logistics. Also, knowledge and learnings regarding the performance of a total cost analysis were included in the research.

3.2.2 Empirical Data Collection

The data collection for the case study was in progress throughout the whole thesis period. The data for the empirical case of the thesis was generally retrieved from JM's framework agreements with suppliers, numerical data from a BIM model, time plans from a reference project, observations at the CLC, and interviews/discussions. The design of the TCA model was inspired by Janné's and Fredriksson's (2018b) 7-step process to perform an ABC analysis of delivering via a CLC. Literature research gave insights that analysis of construction logistics costs is rare and observations at the CLC showed that data regarding various activities needed to be obtained. Janné and Fredriksson (2018b) 7-step guide was considered relevant for this case as an analysis of different activities were to be carried out in the TCA model. The 7-step guide served as a basis for the design of TCA model but were customized to this specific case study. Activity Based Costing (ABC) is one way of performing a TCA where the different activities and the cost those entail is the foundation of the total costs. The data collection was performed with an abductive approach going back and forth between data collection, observations and literature.

During the entire research process, ongoing discussions and reconciliations were held with the Group Manager of Logistics Development and the Head of Logistics Department at JM. These reconciliations enable to discussion of assumptions and approaches in the work of designing the TCA model. In addition to these regular reconciliations, a lot of informal discussions took place with relevant staff within the JM organization. Staff at JM helped to obtain the data needed for the TCA model and to make relevant assumptions.

Meetings were held with the Manager at the Calculation Department at JM to get the actual amounts of materials for the reference project but also to know which are the standard products in JM's projects. The amounts in the reference projects and the standard products were important input to later be able to get information about sizes of the materials and to perform a TCA. Other meetings were held with the Group Managers at JM Supply that shared information about material handling at site and how they calculate the cost for the shifts. The Group Managers of Logistics Panning provided information and data regarding the costs for the telescopic handler. With the Group Manager of Operational Purchasing meetings were also held reoccurring which brought knowledge and information about the purchasing of materials but also invoices and information from the CLC. The Group Manager of Operational Purchasing shared valuable information that was compiled to show the amounts, materials, and suppliers that used the CLC in 2020 and the costs it entailed.

The persons and roles with which these meetings were held are presented below in *Table 3.1*. All the persons in *Table 3.1* also each gave presentations about their department, roles, etc., at the beginning of the thesis work for a better understanding of how JM works.

Table 3.1. Information gathering from personnel at JM

Role	**When**
Group Manager Logistics Development	Every week
Head of Logistics Department	Every week
Group Manager JM Supply	25 January 2021, continuously when needed
Group Manager Operational Purchasing/Materials Planning/ CLC	26 January 2021, continuously when needed
Logistics planning and responsible supervisor logistics	26 of January 2021, continuously when needed
Group Manager Production support	26 of January 2021, continuously when needed
Manager Calculation Department	3 of March 2021, continuously when needed

Further, information about filling rates, sizes of material and pallets, and data regarding deliveries were conducted from suppliers. The data from suppliers were valuable input to the model for the different material categories. Information about some of the materials was also gained when observations at the CLC were conducted, dates for these observations are stated in *Table 3.2.*

Table 3.2. Observations made during the study

Date	**Place**	**Activity**
26 of January 2021	CLC	General warehouse inspection
12th of April 2021	CLC	Material outcoming
13th of April 2021	CLC	Material ingoing

When the observations at the CLC were made, conversations were held with the personnel to get knowledge about what their working methods look like, how an ordinary workday is, and the different activities they conduct. Observations, when a truck was loaded and unloaded at the CLC, were also made to validate the assumptions about the handling time set in the model for the CLC. The aim of the observation was to identify and obtain data on certain handling of material types to avoid too many assumptions in the TCA model.

In addition to the meetings with the personnel at the Logistics Department and observations at the CLC, empirical data was also collected through interviews. Interviews were held with the customer success manager at the CLC, Förlängda Armen, to get a broader picture of their business. Three interviews were conducted with supervisors at site that had worked on the projects that had used the CLC. The supervisors contributed with experience and their perception of working with the CLC, JM Supply but also with the Logistics Department. It can be argued that the Logistics Department works on assignment to improve the situation for the customer, which in this case is the production department where the supervisors work. Therefore, it is interesting to gain knowledge about how the logistics solution has so far been received in production.

Further, information was gathered through email and phone calls with the suppliers to get information about the goods carriers they use, how they usually deliver and some prices in the contracts that needed to be further explained. When the meetings were held some of the suppliers also shared their perception of delivering via the CLC and experiences and challenges with the new ways of working.

The data gathered from the interviews with the supervisors and the suppliers are presented in Chapter 4 and the other knowledge gained is included in the build-up of the TCA model in Chapter 5. All interview participants and dates for the actual interview are reported in *Table 3.3*.

Table 3.3. Interviews conducted during the study

Role	Company	When
Staff at CLC	Förlängda Armen AB	26th of January & 12-13 of April 2021
Customer success manager	Förlängda Armen AB	9th March 2021
Supervisor Logistics	JM	16th of March 2021
Supervisor Interior Design	JM	16th of March 2021
Supervisor Interior Design	JM	17th of March 2021
Supplier of Front & Interior Doors	Supplier E	7th of April 2021
Supplier of Insulation (walls & garage ceiling)	Supplier J	18th of April 2021
Supplier of Tile & Clinker	Supplier L	27th of April 2021
Supplier of Plinth & Jamb and Door Lining	Supplier G	28th of April 2021

The interviews were performed in a semi-structured nature which means that questions were prepared, but there was also time for the interviewee to speak freely (Bryman & Bell, 2015). Bryman & Bell (2015) state that questions that are open-ended, as questions in a semi-structured interview, tend to give answers that are long and unique which is in line with the qualitative approach in this study.

3.3 Research Quality

To ensure the quality of the research, Bryman & Bell (2015) suggest that qualitative studies should be evaluated based on trustworthiness and authenticity. Trustworthiness is according to Bryman & Bell (2015) said to consist of four criteria; *credibility*, *transferability*, *dependability*, and *confirmability*. To ensure that the study has *credibility* the focus has been on validating input data. Participating people have been able to see how their input has been used and thus had the chance to validate that the data is correct. Regarding *transferability*, Bryman & Bell (2015) state a threat to the validity of data can be that the participants have the same perspective and therefore not representative of the holistic view within an industry or a company. In this study, the empirical data has been conducted from many of the involved actors, such as the Logistics Department, different suppliers, the supervisors in production, and staff at Förlängda Armen AB. All the involved actors increase the transferability and made the results from the case less polarized.

Throughout this study, the different processes have been under continuous evaluation by the supervisor of the master thesis. Additionally, events where other students have been involved with evaluating the work, performing opposition, and asking questions, have been executed. These occasions are considered highly valued for the quality of the final product and helps to ensure the criteria of *dependability*. The fourth criteria are *confirmability* which implies that the author's own personal values are kept aside and do not affect the results of the thesis. The confirmability is reassured by having two authors that are equally involved in all parts but also by having two supervisors, one at Chalmers and one at the case company, to overlook the thesis work.

An important remark to consider regarding the quality of the TCA model is that the model takes off in a "best-case scenario", thus, that everything flows in accordance with the plans being made. As the study investigates a future scenario that has not yet happened, it is not possible to measure whether unpredicted things would happen, for example, damage during handling at the CLC or that certain deliveries would be late. The input in the TCA model, therefore, does not account for any extra costs besides the ones found in the framework agreements and from data gathering from interviews, etc.

3.4 Ethical and Sustainable Conduct

Bryman & Bell (2015) suggest four main areas regarding ethical consideration of research. The following four areas are suggested to evaluate:

- Weather there is harm to participants
- Weather there is a lack of informed consent
- Weather there is an invasion of privacy
- Weather their deception is involved

No participant can be considered harmed during the process of this thesis as the empirical data collection mainly consisted of interviews and observations executed by the authors. Bryman & Bell (2015) state that the participants should be given as much information as possible about the study in advance before they make the decision to participate or not in accordance with the principle of informed consent. The informed consent was ensured by giving all interviewees and other contracted parties as much information as possible in advance about the study purposes and how their expertise could contribute to the research. At the beginning of the interviews, the interviewees were also informed about the topics that they were going to be asked about and discussed during the interview. Ahead of every interview, with regards to every participant's privacy, they were asked if it was approved that the interview was recorded and if they accepted to be named in the report or not. Those who are named in the report have approved this.

Regarding the selection for interviews and other people to contact in the study, ethical questions have been carefully regarded. The participants were chosen only based on their role and that their expertise would contribute with useful knowledge to the case in the thesis. No other values regarding e.g., personalities have been considered when choosing persons to contact in the empirical data gathering.

From a sustainability perspective, this study can lead to an impact on all three areas of sustainability: social, economic, and ecological. If the results from the TCA model in the case study are used the company can, before the project is even initiated, get a platform for decision making. The TCA model can help to choose alternatives with less costs, something that is not only beneficial for JM but for the society since JM construct residential buildings for many people. The results show valuable information regarding transportations and usage of materials that can be ecologically beneficial. The ecological benefits are closely linked to the social sustainability of those who work on and live close to a construction site and decreasing the resource usage in a project.

4 Empirical Inquiry

This chapter presents a company description of JM AB. In section 4.1, the company's business areas and ambitions are highlighted and a description of how the Logistics Department is organized in relation to the company is presented. Section 4.2 describes the reference project in this case study. Section 4.3 presents the logistics solution to be analyzed with the third-party logistics company and the CLC in question. Data and conclusions from previous logistics initiatives are presented in section 4.4. The chapter concludes with section 4.5, in which a summary of interviews conducted with employees involved in pilot projects working towards the CLC is presented. Section 4.5 also includes a summary with thoughts from the suppliers about the CLC.

4.1 The Construction company JM

JM AB is a Swedish construction company, founded in 1945. Most of JM’s business is focused on building new residential homes in expansive metropolitan areas in Sweden, Norway, and Finland. The company's business idea is: *"With people in focus and through constant development, we create housing and sustainable living environments"*. JM works with project development of entire residential areas and conducts operations that include the acquisition of development properties, early planning, design, production, and sales of residential buildings. The company is listed on NASDAQ Stockholm, in the Large Cap segment, and is one of the largest construction companies in Sweden. During the year 2020, the production of 3199 new homes was started. The company has just over 2,500 employees and the revenue in 2020 was 16.7 billion SEK.

The company's highest decision-making body is the annual meeting of owners. The owners elect a board that governs the company's orientation. Furthermore, the company is managed by an organization divided into Group Staffs, Business Units, and Regions. Group staff includes *Finance & treasury*, *Legal affairs & development*, *Operations development*, *HR*, *communication & marketing*, and *Production*. Five different business segments exist; *JM Residential Stockholm*, *JM Residential Sweden*, *JM International*, *JM Property Development*, and *JM Construction*. This study deals with construction logistics, which is located as a department within the group staff *Production*, see *Figure 4.1*.

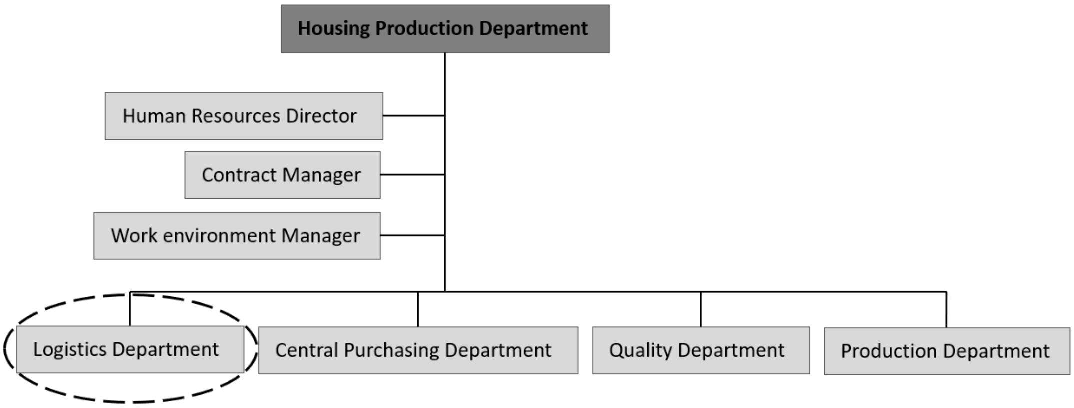

Figure 4.1. Organizational chart over JM's Housing Production Department.

4.1.1 The Logistics Department as Part of JM Production

Since 2010, JM has been working with a strategy named *Structured production* with the main purpose of structuring the company's production. As part of this strategy, some work methods have been standardized and various guides have been produced, e.g., logistics instructions, delivery instructions, assembly instructions, etc. To remain competitive, JM identifies the need to shorten lead times in production. The Logistics Department has emerged as part of this strive to develop the material flows in production so that the value-creating time for craftsmen is increased and lead times are reduced.

As there are various forms of logistics work in several places within the material chain, a distinction of responsibility has been made between the Logistics Department and Production. The areas of responsibility within logistics have been divided between the two departments in the company to get a more efficient supply chain. The Logistics Department is responsible for the flow of some chosen building materials from the supplier to the assembly area on-site as well as handling of waste and returns, see *Figure 4.2.* The Production management is then responsible for all tasks related to planning, preparing, and performing assembly. The chosen materials included in the scope of the Logistics Department have varied a bit in the pilot projects but are generally materials for the interior design phase. One ambition is that the results of this study should contribute to the decision-making of this scope and the relevant material types investigated are presented in chapter 5 of this report.

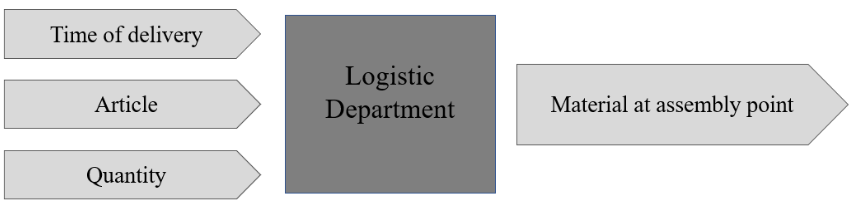

Figure 4.2. The area of operations for the Logistics Department at JM.

JM summarizes the Logistics Department vision: "*Right now we are developing an industrialized logistics function that takes overall responsibility for the material supply, all the way from supplier to assembly area*". As part of optimizing logistics solutions, JM established an affiliated company named JM Supply in 2017. JM Supply has employees who work at construction sites in the afternoons and evenings receiving material and transporting it to the assembly area. The employees at JM Supply are paid by the hour and has an agreement that they always gets paid for at least 4 hours each shift even if they work for shorter time. JM Supply works at all of JM's projects in Stockholm, thus, there is not JM Supply shifts every day. The work structure with JM Supply, enables craftsmen to begin their value-creating work immediately in the following morning as well as minimizing on-site inventory.

JM has established an in-house logistics function for material handling on-site instead of a TPL. Other advantages with JM Supply are that more hours of the day are used and that there will be fewer disturbances for the craftsmen when the materials are being transported to the assembly area in the afternoons. The disturbances for the material transportation will also be reduced when the resources such as elevators on-site will not be occupied with staff. JM Supply is specialized in transporting the materials on site. The idea is that with knowledge sharing as well as development of processes and tools the logistics works could be carried out faster and more ergonomically.

4.1.2 Business Goals to Stronger Competitiveness Affecting Logistics

The construction industry is a competitive industry with many companies competing for tenders, which means that operating margins are often quite small. Like other companies that aim to stay competitive, JM seeks to increase its competitiveness by setting different goals to strive for in the future. To gather resources, prioritize what to do and what should be put aside, JM has adopted the approach and method known as *Must Win Battles, MWB*. The method applies to the entire company and lasts for about four years. One of the identified MWB is to increase profitability through shorter lead times and reduced costs, and therefore JM has launched a project themselves named *Must-win battle 2.0* where the main objective is *"efficiency through an increased degree of industrialization without sacrificing work environment and customer satisfaction*". In MWB 2.0 the lead times should be reduced by 25 percent by 2025. This 25 percent should also be cut without increasing the overall costs in the projects. Initiatives that are intended to support this include as an example; new central organizations for product and process development, lead time shortening with prefabrication (tests of bathroom modules and ceiling cassettes), development of logistics and material handling, and increased pace in product development.

In addition to the goals of production efficiency, there are distinct goals within the company regarding climate impact that will affect production and logistics work. JM is part of the Haga initiative and signed an ambition to reduce climate-affecting emissions by 85 percent from a

2010 level. As of 2018, all residential units that enter the pre-construction phase will be certified in accordance with the Nordic Swan Ecolabel. The Ecolabel, for example, sets demand regarding material choices and a quality-assured construction process which minimizes the risk of materials getting wet and creating mold problems.

4.2 The Reference Project

JM AB works as presented in section 4.1.1 with standardized working methods and schedules. The company continuously reviews these approaches and sometimes launches pilot projects to find new better standards for future projects. As part of the goal to shorten the lead times to the year 2025, the company has now put together a project group working on a pilot project under the project name All In. The All-In project is designed around the construction of a new residential building with apartments. The main objective of the project is to shorten JM's production lead times by 20 percent compared to regular projects. The reference project is named the All In project since JM aims to go "all-in" with new implementations and solutions from several different departments at the company.

The project is located in the Dalénum district, a former industrial area at Lidingö in Stockholm, that JM has developed and converted into a residential area during the last decade. The reference project is JM's last project in the area and is planned to be completed in the autumn of 2022. The project consists of 58 condominiums in various sizes, from one to six rooms and a kitchen. At the bottom of the house, there will be a garage for vehicles. The residents will have close communications to the Stockholm city center by public transfer by boat, bus, and commuter trains. An image of how the project will look like when it is completed is seen in *Figure 4.3*.

Figure 4.3. The reference project a residential building project.

To reach the goal of shortening JM’s production lead times by 20 percent the project schedule has been looked over in more detail than usual to reduce the gaps. According to the current standardized schedule, the project would be completed in 365 days from sheet pile driving to the first move-in. By testing several different solutions, such as changed planning of the production schedule as well as new manufacturing methods, the company now aims to complete the project in 281 days instead, a decrease of 21 percent in total. The All-In project has not only invested in the logistics solution to be able to shorten lead times, but another example is also that some of the subcontractors will work in two shifts to use a larger proportion of the available hours in a day. JM has also reviewed some of the assembly activities to perform them in another way or parallel with other activities to make the production more efficient. One example is the choice to use a carpet of reinforcements that can be rolled out, instead of traditional reinforcement methods which must be attached manually rebar by rebar.

Usually, in a JM project, the schedule is planned per apartment for a production rate constructing one apartment a day. If one apartment is smaller than the average one and takes less time the gap is used when an apartment is bigger and needs more time so that the average remains an apartment/day. The plan with the reference project is that there should be no such gaps but instead, the planning should be more in detail to use the time more efficiently. This means that in this project, the idea is not to change the production rate and that the craftsmen should work "faster" but to plan and work differently to avoid unnecessary gaps.

The Logistics Department at JM’s noticed that there is a lot of time while the apartments are empty during construction and no work is being done, which is intended to be avoided in this project. To make it possible to perform activities in all the apartments at once great demands are placed on a logistics function without disruptions. It will be essential to have all the materials needed in place at the right time as well as no materials not needed hindering the work. JIT-deliveries will be a prerequisite for successful implementation as well as functioning waste management to remove the waste. In performing successful JIT-deliveries and logistics management, the CLC described below in section 4.3 will be an important part as well as the work of JM Supply. In the company's usual structure, materials are normally ordered for five apartments per delivery, which then is delivered at the same time. In the reference project, the ambition is to test a delivery structure that implies ordering and receiving separately for each apartment the day before the material is to be assembled. To just deliver materials to one apartment a day puts a high demand on the delivery to arrive when decided and to be able to co-load materials to avoid a lot of transportation.

4.3 JM Construction Logistics Center

The Construction Logistics Center that JM uses for a few of their projects in the Stockholm region, and that will be used in the reference project, is owned, and run by a TPL company named Förlängda Armen AB. In the procurement of the TPL, JM stated in the assignment description that the CLC will act as a consolidated load spot. The CLC will receive trucks with goods that later will be co-loaded and delivered to JM's sites in Stockholm. If there are any returning goods or pallets at the sites, the trucks will be loaded with these and return to the CLC. The CLC will also work as a buffer zone for materials and to make sure that JIT-deliveries can be managed, however, the CLC is not planned to work as a long storage unit.

The CLC is located in Järfälla, northwest of Stockholm, close to highway E18 that runs across Sweden and connects Stockholm with Oslo. The TPL has a CLC consisting of several warehouses with different conditions for different product storage. The main part of the goods that JM keeps in the CLC is stored in a non-tempered warehouse with a storage area of 4500 m^2. The warehouse consists of a big open area to arrange the incoming and outgoing goods and can be used to offload trucks if needed, see *Figure 4.4*.

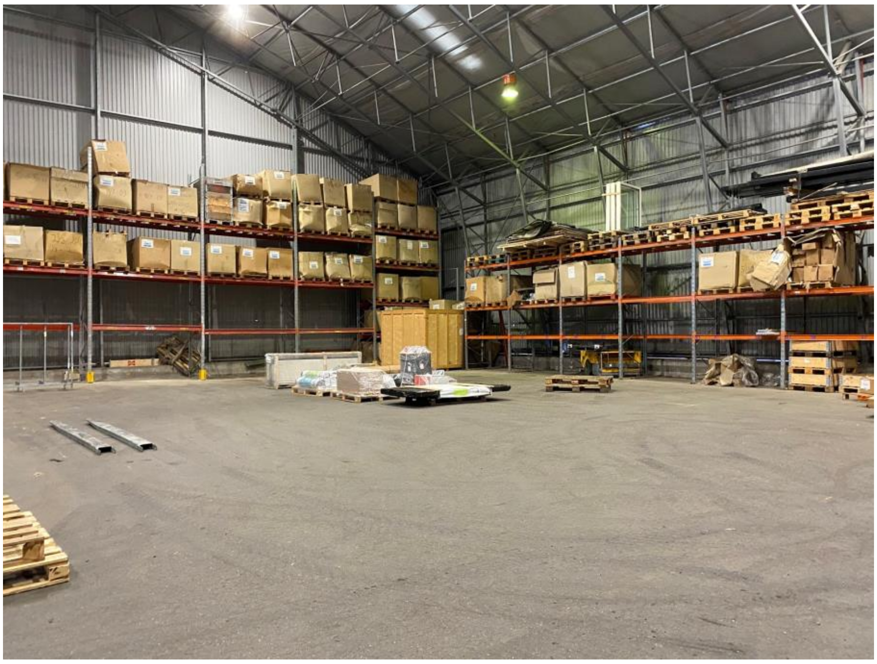

Figure 4.4. Open area to arrange goods at the CLC.

For storage of materials that are not needed at once, there are steel racks to store regular pallets in but also space on the floor for material storage, see *Figure 4.5*.

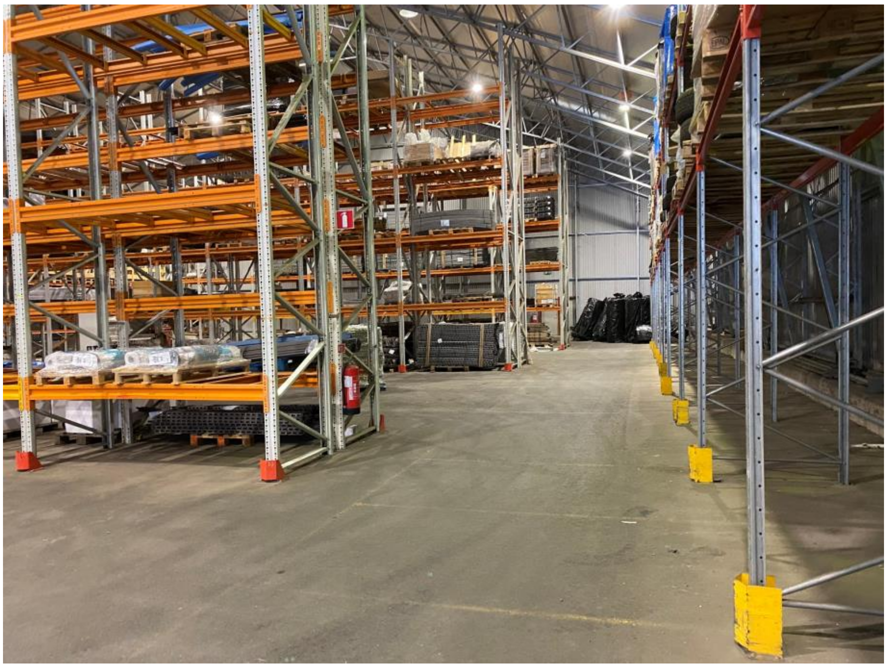

Figure 4.5. Racks for pallets and space on the floor for other goods carriers at the CLC.

In the agreement between JM and Förlängda Armen AB is a pricelist that states the fee for the different services. JM pays a monthly fee to Förlängda Armen AB for every square meter that they use in the warehouse and for the time spent on receiving goods, handling goods, and loading trucks. JM also pays for the deliveries to site which is done by the TPL's trucks. The TPL company charges by the hour for the deliveries from the CLC to the sites. Förlängda Armen AB has about 60 vehicles to support their customers with, the trucks that deliver to JM's projects are run by HVO100 fuel. The choice of fuel for the vehicles is a demand from JM to reach their previously mentioned sustainability goals. Besides the company goals, transportations also need to fulfill the current environmental laws that the City of Stockholm has set (Stockholm City, 2021). The city is divided into environmental zones and since JM's projects are located in different places in Stockholm the trucks need to be able to deliver to all of them.

When the goods from the suppliers arrive at the CLC, the personnel are responsible for unloading the goods and do a check-up of the consignment note (that the right things are delivered) and look for any damages. If any damages are found on the materials or the packing, the personnel should take a photo, make a note on the delivery note and then inform JM. When the ocular inspection is done the materials should be labeled with project, order number, and date for delivery and then put away in a suitable location in the warehouse. The materials that arrive at the CLC are logged in Förlängda Armen AB's warehouse management system, WMS - Ongoing which JM also has access to. In the WMS all materials that are stored at the CLC can be seen that they are there, it is also possible in the WMS to see the call-offs that JM has done in their system. When the planned delivery date to site comes or when JM places a request for a certain material the TPL loads the goods in their trucks and delivers them to the sites. The trucks should be chosen depending on the size or amount of the goods since the trucks going to the site(s) should strive for a high degree of filling ratio.

The CLC can receive trucks on weekdays between 07.00-14.00 and the TPL can deliver to the sites between 07.00-19.00, which is a more flexible timetable than usual for both suppliers but also the projects. Suppliers get a delivery window to the CLC from one to 21 days ahead of the desired delivery to the construction site. This time span enables the suppliers to fully load their trucks as well as deliver at a time that suits them best. The sites can also get more precise deliveries since the TPL delivers all days of the week but also is procured to specifically handle the off-site logistics for JM. Since many of JMs suppliers have an extra fee on their deliveries when they must arrive on a certain day or time, JM can save money with this solution since there is a large arrival time span.

JM has their logistics company, JM Supply, that does almost all their material handling on-site in the afternoons and evenings. JM Supply's work is also facilitated by the CLC since the deliveries can arrive in the afternoon instead of in the mornings, which is commonly when most suppliers prefer to deliver to the sites.

4.4 Previous Logistics Initiatives

During 2020 there have been three JM projects in Stockholm that have been connected to the CLC in Järfälla as part of an initial test. These projects are all to be regarded as typical JM projects consisting of residential housing buildings. The projects have been co-loading some of their building materials at the CLC. The ordering structure in these projects has followed the JM standard with batches of five apartments per delivery. In the reference project, the method that will be tested is to deliver interior material to just one apartment per delivery but to deliver different materials to several apartments a day. So far, the outcome has not been analyzed on more than one overall level with a focus on the decrease of number of transportations to site when delivering to five apartments per delivery.

JM's internal investigation showed that the usage of the CLC in Järfälla reduced the number of transportations to the actual construction sites by 83 %, this is visualized in *Figure 4.6*. The CLC has made it possible for suppliers to fill the trucks with construction products and materials for more than one construction project at a time. The investigation proved that these consolidated deliveries reduced the number of long-distance truck transportations with 56 % fewer trips.

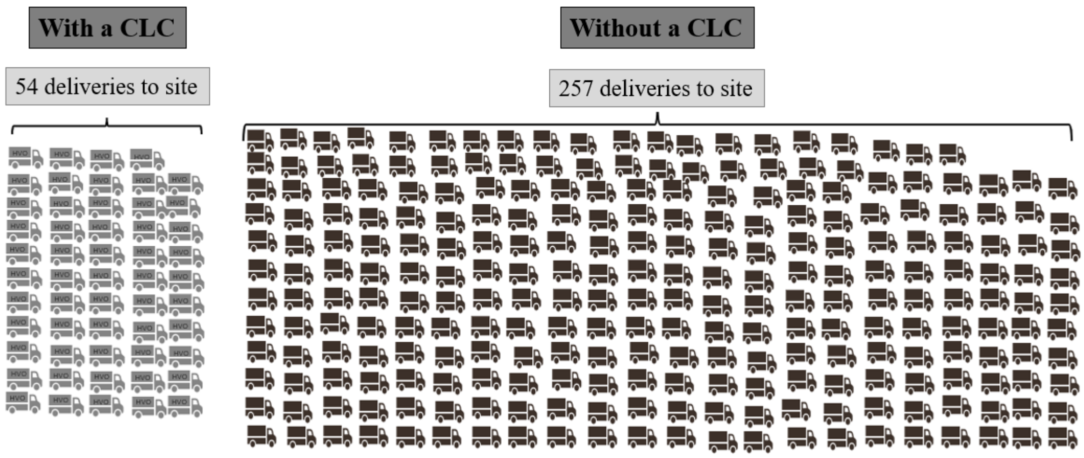

Figure 4.6. The number of deliveries to site with and without the CLC.

There are no exact numbers available in this area, but the reduced number of transportations is expected to reduce carbon dioxide emissions, especially since the transportations from CLC are powered by the renewable fuel HVO100. It is also highlighted that fewer transportations imply a better working environment and everyday life for the surroundings with less noise, improved air quality, and reduced risk of traffic accidents.

4.5 Perceptions of the CLC from Site Supervisors and Suppliers

In this section, the different perceptions of the use of the CLC and JM Supply are presented. In the first section, the answers from interviews with the supervisors at the projects that used the CLC during 2020 are presented. In section 4.5.2 the suppliers' perceptions are presented.

4.5.1 Supervisors at the Sites and the CLC

As one of the main reasons for using a CLC is to improve the production flow, it is important to know how the CLC solution so far has been received by the personnel in the projects. Three interviews were conducted with supervisors who worked on the various projects that used the CLC in Järfälla. All three supervisors have worked in the construction industry for many years, first as carpenters and lately as supervisors, and can be considered experienced. Two of the supervisors are responsible for leading the interior work and the third has the title of logistics supervisor, a new role at JM that is responsible for the flow of materials on-site.

The view of construction logistics differs historically between the supervisors. One of them firmly claims that that logistics is a big problem, while another describes the logistics as quite messy especially in inner-city projects. The third interior supervisor states that there are probably a lot of construction logistics problems, but that they are often hidden both in time and cost and that "*things are always solved, but maybe not at the best price and time*". All the supervisors feel that there has been a greater focus on logistics in recent years.

The different orientations of the supervisors' role show that they received different introductions and information about the use of the CLC and JM Supply. The logistics supervisor was placed within the Logistics Department and was well informed of the logistics solutions that were to be used. The other two interior supervisors expressed that the use of a CLC and JM Supply was forced upon them when they arrived at the project. Both of the interior supervisors explained how they at first had a bit of a negative setting towards the use of a CLC as well as to have JM Supply receive and handle the materials on-site. There is thus a demand for greater participation earlier in the process for the interior supervisors and that they also think they should be able to have a greater ability to affect and bring their opinions into the design of the logistics solution based on the specific conditions of the projects.

All three supervisors participated in projects that were among the first of their kind within the organization and all of them described some teething problems at the initial stages. It took a while to get a grip and get into the new methods and division of responsibilities, but both interior supervisors said that the CLC worked better after a while.

The logistics supervisor's experience with the CLC from the project was very good as the trucks arrived at the right time and it was the same driver of the deliveries all the time. The logistics supervisor also explained a great difference in site traffic when just one or two trucks arrived in the afternoons instead of the usual around six or seven like there usually are. The logistics supervisor explained that before the implementation of the CLC they had trucks that had to wait outside the site due to lack of space. On the contrary, one of the interior supervisors did not experience that the use of the CLC resulted in fewer phone calls or trucks arriving at the site. Instead, there was a problem when all the materials arrived at the same time in the afternoon since then the site needed a larger area for unloading. When the deliveries came during the whole day the unloading area could be smaller since then they had time to move the materials before the next truck arrived.

Regarding the daily work and tasks, the logistics supervisor noticed a difference in time spent per day on the receiving of materials when using the CLC compared to when not. In the project when they used both the CLC and JM Supply the logistics supervisor said that "*There is a big difference. Now I tried to just set aside one hour during the day to make sure that everything was ready for JM Supply in the afternoon, make sure there was a telescopic handler available and inform the affected parties during the day and then just let it go completely".* Regarding med-hours, the logistics supervisor saved 4-6 hours a week when using the CLC and JM Supply, and as a result, follow up on planning improved by this way of working.

The interior supervisors who did not have the same information when they started their projects with the CLC did not experience that they saved time. Both instead explained that it took more time since they had to work differently from what they were used to. Also, when the Logistics

Department was involved, the interior supervisors felt like they had to spend time explaining how things work on-site since the logistics employees did not have that experience in the beginning. The general idea was that the Logistics Department was partly responsible for the ordering and call-off materials since the idea is that personnel at the projects should not have to spend their time on logistics. The two interior supervisors experienced that working like that just meant more work for them since all the problems occurring when something did not work out ended up in their lap anyway. In addition to those issues, the supervisors also felt that the Logistics Department lacked a bit of understanding when things had to be rescheduled due to changes in production.

None of the supervisors expressed that they experienced the implementation of the CLC solution as something negative from a general point of view. The concerns instead seem to relate to the division of responsibilities and the information within the solution and whether it is economically advantageous with this solution. The main problem that created frustration among the interior supervisors seems to have been the division of responsibilities and lack of building-specific competence at the Logistics Department. This meant that production on-site felt that the Logistics Department was unable to provide beneficial conditions for production to the extent promised from the beginning. One of the supervisors thinks that the CLC and JM Supply is just an extra cost. If it is to be used, the Logistics Department has to take the whole responsibility connected to the logistics so that the supervisor can let go of it completely and really save time. The other interior supervisor expressed concern about the receiving and inspection of the goods. Currently, JM Supply does an ocular inspection when the goods arrive from the CLC but since they lack the knowledge about what the goods need to include the interior supervisor anyway needs to do an own goods receipt the day after to make sure that all the needed material has arrived. The interior supervisor also said that JM historically has been having issues with the goods receiving. The interior supervisor claims that they have gotten better control but that there is a concern when more parties are involved to know when and where any damages occur.

On a general level regarding future development, all three are relatively positive to an upscaling of the solution with a CLC. The logistics supervisor thinks that smaller batches will be important in the future, especially in inner-city projects with a shortage of space at the site. The logistics supervisor wants as few trucks as possible and once again points out the perceived benefit of how much easier it is with the same truck driver, telescopic driver, and coordinator from JM Supply. The logistics supervisor says, "*It is very important, so you do not have to reinvent new relationships all the time and learn how everybody wants it, so it will be successful*".

However, some warnings are highlighted. One of the interior supervisors is skeptical about the idea to make the time plan more detailed to reduce gaps and try to achieve a one-apartment per delivery flow and even shorter "safety margins" in production. The interior supervisor says, "*It is people we are dealing with, not robots"*. The supervisor sees a risk that the quality will suffer and that it will be difficult to get more satisfied customers. The interior supervisor believes there must be other ways to earn time and money for JM and claims that a house construction must be allowed to take some time for quality. Regarding an upscaling of the project, the interior supervisor emphasizes that this will place even greater demands that the right competence exists in all parts of the organization.

4.5.2 Suppliers and the CLC

During the process of data gathering, many suppliers were contacted to answer questions about loading capacity and transportation. It was an opportunity to ask questions and discuss their views of construction logistics and eventual experiences of delivering to a CLC. Almost all the suppliers expressed that the strive towards a CLC solution is the right way to proceed. Supplier G said that "*This is a way better delivery solution for us, then we do not have to drive around carrying air*". As co-loading of materials to several JM projects to the CLC there are higher filling rates in the trucks, and the suppliers can also arrive when is best suited for them. This is something that Suppliers G mentions, but also other suppliers bring forward.

Another supplier mentions that to have the opportunity of a time window of four weeks instead of half an hour in the afternoon is much more compatible with their manufacturing but also with their transportations. Many of the suppliers have their production in smaller towns all over Sweden. Supplier G claims that with the current solution, without a CLC, the transportation cost more than their products since the distance is so far and the trucks are half full.

Supplier E expressed to JM when they introduced this solution that; "*this sounds very interesting! It gives us a lot of new opportunities. Now we can rethink both our production and transportation to the customer*". Supplier E precives that the delivery to the CLC during year 2020 had worked out really well. Regarding the vision of smaller batches, Supplier E said that some prices in the current agreements have to be changed if the ways of delivery would change. According to Supplier E, prices for delivery to a CLC instead of directly to site may be lower, but if smaller batches are desired, other costs may be added for more pallets and wrapping.

Supplier J provides a material that JM usually procures as a package-deal with a subcontractor that gets responsible for material supply and installation. The supplier described that their shipping terms are very much based on encouraging large orders and deliveries. Supplier J therefore believed that JM would save money by taking over the responsibility of the material supply themselves. In this way, JM could benefit from the supplier's economies of scale and avoid what the supplier thinks are additional extra margins that the subcontractor applies. But, as Supplier J also points out, it is also resource-intensive to have staff who know what and how much to order, so JM has to assure that competence first.

Supplier L expressed that it was about time that the construction companies started to pay attention to the logistics. Supplier L has been working with tile and clinker and their logistics for many years. The costs for different delivery sizes have not been considered previously. The construction companies just want a number to be able to calculate the costs in an early stage instead of optimizing the way to deliver to save money.

On a general level, most suppliers perceive the CLC solution as something that simplifies logistics for them. They see opportunities of greater efficiency in their transportation as they can load for several projects at the same time, deliver to one single place with a not-so-specific time window for delivery.

5 Total Cost Analysis at JM

This chapter presents the Total Cost Analysis (TCA) model at JM and thus covers research question one regarding the design of the TCA, and evaluation of costs and cost drivers. Section 5.1, presents the scope of the TCA model, including which materials that are considered. Section 5.2 presents the design of the TCA model based on Janné's and Fredriksson's (2018b) seven-step process to perform Activity Based Cost modeling (ABC) of a logistics solution. Parameters in the TCA model and their impact on the result are also presented. Finally, in section 5.3, the results for the various logistics alternatives are presented and discussed.

5.1 The Scope of the TCA model

In the initial stage, the material types to be included in the TCA model are selected, corresponding to in total 21 material categories. The selection is based on a working document provided by JM's Logistics Department that states which materials that could fit into the solution with a CLC. The list of materials that are included and thus, analyzed in the TCA model are (the Swedish name in parenthesis):

- Bathroom furniture *(Kommoder/Våtrumsinredning)*
- Bicycle rack (*Cykelställ)*
- Brick *(Tegel*)
- Door hardware and hooks *(Dörrbeslag och krokar)*
- Front door *(Tamburdörrar)*
- Hat racks *(Kapphyllor)*
- Heated towel rail *(Torkställning)*
- HVAC shaft doors *(VVS schakt fronter)*
- Interior doors *(Innerdörrar)*
- Jamb lining *(Smygar)*
- Kitchen *(Kök)*
- Net walls for storage *(Nätväggar)*
- Parquet flooring *(Parkett)*
- Plinth and door lining *(Sockel, foder & anslagslist)*
- Roof insulation garage *(Takisolering garage)*
- Shower cabin walls *(Duschväggar)*
- Sliding wardrobe doors *(Skjutdörrsgarderober)*
- Tile and Clinker *(Kakel & Klinker)*
- Wall insulation *(Väggisolering)*
- Wall mounted range hood *(Spiskåpor)*
- Windowsill *(Fönsterbänkar)*

Among these materials, a selection of materials (bathroom furniture, front door, HVAC shaft, interior doors, jamb lining, plinth, door lining, kitchen, shower cabin walls, sliding wardrobe doors, wall mounted range hood) have been tested to be part of a solution where delivery takes place via the CLC in pilot projects, while the rest of the materials are still only considered to be part of such a solution in the future. The TCA is a part of the decision making regarding whether to proceed with the current solution with *Direct Delivery* or change to a CLC solution. A prerequisite for being able to use the CLC for a certain type of material is that the supplier is connected to JM's call-off system. Some of the materials in the list (bike racks, net walls for storage, bricks, and roof insulation in the garage) are not connected to JM's call-off system yet. But these material types are investigated in the TCA for future decision-making regarding the possibility to include them in the CLC solution or not.

The materials are in most cases used in the final stages of the production phase with interior work. The decision to focus on interior materials is because these material deliveries are intensive at the interior stage of production. JM aims for a specific pace in the production phase and to increase the value-creating time for the craftsmen in production. By using JM Supply for on-site materials handling, materials can be ready for assembly in the apartments by the work of craftsmen. At the final stages of production, there are many different material deliveries from several different suppliers and when the quantities are to be distributed per apartment, it places great demands on delivery management. In this production phase, a CLC enables to co-load various smaller deliveries in relation to production pace, thus, when needed on-site, in accordance with JIT-deliveries. In the interior phase, often a time-constrained phase in production, the CLC could also create extra security in the materials supply and robustness in the system and improve the probability to attain the production time plan.

5.2 The Design of the TCA model

The TCA model is designed by taking inspiration from Janné's and Fredriksson's (2018b) seven-step to an Activity Based Costing (ABC) analysis, but the steps towards the TCA model are modified to fit the JM case. The following sections define the creation of the TCA model including processes, activities, resources, costs, and cost drivers.

5.2.1 System Boundaries and Breakdown of Processes into Activities

The system boundaries are established to include the truck departure from the first-tier supplier to the assembly area on-site. Inside this system boundary, there are the two logistics processes that are compared: *Delivery via CLC* and *Direct Delivery*. These two processes in turn consist of subprocesses, including activities (see *Table 5.1).* The system boundary and its subprocesses and activities are visualized in *Figure 5.1*.

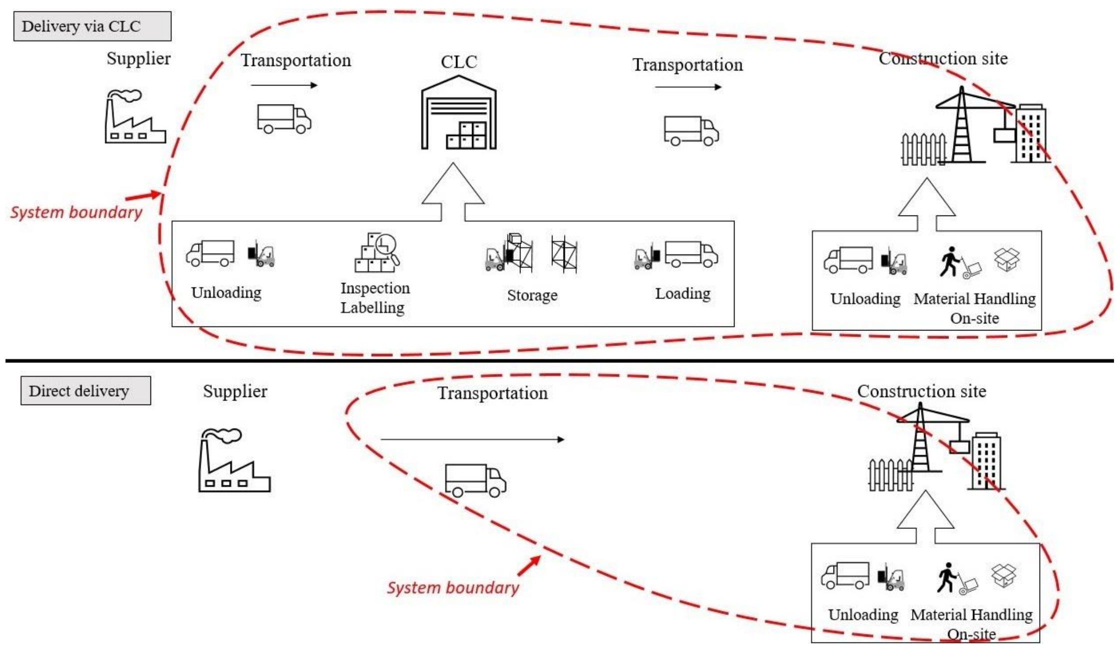

Figure 5.1. The two different logistics processes studied and their activities

Table 5.1. The logistics processes including subprocesses and activities

Logistics process	Subprocess	Activity
Delivery via CLC	Transportation to CLC	Transportation, Announcing.
	CLC operations	Unloading, Quality inspection, Registration, Labeling, Storage, Moving of goods, Planning, Loading, Receiving returned pallets.
	Transportation to site from CLC	Transportation, Announcing.
	Material Handling on-site	Unloading, Transportation to the assembly area.
Direct Delivery	Transportation to site	Transportation, Announcing.
	Material Handling on-site	Unloading, Quality inspection, Transportation to the assembly area.

The subprocesses are divided into activities that take place within each subprocess. The activities that are identified within the subprocesses *Transportation to site*, *Transportation to CLC* and *Transportation to site from CLC* are: the *transportation* of goods with a truck and *announcing* which is done by the truck driver so that the one receiving the goods knows it is arriving. Within the subprocess: *CLC operations* there are several activities happening. The arrived goods are *unloaded* and placed in the warehouse for a *quality inspection* to assure that there is no visible damage to the goods. After the inspection, the goods are *registered* in the WMS and *labeled* before being placed into *storage*. The WMS does not show where in the warehouse something is stored and therefore the staff working there must keep track of the goods themselves. The use of a WMS that lacks this mapping function contributes to additional *moving of goods* to make place for other materials or to make sure that what is needed most urgently are stored with an easy access. Other activities within the CLC are *planning*, including where to place the goods and how many trucks are needed each day to transport the goods to the sites. However, the *loading* of the trucks to the site, and *receiving* and handling the empty pallets that are returned from the sites are activities within the CLC.

Within the *material handling on-site* subprocess, the activities *unloading* of the truck, *quality inspection* and *transporting the materials to the assembly area* take place. All material handling on-site is done by JM Supply except for bricks. JM Supply always starts their shift in the afternoon, beginning with the unloading of trucks before removing packaging and transporting the materials to the assembly areas with the help of different tools like pallets jacks or telescopic handler.

5.2.1.1 Alternative Batch Sizes for the Two Processes

The two logistics processes have two alternatives regarding batch sizes. The first alternatives are the traditional way, which is the current JM standard. *Batch size standard* is most often five apartments per delivery but there are also material types which is delivered per floorplan or per floorplan and stairway. The standard batch size for each material type is presented in table 5.2 below. The second alternative *is one-piece flow*. In the reference project, the vision is to deliver in a *one-piece flow* and to achieve JIT-deliveries. The *one-piece flow* is dependent on the working pace for one day. The materials concerned in the TCA have different pace for assembling but the idea is to cover for 1-2 days of progress in one delivery. The TCA model has been designed to be able to compare four main alternatives to evaluate the difference in price between the following:

- *Delivery via CLC for batch size one-piece flow*
- *Direct Delivery for batch size one-piece flow*
- *Delivery via CLC for batch size standard*
- *Direct Delivery for batch size standard*

The two different logistics processes for *one-piece flow* are visualized in *Figure 5.2* and the two logistics processes for *batch size standard* are visualized in *Figure 5.3*.

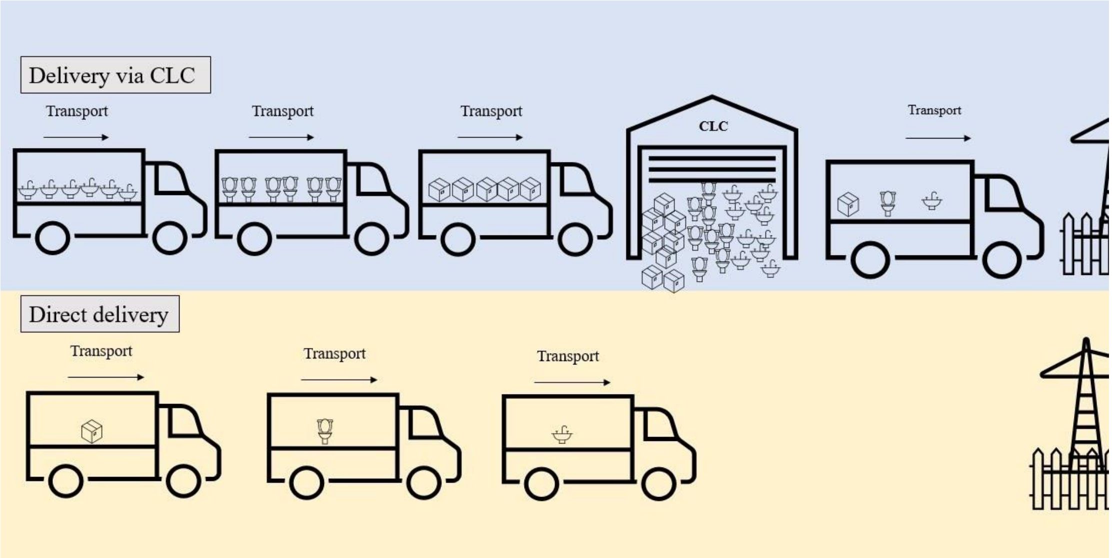

Figure 5.2[1]. The two logistics processes with batch size one-piece flow.

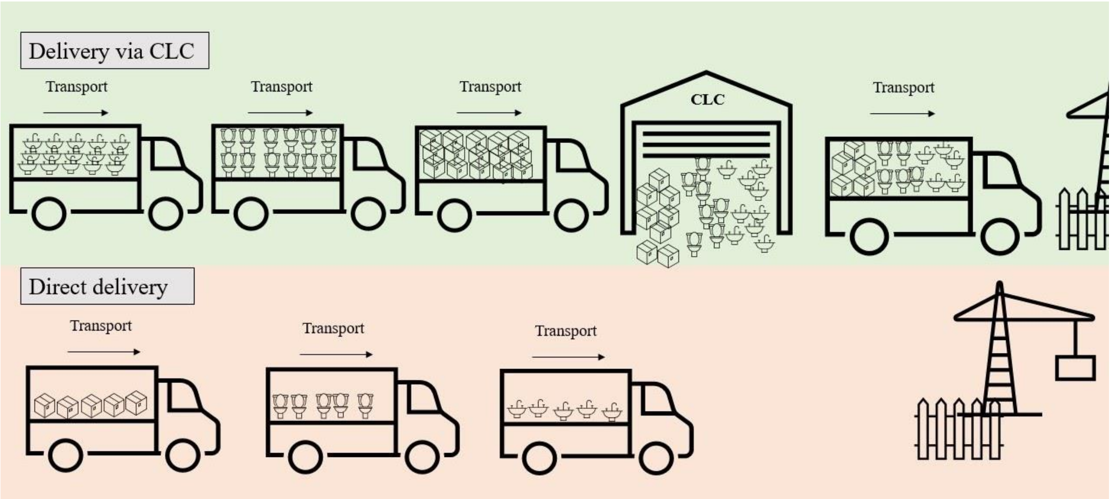

Figure 5.3[2]. The two logistics processes with batch size standard

The activities in both batch size alternatives are thus the same, but the quantities delivered are different. In the *batch size standard*, materials are usually delivered to cover for 5 or 12 apartments per delivery, whereas the *one-piece flow* covers one apartment per delivery. The materials in the JM standard alternative that are divided to be delivered by floorplan and stairway get delivered the same way in the *one-piece flow*. This division of unit per delivery to site is made because the *batch size standard* is already to be considered as a *one-piece flow* since one floor plan in one stairway is assembled in one day. For the materials that usually are delivered in full trucks just a few times during production, the *one-piece flow* definition is determined by looking at average material consumption and production times for the actual material. *Table 5.2* below presents how the different batch sizes and the intensity of deliveries have been defined in the TCA model.

[1] Blue=Delivery via CLC; One-piece flow. Yellow= Direct Delivery; one-piece flow.
[2] Green= Delivery via CLC; batch size standard. Red= Direct Delivery; batch size standard.

Table 5.2. All the included material categories, their supplier and the batch sizes delivered to site

no	Material	Supplier	*Standard batch size* per delivery to site	*One-piece flow* batch size per delivery to site
1	Bathroom furniture	Supplier A	5 apartments	1 apartment
2	Bicycle rack	Supplier B	Full truck	*Not applicable*
3	Brick	Supplier C	Full truck, 21 pallets	12 pallets
4	Door hardware and hooks	Supplier D	5 apartments	1 apartment
5	Front door	Supplier E	1 floor in 1 stairway	1 floor in 1 stairway
6	Hat racks	Supplier D	5 apartments	1 apartment
7	Heated towel rail	Supplier F	5 apartments	1 apartment
8	HVAC shaft doors	Supplier E	1 floor in 1 stairway	1 floor in 1 stairway
9	Interior doors	Supplier E	5 apartments	1 apartment
10	Jamb lining	Supplier G	12 apartments	1 apartment
11	Kitchen	Supplier H	5 apartments	1 apartment
12	Net walls for storage	Supplier B	Full truck	*Not applicable*
13	Parquet flooring	Supplier I	5 apartments	1 apartment
14	Plinth and door lining	Supplier G	5 apartments	1 apartment
15	Roof insulation garage	Supplier J	Full truck, 20 pallets	2 pallets
16	Shower cabin walls	Supplier A	5 apartments	1 apartment
17	Sliding wardrobe doors	Supplier K	5 apartments	1 apartment
18	Tile and Clinker	Supplier L	5 apartments	1 apartment
19	Wall insulation	Supplier J	12 apartments	1 apartment
20	Wall-mounted range hood	Supplier M	1 floor in 1 stairway	1 floor in 1 stairway
21	Windowsill	Supplier N	12 apartments/day	1 apartment

5.2.2 Resource Use in the Activities and Cost Data Gathering

When the activities in each process are identified and defined, the resources connected to the activities are identified, for example, trucks and warehouse labor. Resources are also tools, machines, and people that are needed to be able to carry out the activity. The resources identified in the subprocesses *transportation to CLC, transportation to site, and transportation to site from CLC* are; a *truck* to transport the goods with, and a *driver* for the truck, also a *phone* to be able to announce. In the subprocess *CLC operations* the resources needed to carry out the activities are: foremost, the *warehouse labor*, which needs *forklifts* to load, unload and move the goods, a *Warehouse Management System* (*WMS)* to register the goods in and also a *storage area* to be able to store the goods. In the subprocess *Material handling on-site* the following resources consumed are identified: *material handling labor*, *telescopic handler,* and *driver to telescopic handler* to unload the goods and sometimes lift it up to the apartments when it does not fit in the elevator, *tools* to move the materials with, such as pallet jack and gypsum carriage and *elevator* to transport the materials in. All the resources connected to the activities are listed in *Table 5.3* further below.

The costs for the activities in the subprocesses *Transportation to site* and *Transportation to CLC* are gathered in the framework agreements that JM has with different suppliers. Some of the framework agreements state that the delivery cost is included in the material price, "free of charge". The distribution of logistics costs is not visualized in the TCA model when the delivery cost is included in the material price which lowers the logistics cost but does not affect the total cost related to that material in a holistic perspective. This difference is not accounted for in the TCA model. The costs in the subprocess *CLC Operations* and *Transportation from CLC to site* are gathered from the contract with the TPL; Förlängda Armen AB. Also, invoices from year 2020 have been used to create cost estimations of various cost drivers within the CLC. The cost data connected to the subprocess *Material handling on-site* is gathered from JM Supply, and the cost for the telescopic handler is based on an average cost that the JM Logistics Department uses based on previous project data.

5.2.3 Cost Drivers for the Identified Activities

Connected to the cost data each activity has different *cost drivers*, that is, certain aspects that affect the cost for each activity. When aspects related to increased numbers and/or amounts take place, the cost related to the material gets higher. The cost drivers for each subprocess are presented in *Table 5.3*. In the subprocess *Transportation to site,* the cost driver identified is the *number of deliveries*. This relates to that costs are often paid per transportation and extra fees are usually added when a fixed delivery time at the site is desired. Almost all the suppliers studied charges an extra cost when a fixed arrival time at site is requested. The more specific the time delivery get, the higher are usually the costs for transportation.

Another cost driver in the subprocess *Transportation to site* is the *size and weight of the goods*. Six out of fourteen of the suppliers base the transportation cost on these parameters, thus, the cost for transportation increases with the weight of the goods. The size of the goods is connected to *loading meters*. A loading meter is a unit to calculate how much goods that fit in a truck, and a loading meter is calculated by dividing the area of the pallet [m^2] by 2.4 [m] (DB Schenker, 2021). Some of the suppliers base their transportation charges on the number of loading meters, which makes the loading meters a cost driver as well. *Loading meter, number of deliveries,* and *size and weight* are also cost drivers in the subprocess *Transportation to CLC*.

In the subprocess, *Transportation to site from the CLC,* it is the TPL company that operates the CLC that drives the trucks to the site. Their costs are connected to the time that it takes to deliver but also how many trucks that are needed. The cost parameters, time and the number of trucks needed imply that the cost drivers are; *the number of pallets* and *loading meters*, since more pallets take longer time to unload and more loading meters can implicate one or more extra trucks. The *filling rate of the pallets* is another cost driver since fully loaded pallets mean fewer pallets. The *distance* to the site is also a cost driver since the longer the distance the longer time it takes to deliver the materials.

In the subprocess *CLC operations*, the costs are connected to the storage area and the labor time for the staff. This makes the *number of pallets* a central cost driver since more pallets take more time to handle but also occupies a larger area in the warehouse. The *size of the pallets* also affects the cost since it is determined by the area of pallets and *storage time*, which is also a cost driver. The *filling rate* on the pallets is another cost driver. If the pallets are fully loaded it will result in fewer pallets which means less handling time and fewer square meters in the warehouse. *The number of relocations* of the pallets is also a cost driver, thus, if the pallets need to be moved several times that takes time, and the cost increases.

In the last subprocess, *Material handling on-site* the cost drivers are also the *number of pallets* to unload. The number of pallets affects the time that the telescopic handler is needed and since the handler is paid by the hour the number of pallets is a cost driver. The *size and weight* are also cost drivers since materials that are big or heavy need to be moved by the telescopic handler or carried piece by piece since they cannot be moved with a pallet jack. The employees at JM Supply also get paid by the hour, so the *time* they spend for materials handling is also a cost driver. The time JM Supply spends on-site relates to how much materials there are to transport to the assembly areas in each shift. The difference here is that independently of the way of transportation to the site, the material handling on site is the same since the material still needs to get to the assembly area. What makes the cost vary is how many materials there are each day to share the fixed costs to start and end a JM Supply shift. There may be differences in time spent on each material and apartment when the batch sizes delivered vary, but those differences are not considered in the TCA.

The cost drivers for the two logistics processes, including subprocess, activities, resources and cost drivers are presented in *Table 5.3* below.

Table 5.3. Identified resources and cost drivers connected to the activities

Logistics process	Subprocess	Activity	Resources	Cost Drivers
Delivery via CLC	Transportation to CLC	- Transportation - Announcing	- Truck driver - Trucks - Phone	- No. of deliveries - Size/weight of goods - Loading meter
	CLC operations	-Unloading -Quality inspection -Registration -Labeling -Storage -Moving of goods -Planning -Loading -Receiving returned pallets	-Warehouse labor - Forklifts -WMS - Storage area	- No. of pallets - Size of the pallets - No. of relocations - Storage time -The filling rate of the pallets
	Transportation from CLC to site	- Transportation - Announcing	- Truck driver - Trucks - Phone	- No. of pallets - Distance - Loading meter -The filling rate of the pallets
	Material handling on-site	-Unloading -Quality inspection -Transportation to the assembly area.	- Telescopic handler -Driver for telescopic handler -Personnel on-site - Tools to move materials -Elevator	-No. of pallets - Size/weight of goods - Time
Direct delivery	Transportation to site	-Transportation -Announcing	- Truck driver - Trucks - Phone	- No. of deliveries - Size/weight of goods - Loading meter
	Material handling on-site	-Unloading - Quality inspection -Transportation to the assembly area	- Telescopic handler - Driver for telescopic handler - Personnel on-site - Tools to move materials -Elevator	- No. of pallets - Size/weight of goods. - Time

5.2.4 Allocating Costs to the Activities

The next step in the design of the TCA model is to allocate costs to the activities. To get the actual costs for the different logistics processes and batch sizes the amounts of various materials are gathered from the reference project. The amounts needed at different times and the cost data related to these amounts are the foundation for the TCA model results. Most of the costs are directly connected to the different materials, but some costs need to be divided between materials. The costs that are divided between materials are the transportation cost from CLC to the site (as materials are co-loaded), the cost for the telescopic handler, and the fixed costs for JM Supply to start and end their shifts.

The transportation costs from the CLC to the site are allocated in the model by making a delivery plan that is based on the time plan for the reference project. Since there are two different alternatives for batch sizes, two delivery plans are performed. A picture of the *one-piece flow* delivery plan is visualized in *Figure 5.4.*

Week	Monday										
	Select material type	Unit	Choose amount	LDM	telescopic truck	Cost telescopic t	Transport area	Transport real	Supply Time[h]	Supply[kr]	Total [kr]
	Window Sill	Apartment	1	0,3	YES	xxxx kr	xxx kr	xxx kr	0,4	xxx kr	xxx kr
	Jamb lining	Apartment	1	0,8	NO	- kr	xxx kr	xxx kr	0,3	xxx kr	xxx kr
	Parquet flooring	Apartment	1	1,1	NO	- kr	xxx kr	xxx kr	1,4	xxx kr	xxx kr
	Kitchen	Apartment	2	3,2	YES	xxxx kr	xxx kr	xxx kr	6,5	xxx kr	xxx kr
	Bathroom furniture	Apartment	1	0,4	NO	- kr	xxx kr	xxx kr	0,1	xxx kr	xxx kr
	Shower cabin walls	Apartment	1	0,5	NO	- kr	xxx kr	xxx kr	0,1	xxx kr	xxx kr
	Heated towel rail	Apartment	1	0,4	NO	- kr	xxx kr	xxx kr	0,0	xxx kr	xxx kr
W17	Plinth, door lining	Apartment	1	1	YES	xxxx kr	xxx kr	xxx kr	0,5	xxx kr	xxx kr
	Door Hardware and hooks	Apartment	1	0,4	NO	- kr	xxx kr	xxx kr	0,0	xxx kr	xxx kr
	Interior doors	Apartment	1	0,9	NO	- kr	xxx kr	xxx kr	0,7	xxx kr	xxx kr
	Wall Insulation	Apartment	1	0,9	NO	- kr	xxx kr	xxx kr	1,1	xxx kr	xxx kr
	Select material type	0	Choose amount	0	0	- kr	- kr	- kr	0,0	- kr	- kr
	Select material type	0	Choose amount	0	0	- kr	- kr	- kr	0,0	- kr	- kr
	Select material type	0	Choose amount	0	0	- kr	- kr	- kr	0,0	- kr	- kr
	Select if big telescopic truck	Tot LDM	% of truck	no. trucks	no. material	no. mtrl Lull	Empty area	Cost "empty" area	Supply Fixed cost	Supply tot	Tot today
	xxx kr	9,90	138%	2	11	3	63%	xxx kr	xxx kr	xxx kr	XXXX kr

Figure 5.4. A snapshot of the one-piece flow delivery plan in the model

To know how much space each material requires in the trucks, and thus the allocated cost, the loading meters for the pallets for each material are measured or information is gathered from the suppliers. Also, information regarding how many pallets with material each apartment requires is an important input in the model to know how much material that can be co-loaded on one truck each day. Since the alternative batch sizes were *one-piece flow* or *standard* (of mostly five apartments) the loading capacity varied. The delivery plans make it possible to know how many trucks that are needed each day and the filling rates for each trip from the CLC to the site. Also, the costs for each material for each delivery is visualized in the delivery plans.

When unloading trucks at the construction site a telescopic handler is needed for some materials. The cost of the telescopic handler for each material is also allocated in the delivery plans. As previously mentioned, the cost for the telescopic handler is paid for by the hour including the time for transportation to and from the site. The other materials that do not need a telescopic handler are assumed that they can be unloaded with the lift at the back of the truck.

The costs for JM Supply are also allocated to the different materials in the delivery plan. A fixed price is retrieved from a data sheet. The more materials there are delivered on one day, the lower the fixed cost for each item that day regarding JM Supply's materials handling. The estimated time required to transport the materials per apartment and the related costs are also retrieved and visualized in the delivery plans.

The cost for delivery to the site, telescopic handler, and JM Supply found in the delivery plan for each material is then connected to a separate sheet for each material, visualized in *Figure 5.5*.

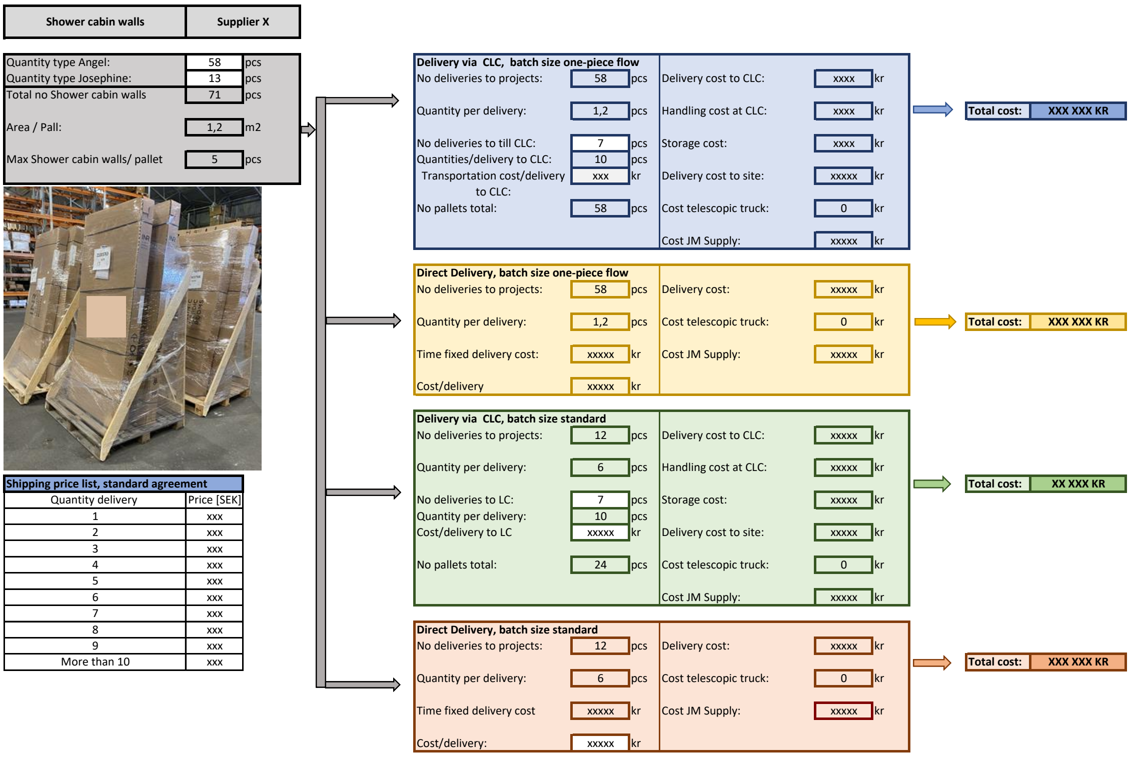

Figure 5.5[3]. A snapshot of the specific material sheet in the model (costs parameters hidden).

As visualized in Figure 5.5, on the specific material sheet, the costs for the two logistics processes and the two batch size alternatives are visualized. Besides the costs gathered from the delivery plans, the other costs for *Delivery via CLC* or *Direct delivery* to site are calculated as well as the costs for materials handling and the storage cost at the CLC. The input in the sheet varies for different materials since every supplier has different contract conditions and prices for their material supply. Fees for deliveries and fixed time delivery is varying but also the number of pallets varies a lot between different material types.

The storage cost is calculated by taking the area of the pallets for each material and multiplying it with the number of pallets, the storage time, and the fixed price per used storage area and time at the CLC. The storage time is set to an average of three weeks since the suppliers must

[3] Blue=Delivery via CLC; One-piece flow. Yellow= Direct Delivery; one-piece flow. Green= Delivery via CLC; batch size standard. Red= Direct Delivery; batch size standard.

arrive with the materials one week before it is needed on-site, and the suppliers have a window of four weeks to deliver. This time window of four weeks plus one week ahead set the average time that materials can be stored to three weeks. To further verify this assumption, data from the pilot projects have been obtained that show how long in average the materials were stored at the CLC. The materials handling cost in the CLC is dependent on the time. To retrieve a cost for each material the time spent on each pallet is multiplied by the number of pallets for each material and the labor cost. The data on time spent on each pallet is found in invoices from the CLC to JM from 2020. The hours spent each month are divided with an average of the incoming number of pallets to the CLC and the outgoing number of pallets. The average time that is spent on each pallet is set to 0.4 hours, equal to 24 minutes.

5.3 Analysis of Results from a Total Cost Perspective

When all the data from the reference project are collected and analyzed by using the TCA model, the costs for the two logistics processes (*Delivery via CLC* or *Direct Delivery*) with the two different batch sizes (*batch size standard* and *batch size one-piece flow*) are presented on a separate sheet that shows the total cost of the logistics alternatives. The total costs for all the materials that can be delivered in all four of the logistics alternatives and are compatible with JM's call-off system are shown in a diagram, see in *Figure 5.6*. The materials that are compatible with all of the four delivery alternatives are: *door hardware and hooks, plinth and door lining, hat racks, heated towel rails, shower cabin walls, bathroom furniture, kitchens, interior doors, sliding wardrobe doors, parquet flooring, tiles and clinker wall-mounted range hoods, HVAC shaft doors, front doors, windowsills, jamb lining,* and *wall insulation*. The materials that are excluded from the joint compilation are the *bike racks, net walls for storage, bricks*, and *the roof insulation in the garage*. These materials are deducted because they have unique prerequisites and are not considered to be able to be part of all the four alternatives.

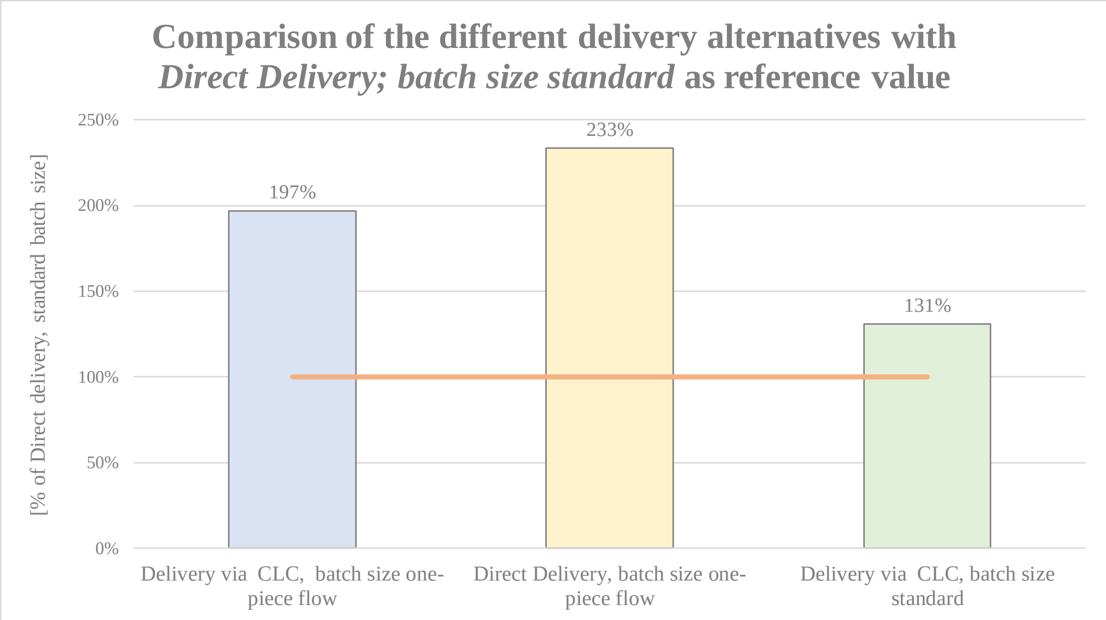

Figure 5.6[4] *A diagram of the cost for the four different delivery alternatives in the reference project.*

In *Table 5.4* the result for the materials is presented. As in *Figure 5.6*, the cost for the common delivery alternative at JM, *Direct Delivery; batch size standard*, is set to 100% for every material and the other delivery alternatives are in reference to this value. Data from *Table 5.4* is visualized in *Figure 5.7*.

[4] Blue=Delivery via CLC; One-piece flow. Yellow= Direct Delivery; one-piece flow. Green= Delivery via CLC; batch size standard. Red= Direct Delivery; batch size standard.

Table 5.4. The cost for the different logistics processes and batch sizes compared

No	Material type	***Delivery via CLC, batch size one-piece flow***	***Direct Delivery, batch size one-piece flow***	***Delivery via CLC, batch size standard***	***Direct Delivery, batch size standard***
1	Bathroom furniture	173%	487%	79%	100%
4	Door hardware and hooks	248%	384%	111%	100%
5	Front door	87%	89%	100%	100%
6	Hat racks	235%	332%	116%	100%
7	Heated towel rail	291%	141%	167%	100%
8	HVAC shaft doors	66%	83%	98%	100%
9	Interior doors	137%	291%	110%	100%
10	Jamb lining	479%	584%	127%	100%
11	Kitchen	180%	137%	183%	100%
13	Parquet flooring	207%	158%	143%	100%
14	Plinth and door lining	227%	263%	110%	100%
16	Shower cabin walls	176%	453%	83%	100%
17	Sliding wardrobe doors	214%	362%	121%	100%
18	Tile and Clinker	169%	137%	183%	100%
19	Wall insulation	447%	317%	254%	100%
20	Wall-mounted range hood	51%	70%	111%	100%
21	Windowsill	693%	735%	174%	100%
	Total	**197%**	**233%**	**131%**	**100%**

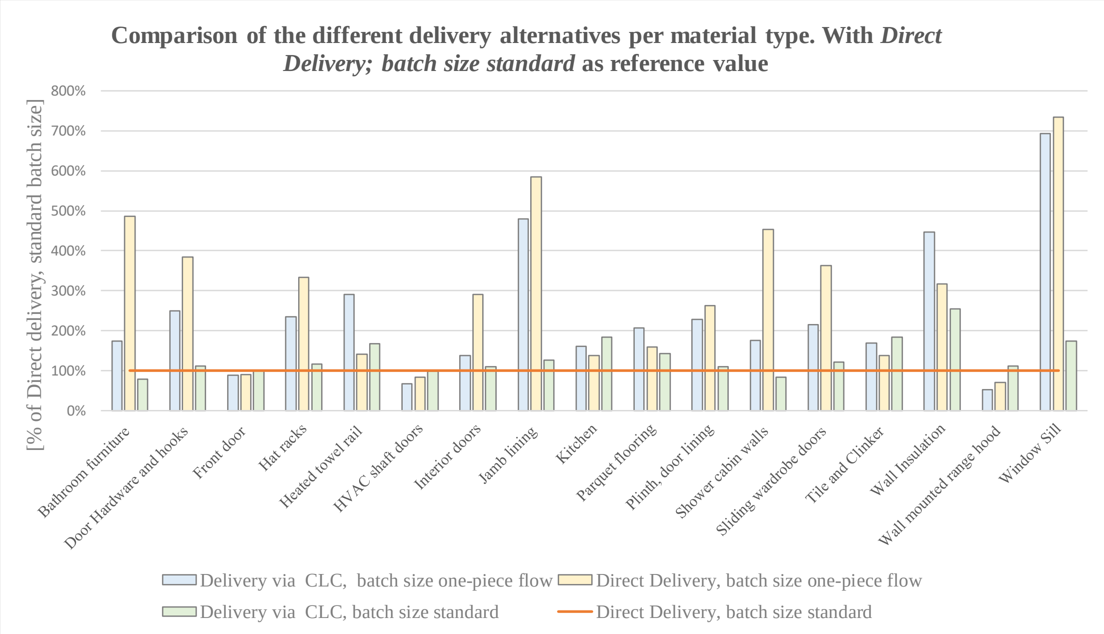

Figure 5.7[5]*. Illustrating differences in cost for the different logistics alternatives in TCA.*

5.3.1 Analysis of Results for Each Type of Material

In this section the conditions and outcomes in TCA for each material type (see *Figure 5.7*) will be analyzed and discussed. The materials are reviewed in alphabetical order except for the Bicycle rack, Bricks, Net walls for storage and Roof insulation garage since all four logistics alternatives could not apply to these materials and they were excluded from the joint summary of the TCA analysis in *Figure 5.6*. These four materials are presented at the end of the section.

1. **Bathroom furniture**

In the material category bathroom furniture, the commode with the sink and the bathroom mirror is included, sometimes also the bathroom locker above the commode. The materials are delivered on a standard EU pallet and usually, furniture to 3-5 apartments is co-loaded on one pallet. When the *batch size; one-piece flow* is delivered, material to one apartment per delivery is placed on one pallet which affects the storage cost in the CLC and the filling rate in the trucks both from the CLC but also from the supplier direct to site and to the CLC. This is shown in *Table 5.4.* The most expensive alternative for bathroom furniture is the *one-piece flow; Direct Delivery* since the delivery cost is higher when just little material is delivered per delivery. The fixed-time delivery cost also affects the costs for *direct delivery* to site, although this cost is shared with the shower cabin walls the cost is still high.

The most cost advantage alternative is the JM *batch size standard* of five apartments and *Delivery via CLC*. The *batch size standard* via CLC generates a lower cost since the number of

[5] Blue=Delivery via CLC; One-piece flow. Yellow= Direct Delivery; one-piece flow. Green= Delivery via CLC; batch size standard. Red= Direct Delivery; batch size standard.

pallets is reduced by almost a half, which makes the storage and handling costs at the CLC lower. The number of transportations from the CLC to site is also lower which is why it costs less to deliver with the *batch size of five* than with the *batch size of one-piece flow* from the CLC.

The second most cost advantage alternative is the *Direct Delivery; batch size standard,* five apartments, this is also the alternative that the framework agreement is set to align to. The cost is very close to the most cost advantageous alternative, but what makes the cost rise is the cost for fixed-time delivery.

4. Door hardware and hooks

Included in this material category is the door hardware for the inner doors and front doors and the hooks for the towels in the bathroom. The results shown in *Table 5.4* show that the most cost advantage delivery alternative is *Direct Delivery; batch size standard* of five apartments. Supplier D's agreement states that the delivery cost is "free" but there is an extra fee for the fixed-time delivery. The fixed-time delivery charge is still lower than the cost for handling and storage at the CLC and the cost for *delivery from CLC to site*. The reason for why the *Direct Delivery; batch one-piece flow* price is the highest is because of the fixed-time delivery. The *one-piece flow via the CLC* is still almost three times as high as the *Direct Delivery; batch size standard,* since the delivery cost to the site from the CLC is rather high compared to the "free" delivery when the material is *delivered directly* from the supplier.

Supplier D has its own logistics center in Stockholm where they repack the goods and deliver them to many projects and customers. This supplier has not delivered to the CLC during year 2020 and according to the results from the TCA, the best way is to continue to *deliver directly* to site. Since the trucks from this supplier departure from a logistics center in Stockholm, using the CLC would just add an extra stop on the way to the site that would not add any value to the supply chain.

5. Front door

The front doors are delivered on a pallet that has the same size as the door when it is stored horizontally. The door frames are delivered in bundles that are put on a separate pallet or on top of the doors depending on the number of front doors that are to be delivered at the same time. The delivery costs depend on the value of the ordered material as the delivery cost direct to site or to the CLC is the same independently of the amount delivered. The batch sizes for this material type are the same for all the four alternatives. The differences in cost visualized in *Table 5.4* are due to a higher degree of co-loading with other materials when the *one-piece flow* delivery plan is used. The costs for JM Supply and the telescopic handler for unloading are also shared among several materials in the *one-piece flow* alternatives.

6. Hat racks

The hat racks are delivered on EU pallets and the supplier charges extra, for fixed-time delivery but otherwise, the delivery is "free". The fixed-time delivery cost affects the *Direct Delivery; batch size one-piece flow* the most, this is also seen in *Table 5.4,* since that alternative is the most expensive. The most cost advantageous alternative is the *Direct Delivery; batch size standard*, the cost included in that alternative is the fixed-time delivery and the cost for material handling on-site by JM Supply. In the delivery alternatives via CLC, the higher costs stem from the material handling cost, storage cost and the cost for transportation from CLC to site. The storage cost is low because the assumption is that the pallets are loaded with materials for ten apartments in the CLC and then the material for one apartment is relocated to another pallet when delivered to site. This way of handling the material at the CLC was considered possible since the package with the hat rack is small and easy to move and the number of pallets would have been very high if just one hat rack were to be placed on each pallet.

7. Heated towel rail

The cost for delivery from the supplier for the heated rails is set per heated rail and independently of how many that are delivered at the same time. When the material is *delivered directly* to site there is no extra cost for fixed-time delivery, and since the delivery cost is the same to the site or the CLC the most cost advantageous alternative is the *Direct Delivery; batch size standard*. The reason why *direct delivery* with *batch size one-piece* is more expensive than the *batch size standard* is because of the cost for JM Supply; more shifts are needed for *one-piece flow* and thereby the fixed price for the shifts is higher in total. The delivery alternative *Delivery via CLC* is the most expensive since the costs for the processes at the CLC just becomes extra costs compared to when the material is delivered directly to site.

8. HVAC shaft doors

The alternative batch sizes for the *batch size standard* and *one-piece flow* are the same for this material. However, the costs for the two differ as presented in *Table 5.4*. The costs differ because in the *one-piece flow via CLC* the HVAC shaft doors are co-loaded with more materials and therefore the transportation cost from the CLC to the site is lower. The fixed cost for material handling on-site by JM Supply also varies between the *one-piece flow* and the *batch size standard*, this is also why the *batch size standard* delivery alternative differ from each other.

The HVAC shaft doors are delivered at the same time as the front doors and from the same supplier. Because of the co-loading with the front doors, the fixed-time delivery cost when the material is *delivered directly* to site is only half compared to if the HVAC shaft doors would have been delivered separately. The *direct delivery* option is still the most expensive alternative when only the delivery costs are considered. Overall, the *one-piece flow via CLC* is the most cost advantageous option for this material since the costs for transportation to site and the fixed costs for material handling on-site are shared with many other materials.

9. Interior doors

The interior doors are delivered on pallets with the same size as the door when it is placed horizontally, the door frames are nailed and have the same size as when they are assembled in the wall. When interior doors are delivered according to the *batch size standard* the doors are placed on one pallet and the door frames on one or two pallets depending on the number of doors in the apartments. *Table 5.4* presents that the delivery alternative with the lowest cost is

Direct Delivery; batch size standard, five apartments at the same time This is the most advantageous alternative even though the supplier has a high cost for fixed-time delivery. The cost for delivery is based on the value of all the interior doors and is therefore the same for *delivery to CLC* or *direct* to site. What makes the difference in costs between the alternatives is the fixed-time delivery for every *Direct Delivery* to site, the handling and storage cost at the CLC, transportation costs from CLC to site, and also the cost for material handling at site by JM Supply.

10. Jamb lining

The results for jamb lining visualized in *Table 5.4* show a significant difference between the *one-piece flow* and the *batch size standard*, where several factors affect this difference. The most prominent one is that the cost for delivery from Supplier G is based on weight and the more that is delivered at the same time, the lower the cost is per kilo. Another cost that affects the cost for *delivery via CLC* is the fact that the goods with jamb lining are bulky, up to 2.5 meters long. This affects the storage cost but also the delivery cost from the CLC to site. Since the material in *batch size standard* for 12 apartments is loaded on one pallet and the *batch size one-piece flow* is loaded on 12 pallets, the cost for storage increases.

Supplier G also has a cost for fixed-time delivery, which, together with the delivery cost makes the cost for *Direct Delivery; batch size one-piece flow* high. The *Direct Delivery; batch size standard* is much lower since only five deliveries are needed in the reference project with *batch size standard* instead of 58 that is required if delivering in a *one-piece flow*.

The analysis only considers two “extremes", 1 or 12 apartments. Maybe some number in between 1 or 12 apartments would be suitable to optimize the delivery costs at the same time as JIT-deliveries are enabled. When the amount for *one-piece flow* was decided, other factors may have been missed and the reality may be that more than one apartment's jamb lining will be assembled in one day and that the deliveries should be every other day but for two or three apartments at the time instead. To change the amounts for *one-piece flow* into something more realistic would in this case probably decrease the costs.

11. Kitchen

Kitchens are bulky material where several pallets are needed for every apartment. As visualized in *Table 5.4,* delivery alternatives *via CLC* face higher costs due to the high number of pallets related to handling and storage at the CLC. The delivery cost for *direct delivery* or delivery to the CLC is also free when the value on the ordered goods exceeds a certain cost. Therefore, the cost visualized in *Table 5.4* for the *Direct Delivery; batch size standard* is the cost for fixed-time delivery, the telescopic handler and JM Supply, where the two latter are included in the other delivery alternatives as well.

13. Parquet flooring

Parquet has traditionally been procured as a complete solution where a subcontractor takes the overall responsibility for material purchase, material handling on-site, and assembly. The supplier of JM's parquet variants provides "free shipping", but the subcontractor instead charges higher fees for materials purchase. With this design of the supply chain, the actual costs for logistics are hidden. In the TCA model, the hidden costs for delivery contribute to a more beneficial cost for *Direct Delivery; batch size standard*, with as few handling costs as possible. The alternatives with more material handling get more expensive since the storage and handling costs are higher than the transportation costs. The supplier also only offers "free shipping" when delivering completely filled pallets. A potential *one-piece flow* would require deliveries with fewer filled pallets, which also increases the costs for the *one-piece flow* alternatives. To make it more cost-effective with a *one-piece flow*, JM needs to review the agreements with the supplier and jointly together develop the packing of pallets and the alternative batch sizes without entailing a higher cost. Repacking of parquet at the CLC could also be an option, but it would require a lot of investigations and training of staff. An important aspect of the parquet is that the material is very sensitive to the surrounding climate. The material must be stored in a dry room with the right temperature, which makes it even more expensive as JM's non-tempered storage at CLC cannot be used.

14. Plinth and door lining

The plinth and door lining are bulky material since it is up to 3 meters long. It is usually delivered in batches of five apartments per delivery. The result in *Table 5.4* shows that the *Direct Delivery; batch size standard* is the most cost advantageous alternative since the delivery cost gets lower per kilo if more material is delivered at the same time. There is also a cost for fixed-time delivery which adds to the high cost for the *Direct Delivery; batch size one-piece flow*. When the material is delivered as *one-piece flow*, the material to each apartment is placed on an own pallet. Since the *batch size standard* of five apartments results in the same area of the pallet the storage cost at the CLC is much higher for the *batch size one-piece flow*. The handling costs also increase since there are more pallets to handle when each apartment's materials are placed on an own pallet instead of sharing one pallet with five other apartments.

16. Shower cabin walls

The shower cabin walls are delivered together with the other bathroom furniture from the same supplier. The delivery costs are however separated. The delivery cost for shower walls is based on the number of Shower walls that are delivered at the same time, the more shower walls, the lower the price. This is one of the reasons why the *Delivery via CLC; batch size standard* is the most cost advantageous alternative since about 10 shower walls are delivered at the same time to the CLC. Another reason why the *Direct Delivery; batch size standard* costs more for this material is that the Supplier A has a cost for fixed-price delivery. This cost is however shared with the other bathroom furniture.

The most expensive delivery alternative is the *Direct Delivery; batch size standard*, since the cost for delivery is the highest per shower wall when just one shower wall is delivered, and also that the cost for fixed-time delivery gets high when 58 deliveries are needed. The filling rate for the pallets is also very low when just one apartment at a time is delivered. The low filling rate is also a reason why the *Delivery via CLC; batch size one-piece flow* is higher than *Delivery via CLC; batch size standard*, and the handling, and storage costs increase since many pallets are needed.

17. Sliding wardrobe doors

As shown in *Table 5.4,* the *Direct Delivery; batch size standard* is the alternative with the lowest cost. Supplier K bases the cost for delivery on the value of the ordered material, and when the value exceeds a certain limit, the delivery is free of charge. For the *batch size standard,* the delivery cost is none, but there is a cost for fixed-time delivery when *delivered directly* to site. The number of wardrobes in *batch size one-piece flow* does not exceed the limit for free delivery, and the cost for delivery, plus the cost for fixed-time delivery are the reason why *Direct Delivery; batch size one-piece flow* is the most expensive alternative.

The cost for fixed-time delivery for the *Direct Delivery; batch size standard* does not exceed the costs for handling, storing, and delivering from the CLC and that is why *direct delivery* still is the most cost advantageous alternative. The *one-piece flow via CLC* is also more expensive than the *batch size standard via CLC* since the material is not co-loaded with other apartments in the *one-piece flow.* This directly affects the number of pallets which is a cost driver for storage and material handling at the CLC. With a Delivery *via CLC; batch size one-piece flow,* the transportation costs to site are also higher than *batch size standard* since the filling rate on the pallets are lower and thus more pallets means more loading meters.

18. Tile and Clinker

The tile and clinkers for bathrooms, entry, and kitchen in each apartment are delivered on half EU pallets by request from JM. The tile and clinker are heavy materials which makes it hard to handle, and the half pallets make the materials easier to transport to the apartments by JM Supply. This request from JM was however made before the CLC was procured. In *Table 5.4* it is shown that the two alternatives with *delivery via CLC* are more expensive for each of the *batch sizes*, and one of the reasons is that the handling cost at the CLC is rather high due to the number of pallets. The delivery cost from the CLC to site is also quite high since there are about three pallets to each apartment which affects the number of loading meters in the trucks and that also affects the cost for delivery to site. Due to the high number of pallets per apartment the most cost advantageous alternative is the *Direct Delivery; batch size standard* since no costs for extra logistics subprocesses are added.

19. Wall insulation

For wall insulation, Direct *Delivery; batch size standard* is the most cost advantageous alternative. The explanation for this is that insulation is a very space-intensive material that will take up a lot of space in the CLC and does not allow for much co-loading to the site. Insulation is a material that is used in many projects, both by JM and other companies, which means that the suppliers have many deliveries of the material and often have it in stock at retail chains close to site. These conditions enable suppliers to offer relatively low transportation costs. Thus, all extra handling that takes place in the CLC also becomes an extra cost that makes the alternatives via CLC disadvantageous regarding costs.

One factor that negatively affects the alternatives with *batch size one-piece flow* is the fact that the filling rate for pallets is much lower compared to *batch size standard*. To make this alternative more attractive, it would be necessary to investigate if some kind of relocation of materials at the CLC could be arranged for.

20. Wall-mounted range hood

The range hoods are assembled in the kitchen after the kitchen is mounted, and the range hoods are delivered by floor plan and stairway which is 2-4 at the same time. The amount delivered in the batch size; *one-piece flow*, and *batch size standard* are the same. The most cost advantageous alternative is the *Delivery via CLC, batch size one-piece flow. Table 5.4* visualizes that both the delivery alternatives for the *batch size standard* is more expensive since the fixed cost for JM Supply and the transportation from the CLC are not shared with many other materials. The reason why the *direct delivery* alternatives are more expensive than delivery via CLC is because of the cost for fixed-time delivery that Supplier M adds to the delivery cost.

21. Windowsills

The windowsills are normally delivered to about 12 apartments at a time as a *batch size standard*. The windowsills made of stone are packed into special boxes for each delivery. When the delivery is below a certain limit, the buyer must pay a fee for each box, which partly explains the result visible in *Table 5.4*. The delivery cost is also based on weight, and the more that is delivered, the lower the delivery cost is. That explains why the *batch size one-piece flow* is much more expensive. The main reason for the high cost of the *one-piece flow* is because the material needs a telescopic handler for unloading and there are ten times more delivery times that need a telescopic handler with the *one-piece flow* compared to *batch size standard*. The material is also assembled before the other materials in the time plan and then the cost for the telescopic handler and the transportation cost from CLC to site is not shared with any other materials. Since there will be 10 times more transportations to site with a *one-piece flow* than with a *batch size standard* of 12 apartments the costs differ a lot.

3. Bricks

Table 5.5 below shows the result for the material type bricks for the different logistics alternatives.

Table 5.5. Delivery costs for bricks

No	Material	*Delivery via CLC, batch size one-piece flow*	*Direct Delivery, batch size one-piece flow*	*Delivery via CLC, batch size standard*	*Direct Delivery, batch size standard*
3	Bricks	1319%	2391%	*Not applicable*	100%

Bricks have special conditions in production which mean that the material cannot clearly be divided into four different delivery alternatives. The number of bricks ordered is based on the size of the facades and cannot be divided in the number of apartments. In the current standard mode, a full truck *delivers directly* from the supplier to the site with about 20 pallets (which corresponds to about 12,800 bricks). These deliveries are so space-intensive and large that the alternative of *Direct Delivery; batch size standard* is unrealistic as the trucks from CLC to the site is smaller than the brick supplier's trucks and thus cannot accommodate the desired amount.

In addition, there would be intermediate storage and handling of very many pallets at the CLC, which would contribute to an extremely high cost.

Trying to divide these deliveries is, as can be seen in *Table 5.5*, not financially defensible. This extreme price difference can be attributed to different reasons. The foremost reason is that bricks are extremely material-intensive with many pallets being consumed. As previously mentioned, the number of pallets is a major cost driver at CLC as there will be both large storage areas that are used and a lot of time to handle pallets. The comparison is also affected by the fact that the standardized solution has such a high filling rate in the trucks and the agreements are written adapted for this solution.

2. Bicycle rack and 12. Net walls for storage

Table 5.6 below shows the result for the material type bicycle rack and net walls for storage for the different logistics alternatives.

Table 5.6. Delivery costs for Bicycle rack and Net walls for storage

No	Material	*Delivery via CLC, batch size one-piece flow*	*Direct Delivery, batch size one-piece flow*	*Delivery via CLC, batch size standard*	*Direct Delivery, batch size standard*
2	Bicycle rack	*Not applicable*	*Not applicable*	*144 %*	100%
12	Net walls for storage	*Not applicable*	*Not applicable*	*Not applicable*	Fixed price, new tender each project

These two types of materials are ordered from the same supplier, Supplier B. Bicycle racks and net walls for storage are special material in the TCA model. The process of data gathering showed that due to different conditions, it is principally not possible to make a division of this type of material into different batch sizes. A reason why the bicycle racks cannot be divided into *batch size one-piece flow* is that the installation of the racks is done in such a short period of time. The installation rate also varies depending on the conditions in the project but mostly because there are several different bicycle racks to choose between. The standard number of deliveries are also few because of the short installation time and that the material for one project often fits in one truck. In the reference project all 9 bicycle racks (of the type with 8 bicycle spaces per rack) will fit in one truck and will be assembled within 5 days. There is, therefore, no economic justification to involve a CLC with extra reception, storage, and transportation costs.

Net walls have similar conditions as bicycle racks, with the difference that the net walls usually require a slightly higher number of pallets, and that the installation takes place over a longer period. These differences make net walls more likely to be an option for *delivery via CLC*, but the data show that it is still not economically feasible to deliver via the CLC.

Due to the procurement as arranged for now, the subcontractor has overall responsibility for both assembly and the material supply. The costs for assembly and delivery are merged in the Supplier B's excel-model, that form the basis for a project unique tender. The recommendation is therefore to continue with the *standard delivery method* but to intensify the collaboration with the subcontractor/supplier. A solution is to be more transparent and show what drives the various costs and jointly try to decrease the cost in the long run.

15. Roof insulation garage

Table 5.7 below shows the result for the material type roof insultation garage for the different logistics alternatives.

Table 5.7. Delivery costs for Roof insulation garage

No	Material	*Delivery via CLC, batch size one-piece flow*	*Direct Delivery, batch size one-piece flow*	*Delivery via CLC, batch size standard*	*Direct Delivery, batch size standard*
15	Roof insulation garage	20714%	5651%	*8281%*	100%

For roof insulation garage, it is most cost advantageous to deliver the material according to *Direct Delivery; batch size standard* with few, larger deliveries. This is partly due to the same reasons as with the wall insulation; it is challenging to divide it into the *one-piece flow* without repacking at the CLC. With a *one-piece flow* without repacking, there are many and large pallets with low filling rate at the same time as the transportation costs are high. The reason for the much higher cost of transportation in *one-piece flow* is that Supplier J has a shipping system based on the filling rate in the truck. The higher the filling rate, the cheaper is the delivery. In fact, you can even get a refund when a full truck is delivered.

Another aspect that makes the *Direct Delivery; batch size standard* more advantageous is the security in relation to having more materials than needed on-site since the production rate varies a lot in this stage of production, according to the subcontractor who orders and assembles the material. Pre-conditions that slow down the production rate are when there are many installations in the ceiling, with a need to make holes in the insulation. This variation in combination with the fact that the amount needed in a project require few full truck loads in total makes it difficult to create a reasonable *one-piece flow*. There is also a higher risk when smaller amounts, like in a *one-piece flow*, are delivered that the craftsmen run out of materials to work with.

5.3.2 Non-Material Bound TCA Results

Besides the costs for the different delivery alternatives and materials, the TCA model can provide for other logistics parameters of JM's projects. From the delivery plans for *standard* *batch size* and for *one-piece flow*, the number of transportations to site from the supplier or the CLC can be derived. In *Figure 5.8* the total number of transportations to site with the different batch sizes and logistics solutions in the reference project are presented.

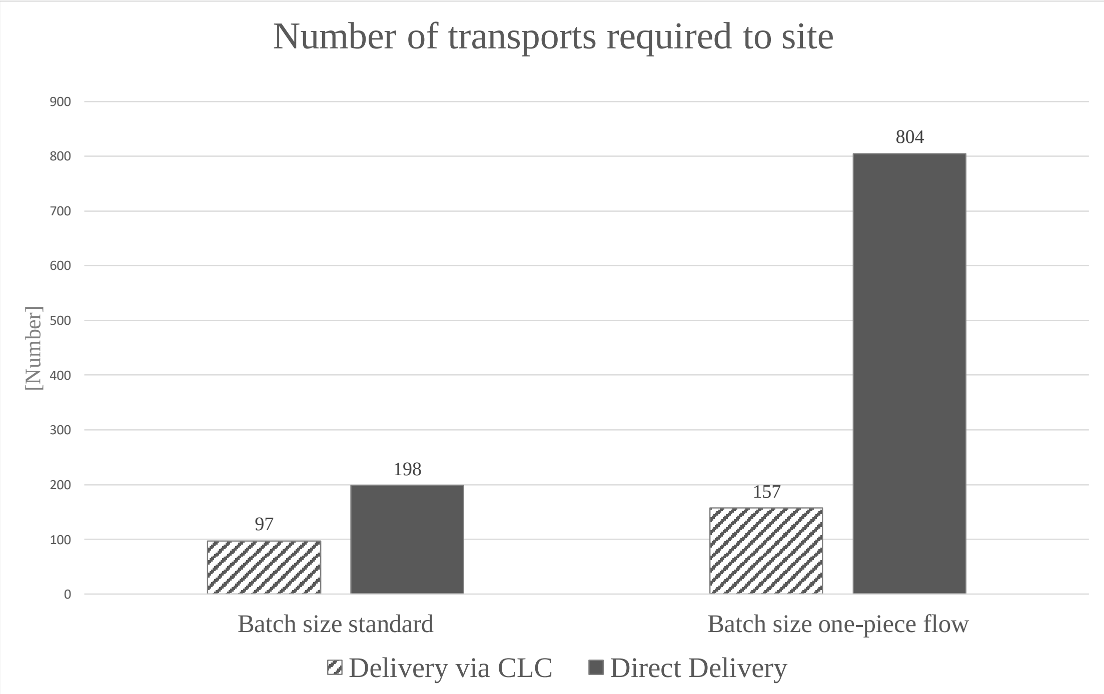

Figure 5.8. Number of transportations to site with and without the CLC and with the two different batch sizes.

In *Figure 5.9* below, the cost related to JM Supply for the delivery alternatives are presented. In the TCA, all delivery reception and material handling on-site is calculated to be performed by JM Supply for the materials included in the joint summary. With the *batch size; one-piece flow* more deliveries are needed, but with less material in each delivery. The increased number of delivery days implies that JM Supply needs to have more shifts to handle the materials on-site. As visualized in *Figure 5.9*, the fixed cost to start and end a JM Supply shift, with start-up meeting, etc., is higher for the *one-piece flow* than the *batch size standard*. The cost for transporting the material from the unloading area to the assembly point is almost the same in both alternatives since it is the same amount of materials needed in the project independently of the batch size of the material deliveries. When more shifts are needed the cost to handle the materials on-site increases. This is most evident in the phases when the material delivery is less intense, wherefore the fixed costs for the shift end up on just one or two material types and the shift may also be very short, but the fixed costs will still be the same.

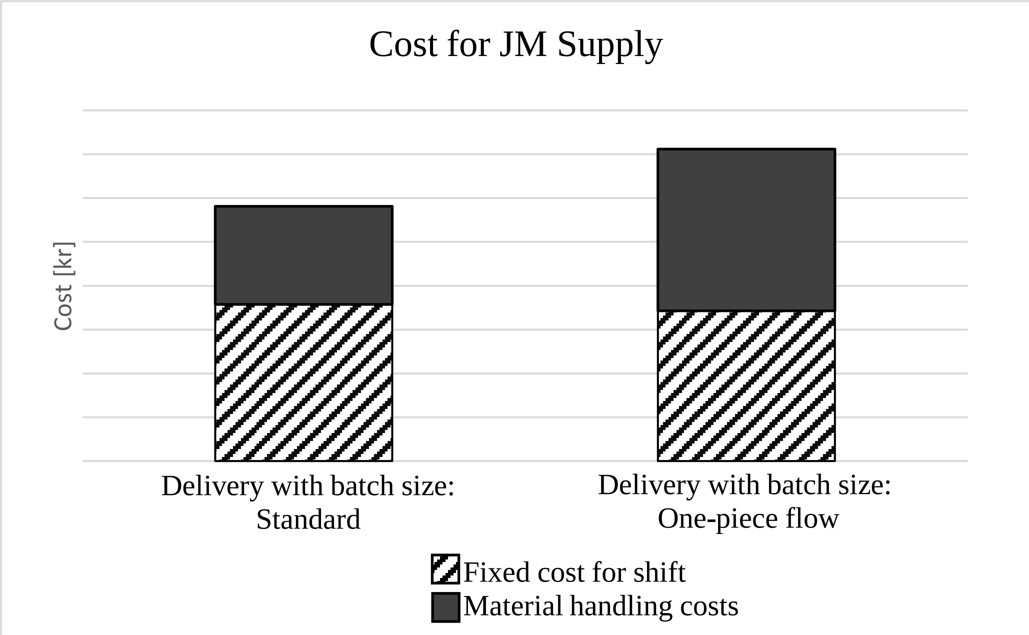

Figure 5.9. The two different costs for JM Supply in the two batch sizes alternatives.

5.4 Discussion of Results from the TCA

The TCA model shows that the delivery alternative, *Direct Delivery; batch size standard*, which has been the standard at JM up until the year 2020, is the most cost advantageous alternative from an overall point of view. The main explanation for this result is the current framework agreements. The agreements that are the foundation of the cost data for the TCA are produced and signed with the plan to *deliver direct* to site and with a *batch size standard*. It is also the *Direct Delivery; batch size standard*, that has been the starting point when, over the years, attempts have been made to develop JM´s logistics solutions with small changes at a time.

The fact that it is the costs defined in agreements that form the basis for the TCA analysis also results in that the costs for the alternatives with a CLC increase. This increase is since a CLC alternative has many more activities that entail costs in comparison to the alternative of direct delivery. One example is that in the CLC there is a defined cost for storage, while the alternative *Direct Delivery; batch size standard* has similar storage on-site which has no cost connected to it. It is therefore important to have this cost allocation in mind when examining the results for the various alternatives. Because, as described in the theoretical framework, storage on-site can lead to other costs due to worse conditions for storage on-site, e.g., weather conditions or unnecessary movements that can harm the materials (Agapiou et al., 1997). Also, as the framework agreements are currently designed, the number of pallets that need transportation, handling and storage is an important cost driver in the activities at the CLC, and therefore the delivery via CLC will be financially disadvantageous.

Despite the fact that many conditions, like the standard agreements and TCA design, seem to favor the *Direct Delivery; batch size standard*, there are already some of the studied materials that are delivered more cost-efficiently with *Delivery via CLC; batch size one-piece flow*. These materials are *wall mounted range hood*, *HVAC shaft doors* and *front doors*. These materials have in common that they are delivered in material-intensive phases and therefore can benefit from co-loading with other materials. With the CLC alternative, the materials also avoid the expensive fees for fixed-time delivery in the agreements. JM wishes to have all materials delivered at fixed times in the afternoon in conjunction with the start of the JM Supply shift. Currently, many suppliers practice the principle of charging extra for a fixed-time delivery and therefore it is conceivable that cost benefits can be gained in the future by using a CLC to avoid this cost as fixed-time delivery is not needed to the CLC.

The alternative *Direct Delivery; batch size one-piece flow* is in most cases, not a realistic option. This is partly because there will be very high costs according to the TCA analysis due to a large number of transportations together with fixed-time delivery costs. This alternative will also not be desirable from a sustainability aspect as it will entail many long-distance transportations with a low degree of filling in the trucks. However, the *Direct Delivery; batch size one-piece flow* gives a clear indication of the difference in costs and that it will be significantly lower for *batch size one-piece flow* if a CLC is used. In addition to the economic benefits, differences in the number of transportations required to site, as visualized in *Figure 5.8*, in comparison for *Delivery via CLC* and *Direct Delivery* prove that a CLC will be a prerequisite for being able to cope with a future reduction in batch sizes.

Materials that have a significantly higher cost for delivery with *batch size one-piece flow* are *jamb lining*, *windowsill*, *hat racks* as well as *door hardware and hooks*. One reason why smaller batches do not seem to fit these materials is that the smaller number of batches increases the number of pallets and consequently, the costs. Both the *hat racks* as well as *door hardware and hooks* have the possibility to be packed together for several apartments on the same pallet. Though, if there is no possibility to perform repacking at the CLC, to place different material types on the same pallet before a delivery to site, these materials must be delivered on individual pallets for each delivery to site, which drives "unnecessary" costs.

Delivery reception and transporting materials at site, undertaken by JM Supply, is an important part of the material flow. The results show that since material deliveries are being divided between many more occasions with *batch size one-piece flow*, JM Supply needs many more work shifts, which increases the fixed costs. The reason for this is that a certain fixed fee is expected in connection to every start of a new work shift. The TCA visualizes that several work shifts for JM Supply will be very short in the *one-piece flow*. This short shift does not correspond to the JM Supply standard of today where the employees are promised at least four paid hours per shift. Therefore, if this full-scale *one-piece flow* is to be implemented, the standards need to be reviewed.

Materials such as kitchen and tile and clinker need many pallets per apartment which entail large storage and handling costs at the CLC. This is avoided with direct deliveries from suppliers to site. When these materials are delivered directly to the site, almost a full truck is used every time, especially when the *batch size standard* or more is desired. When materials that require many pallets are delivered via the CLC there is extra time and money spent on every pallet that does not add any value (but adds to the costs). The number of transportations to the site is almost the same when the materials are delivered via CLC but the handling and storage costs at the CLC are added to the total cost. The benefit of delivery via the CLC may be to secure that the material is delivered when needed and to avoid any delays in delivery. If just the costs are considered, the bulky materials should be delivered directly to the site instead of via the CLC which adds extra costs. An important factor that needs to be considered in the case of pallet-intensive materials is that the transportations from CLC to the site currently is carried out by a truck with a loading capacity of 7.2 loading meters. The truck that the suppliers use often has a trailer as well which entails approximately 19 loading meters in total. If the CLC alternative is to be more cost-effective for materials that require many loading meters per delivery, it seems necessary to investigate the impacts of using a larger truck from the CLC to the sites to be able to co-load more pallets.

The cost differences between delivery alternatives are also affected by how well developed the logistics processes are in the supply chain. This can be exemplified by considering the *door hardware and hook* material category, where the supplier has worked intensively for many years with its delivery methods and established a well-functioning system. The system can be compared to several small CLCs that make "milk-rounds" to different construction projects every day. In this case, it may be difficult to challenge this delivery method with a new system and try to gain cost benefits. In the opposite way, there are material categories where no development has taken place at all in recent decades and the material is treated the same way as it was treated many years ago. In these situations, collaboration and new agreements between JM and those suppliers can provide development and unforeseen solutions that benefit from delivering in smaller batches and via the CLC.

In summary, the materials that have a high filling rate on the pallet but do not consist of too many pallets per apartment are best suited to use the CLC. However, the material should not consist of too small packages either, if repacking at CLC is not an option. When there are small packages that fits in high numbers on a pallet, the filling rate is low when small batches are needed. This affects the storage and handling costs at the CLC. The TCA proves that *Direct Delivery; batch size standard*, is the economically most advantageous alternative of the four alternatives. However, it is important to bear in mind that this is based on the measurable costs currently and there may be other economic gains outside the scope of this TCA. Also, gains in terms of other than economic, such as work environment, quality, etc., could also exist beyond the scope of this TCA. There are indications that cost savings can be achieved with the other three alternatives as well. To achieve beneficial cost deliveries with the other delivery alternatives the framework agreements with suppliers need to be investigated together with development of the CLC solution to improve its efficiency. Finally, the TCA has examined the extreme batch sizes (one apartment per delivery and 5 apartments per delivery), whereas other batch sizes may have greater potential and should be examined as well.

6 Discussion

In this chapter, the findings from the literature study, the empirical data, and the TCA model form a basis for discussion on the findings of research questions two and three. Section 6.1 provides a discussion regarding the design of the present logistics situation and the journey JM has made within logistics over the years. In section 6.2, the benefits of implementing a CLC are discussed including the experiences from staff and the outcomes of the TCA model. In section 6.3, possible disadvantages and challenges that exist when using a CLC are discussed. Finally, in section 6.4, the TCA model is discussed as a basis for decision making including future advancements for JM.

6.1 The Logistics Journey and Current Situation at JM

In recent decades, the focus on construction logistics has increased rapidly, and JM has realized the importance of keeping up with the development and to be a market leader within construction logistics. SCM is about managing and getting control of the supply chain to improve its overall functioning. Dubois et al. (2019) define three configurations that describe various logics for how logistics activities can function and how the supply chain of such activities be organized. JM's development over the years follows a journey from more traditional organizing to advanced organizing in line with these logics.

The first configuration; *de-centralized coordination* is where JM was some years ago, and still is in some projects. This is also confirmed by the supervisors, stating that logistics have not been a high priority and just been handled by whoever needs material. When JM started JM Supply a few years back this was an initiative to achieve the second configuration; *on-site coordination*, to gain control of the on-site logistics and the transportations coming to site. In 2020 JM has taken the next step to gain control of the logistics and the supply chain beyond the site. This involves a CLC in the supply chain, thereby accomplishing the third configuration; *the supply network coordination*. JM has also involved the Logistics Department for overall responsibility of the logistics at the company. The TCA model covers and evaluates the second and third configuration and the associated costs. Accordingly, the second configuration; *on-site coordination* corresponds to the logistics solution; *Direct Delivery,* and the third configuration*; the supply network coordination*, corresponds to the logistics solution; *Delivery via CLC*.

The next step in JM's development is to optimize the batch sizes. The car manufacturing industry has gradually transformed delivery logics and volumes towards more JIT-deliveries and JM has ambitions to start a similar journey in the construction industry (Liker, 2004). These ambitions towards new deliveries with JIT is the reason behind the investigation of different batch size alternatives in the TCA model. In Lean philosophy, JIT-deliveries is one way to reduce waste, where only the amount needed at the moment is delivered instead of large volumes to be kept in storage. Waste in construction is connected to materials storage on-site where JM aims to reduce such waste by adding a CLC to the supply chain and consequently, enabling JIT-deliveries. JIT-deliveries will reduce on-site storage and is expected to increase productivity since stored material will not block areas for assembly work or risk being damaged. JIT-deliveries enable the materials to be delivered when needed which also implies that the batch sizes will get smaller.

6.2 Benefits of a CLC and Driving Factors for Implementation

There are several reasons for how a CLC can improve construction SCM. Lundesjö (2015) highlights that one of the main reasons to implement a CLC in the supply chain is to lower the number of transportations to site. The TCA model shows that for both batch size alternatives the number of transportations to site are reduced. The decrease in transportations to site are visible even though the *one-piece flow* generates more transportations than the *batch size standard*. If smaller batch sizes are desired to achieve JIT-deliveries and avoid storage on-site, a CLC is an enabler for delivering such small batches. In the case of not using a CLC, JIT-deliveries would result in more deliveries with a smaller amount of goods to the site. Thus, the number of transportations would be inconceivably higher.

To lower the number of transportations to the sites and to ensure a high filling rate in the trucks could in the future be considered a key feature for construction in the dense city areas, where many of JM’s projects are located. Examples of CLC´s in Stockholm show that the City of Stockholm has placed demands on fewer transportations in the city area, and accordingly, contractors in the projects must adhere to such demands. Reducing the number of transportations is also key to ensure better air quality in the cities, decrease the disturbances to third parties, and to improve overall traffic flow and congestion. Lundesjö (2015) also states that the improved work environment is beneficial since when the materials are co-loaded fewer transportations are needed, which in turn results in less arrival controls at the site. The improved work environment by using a CLC is also mentioned by the logistics supervisor who experienced fewer phone calls per day, thus less disturbance in the workflow, and improved logistics at the site. When the goods arrived from the CLC it was the same drivers all the time, which the supervisor mentioned as a benefit since the driver then knew where to unload and when to show up. The logistics supervisor also stated that the usual queue outside of the site was much less common when the CLC was used. The queue outside is identified as a problem since it affects the people and stakeholders around the project severely and might even hinder traffic or access to streets (Lundesjö, 2015).

When projects are constructed in dense city areas, space on-site is often limited. The space limitation is mentioned by two of the logistics supervisors who claim that over the years, the space at the sites in projects has decreased. Availability to store the materials at a CLC outside of the site may be the only way to cope with the need to supply the sites with materials but not having the option to store materials at the site to a great extent. This may also be the safest option. Waste connected to materials storage on-site is identified as materials getting damaged by weather or lost when moved around. With a CLC the materials are stored indoors under safe circumstances and are handled by logistics personnel with appropriate skills and equipment, and therefore the waste connected to material storage can be avoided.

Another advantage of involving a CLC in the supply chain is to get better control of the supply chain. In construction SCM, the endeavor is to gain control of the different segments in the supply chain to try to optimize it. Adding a CLC correlates with the configuration of activities characterized by *supply network coordination* (Dubois et al., 2019), that identifies that joint coordination of transportation is one way of gaining control of the upstream supply chain. JM has also identified the need to get control of and to optimize the construction logistics in their projects to reach their goal of shorter production times without increasing the cost.

6.3 Challenges and Key Issues with a CLC

As presented in chapter 5, there is, currently, only 5 of the 21 studied materials that are included in the TCA model that are proven to have economic benefits when being delivered *via the CLC* instead of *direct delivery* to site. This result is perhaps not surprising considering that the several extra steps of transportations and material handling are added in the CLC option compared to direct delivery. By the nature of the CLC solution, there will be more intermediaries who treat the goods, and this has proven to be a cost driver according to Lundesjö (2015). It becomes important to focus on how many steps there are in the material handling and to ensure that all the steps are as efficient as possible. The chase of efficiency in every step connects to Liker's (2004) Lean theories that refer to Muda; any action or step in a process that does not add value to the final customer. In conjunction with Liker's (2004) waste categorization that identifies which step or process that should be eliminated, both *Unnecessary transportation or conveyance* and *Excessive inventory* could be related to and avoided with a CLC.

One supervisor points out that the risks of materials being damaged or lost could increase when more actors are involved. It will also be difficult to know where the damage occurs and perform troubleshooting when things have been damaged. However, none of the supervisors in the pilot projects stated that they encountered problems with damaged materials when using the CLC to a greater extent than direct deliveries. Instead, one advantage was that getting track of and following the deliveries earlier resulted in better detection of major delivery errors, such as wrong quantities and bad quality. Detecting these faults earlier made it possible to solve the problems before it affected the production schedule.

In the future, the logistics processes with the CLC can be further improved to be economically competitive. As analyzed in section 5.4, there are certain material chains that are difficult to challenge economically as they have been developed and refined for many years. It is important to bear in mind that the studied CLC is in the start-up phase in comparison to the *Direct Delivery* alternative that has been implemented for many decades. All the supervisors described some teething problems at the initial stages of the CLC implementation. The biggest source of frustration among the supervisors, and opportunities for improvement, seems to be the division of responsibilities. In the beginning, everyone was new in their role and it seems that there was a lot of duplication of work. The duplication of work entailed that several time savings that could be gained with the CLC have not yet been obtained. One example is that supervisors still had to calculate a lot of quantities to order material, as the Logistics Department did not yet have the competence. Currently, one ocular material inspection is done at the CLC by the warehouse staff, another one on-site by JM Supply, and one the next morning by the supervisor. These many quality inspections imply that no time savings in production have yet been created to the extent that the potential indicates. This relates to Vrijhoef and Koskela (2000) role of SCM that focuses on a transfer of activities from site to the supply chain. With the CLC solution, activities such as storage can be moved to earlier in the supply chain. The quality inspection activities on the other hand are not, as of today, moveable since the knowledge on what to inspect differs between the different stages of the chain.

In the case of a CLC, certain cost items and processes are moved upstream in the chain. This transfer applies to, for example, storage of material, which is now moved from the site to a CLC. Just because inventory is moved from the site does not mean that the challenges – and costs - of inventory disappear. In the TCA, it is difficult to draw comparisons of costs between CLC storage and on-site storage as there is no fixed price on on-site storage in the same way as it is in the CLC. In other words, storage on-site is never calculated in terms of costs. The TCA, however, shows relatively high costs for warehousing and handling of each pallet at the CLC, it is therefore conceivable that costs can be lowered within these activities. There are several risk factors for increased unnecessary costs when the number of projects using the CLC is rising. Lundesjö (2015) describes how a Warehouse Management System (WMS) is needed to keep track of the goods when there are several projects, contractors/companies and a large number of different goods in the warehouse. Presently, there is no such system in place and the goods are not connected to a specific place on the warehouse racks. Instead, the plans are laid out manually and exists only in the minds of the two warehouse employees. The risk with this system is that when projects become more material-intensive or if some employee gets ill or quits, material could get lost and moved around unnecessarily.

Implementing a CLC means major changes in working methods for the involved parties, such as the employees on-site and the suppliers. This requires devoted work with change management for successful implementation. Cheng and Podolsky (1996) address issues that may arise when aiming to implement JIT-deliveries, such as resistance to change and stress related to changed routines. The addressed issues reminiscent of the experiences expressed in the interviews with the supervisors. Requirements to fit in tightly defined roles and with less autonomy could increase employee stress (Cheng and Podolsky, 1996). Cheng and Podolsky (1996) also describe that it is in human nature a general resistance to change that needs to be managed to achieve a change. Frustration could be a sign that the supervisors were not allowed to take part in deciding on the solutions they were forced to use for the material supply. Initial skepticism, identified as a problem by Cheng and Podolsky (1996), is also described by the supervisors. However, the supervisors also talked about how they became more satisfied along the way, when they saw that deliveries via the CLC and material handling by JM Supply worked. This initial skepticism and change management must be taken into account as there are obstacles and challenges when implementing a CLC. One option could be to gradually implement the new ways to deliver and handle the materials on-site. Gradually, it can mean that more and more types of material are included over time and successively evaluated before the solution with a CLC is scaled up. In 2020, JM gradually implemented a testing of a CLC in a small scale through three pilot projects and then evaluated the result before proceeding with the CLC solution to the additional projects.

Implementing a CLC and striving towards JIT-deliveries do not only imply changes for the employees on the site. The implementation of a CLC can demand a completely new way of delivering and packaging materials for suppliers. Mattsson (2012) describes how increased effort towards Lean processes with JIT-deliveries also places higher demands on the partnership with the suppliers. Mattsson (2012) states that it is beneficial to work with few suppliers in *single*, or possibly *dual sourcing* with long term relations. JM has framework agreements with many of their suppliers and strives to have a limited number of original products available for all the projects. JM has together with some of their suppliers developed routines for how materials are packaged and/or delivered to improve material delivery efficiency and quality.

Mattsson (2012) states that the long-term stability that single sourcing provides suppliers with security in investing in their production and encourages collaboration towards new solutions. JM's work with framework agreements and long-term relationships strives towards such benefits. This way of working is a strength and even perhaps also a prerequisite for being able to push through changes in logistics and to develop the framework agreements. When changes in the agreements are needed the single or dual sourcing that JM has is an advantage. The TCA model shows that delivery via CLC entails more costs as of today. Changes need to be made in the agreements regarding how suppliers deliver their products to make the CLC the most advantageous alternative. As presented in section 4.5.2, many of the suppliers indicate that delivery via CLC is an advantage for them and saves both time and money, this should then be reflected in the cost connected to the CLC. Since SCM is about improving the whole supply chain, including benefits for its many members, the alternative that is more effective should be the most cost advantageous for all involved actors in the chain, including JM. It is important not only to focus on the contractor or suppliers own gain in the agreements when changes are made. Instead, it is important to have more holistic perspectives for successful SCM, as to enable value creation and like Christopher (1992) says: *"supply chains compete, not companies"*.

According to Frödell et al. (2013), construction companies are more or less centralized in their decision making. JM has a centralized management regarding logistics and purchasing that handles negotiations for several projects at the same time. This is a strength due to the opportunities for price reduction when larger quantities are ordered as well as decreasing administrative work for the single projects. This also provides a uniformity, that deliveries are made in a similar way in all projects. However, this monotony does not have to be an advantage since all construction projects are unique, project-specific deviations must be possible when special conditions arise. When the logistics demands in the framework agreements need to be updated the requirements reach all of the projects. Vrijhoef and Koskela (2000) states that a strive within SCM is to get a holistic view of the supply chain and a more centralized purchasing and logistics function could be argued to fulfill that strive. The central management is believed to ensure a more consistent and higher degree of delivery performance. The impact on consistency and quality is explained by the centralized management possibilities to follow up and set requirements towards the suppliers for all of the projects instead of each individual project doing this separately.

6.4 The TCA-model as a Basis for Decision Making

As stated by Miquela (2001), a TCA is done to gain valuable information about processes or parts of a company. To perform a TCA, data needs to be gathered and compiled to be able to carry out an analysis. The development and analysis of JM’s TCA model provide important insights of the costs related to logistics at JM in Stockholm. Logistics costs are commonly something that is hidden in the construction industry since it is included and reported in relation to several cost parameters, such as costs for material or labor. Separating the costs for logistics and material is a first step of getting an overview of the cost for the supply chain and to obtain control as to make cost savings. The TCA visualizes the costs of the different solutions as this is valuable information for JM for future decision making about which way to proceed in development of the supply chain strategy.

The TCA model shows that the costs for what Dubois et al. (2019) define as the third configuration, including a CLC in the supply chain, is more expensive than the second configuration where on-site logistics is in focus. When something new is implemented a start-up period is needed to gain knowledge and to try out and learn from possible mistakes. The vision for JM when enforcing the implementation is to be more competitive in the market but also to shorten the lead times in production from start to finish. The potential with continuing with the third configuration and thus the CLC is that these visions can be accomplished. As the economic aspects are important in the logistics process, the results from the TCA point to the fact that the framework agreements need to be updated to make the CLC solution more competitive compared to *Direct Delivery*.

Another way to make the CLC alternative more cost advantageous is to investigate further the costs connected to the activities at the CLC. For instance, can the material handling be done more efficiently, or can the warehouse be better utilized? Also, there are opportunities when looking into the WMS at the CLC and adding features into the software that can show the user where in the warehouse a certain material is located. To have the exact amount and location of all goods in a database is also an important back up. As of now, the whereabouts of the goods is just known by the staff at the CLC. If one of the two employees quit, the information is lost. The efficiency in materials handling can also increase when the WMS can inform about where the material that is needed for a certain day is located in the warehouse and material would not have to be moved around as much as of today. Moving around materials increases the risk of materials getting damaged or lost.

The analysis in the TCA model also indicates that there is a big difference between the two batch sizes. The TCA model could be used to compare which costs the batch sizes in between *one-piece flow* and the *batch size standard* would entail. Maybe the vision gathered from the car manufacturing industry is not the best suited for the construction industry, the *one-piece flow* should maybe be a two- or three-piece flow instead. Data from the TCA model could also be used to make decisions about which materials that are best suited for the CLC solution. An important aspect regarding decision making is to have an "open mindset" and not get stuck in the fact that if a material does not get delivered via CLC, the implementation has "failed". The CLC is simply not suitable for all types of materials and the mindset that all materials have to use the CLC for delivery may turn the solution into a disadvantage on an overall level. The materials that already have functioning logistics are unnecessary to bring into the CLC, as well as the bulky materials that need a lot of pallets for each apartment or week of assembly. Although, some materials are more expensive to deliver via a CLC when only considering that material, an impact in reducing costs for other types of material needs to be reflected upon. The overall cost for delivery via CLC is affected by the number of materials and possibilities to co-load. Sufficient material volumes need to be managed at a CLC to cover the fixed costs related to operating the CLC. The TCA model is designed to analyze one individual project, regardless of the number of other projects using the CLC at the same time. Currently, each project has its own transportation from CLC to site, no delivery with multiple projects on the same transportation is performed (so-called milk round). These conditions make the individual treatment in TCA relevant, but if the conditions change and milk rounds starts to be used, the TCA needs to be customized to capture these transportations changes for the delivery alternatives via CLC.

The TCA analysis considers the logistics from a situation where everything is assumed to flow smoothly as planned. Additional costs that may arise on occasion such as damaged or lost goods are not included. The absence of the unpredicted costs makes it hard to compare the extra costs related to materials handling and storage on-site to the costs when materials are stored at the CLC. The TCA model only examines the costs related to materials delivery and handling in line with the second and third configuration and not with the first one, that is, a traditional approach of no joint coordination of material flows. Future development and use of the TCA model could compare the logistics cost between the three configurations, and what actual cost it would entail delivering without a CLC or JM Supply. As such, this could provide arguments for the various alternatives' pros and cons, and how costs are allocated. Investigations that find measurable times and costs for the extra material handling and storage on-site when not using a CLC would probably be of value to the company. Finding measurable times and costs will help the decision making. The extra costs that arise for the delivery alternatives via the CLC can possibly be outweighed by the extra money expected to be saved by improved production flows, work tasks for supervisors, environment at the construction site etc., when using the CLC and JM Supply.

7 Conclusions

This chapter presents the conclusions including answers to the identified research questions presented in chapter 1 together with recommendations for JM based on the results from the study. Lastly, some ideas for future research are presented including issues that would be interesting to investigate further.

- **RQ1: TCA in relation to direct delivery or delivery via the CLC**

The development of the TCA model for *Direct Delivery* and *Delivery via CLC* including various batch sizes, is the main contribution of the study. The TCA is a way to gain knowledge of how the logistics work and the costs it entails. To be able to perform a TCA, data needs to be gathered about the different processes that are included. Parameters in this TCA model are gathered in the framework agreements, through observations at the CLC and from employees at JM and at the suppliers. It is also important to have a relevant reference project that contributes with quantities and schedules which links together times, quantities and costs. As such, the TCA model has also been tested based on the input from the reference project and provided an output in terms of the ability to compare various logistics solutions from a cost perspective.

The identified subprocesses that are part of the TCA model are: transportation from different suppliers to the site or to the CLC, from the CLC to site, also operations within the CLC and lastly, materials handling at site. In conclusion, the important costs drivers in relation to these subprocesses are identified as: the number of pallets, the size and weight of the goods and the number of deliveries. From the results of the TCA-model the conclusion is that the most cost advantageous logistics process at JM from a cost perspective given the current circumstances of, for instance, how framework agreements are stipulated, is the *Direct delivery* to site.

- **RQ2: The pros and cons of implementing a CLC in residential building projects**

Conclusively, the following pros and cons have been identified in the comparison of *Delivery via CLC* and *Direct Delivery* in residential building projects:

+ By using a CLC materials storage is transferred from site to an indoor environment. Materials storage on-site has proven to be a cost driver as unnecessary movements may be required, and materials may be damaged or lost. Conclusively, waste regarding unnecessary movement and excessive inventory is reduced by using a CLC.

+ Involving a CLC in the supply chain is a SCM advantage that enables better control of the later parts of the supply chain and is presumed to result in better delivery precision to site. Transportations with co-loading requires only one truck with one drive to site instead of many different ones, which makes it easier to handle on-site. The drivers know where and when to show up and which materials that are needed, which enables better control of the deliveries from a site perspective.

+ The number of transportations to site decreases when a CLC is used as materials are co-loaded and delivered in accordance with a weekly schedule. This is an important outcome in several aspects: environmental impact is reduced, less congestion around the site, less handling of arrival control and unloading at the site, and fewer disturbances for site management that needs to approve on arrivals.

+ In the future, requirements may be set by municipalities and authorities regarding filling ratios in transportations to sites to get permission to build. A CLC can ensure a degree of co-loading to cope with such requirements at the same time as delivering in smaller batches in accordance with production flow at site.

+ According to the TCA-model, using a CLC is economically justifiable considering reducing batch sizes coming into site in the future. This is in line with a JIT approach of materials delivery.

– When using a CLC, the material handling activities in the supply chain and number of intermediaries increases which is a cost driver. More intermediaries risk more damages of goods due to more activity related to storage activities, handling, loading, and unloading.

– *Delivery via CLC* is more expensive than *Direct* Delivery, in a compiled overview for all examined materials in this TCA.

- **RQ3: JM's future development of logistics solutions with support from the TCA model**

In conclusion, through the implementation of a CLC and the subsidiary JM Supply, JM has taken successive steps towards what is considered to be efficient construction SCM. The first stage of improvement is to keep track of processes and the costs they entail. Development work in construction logistics is both simplified but also closely related to working with single or dual sourcing and stronger partnerships in customer-supplier relationships in the supply chain. The TCA can be of great help when making decisions in the future about which parts in the supply chain that need to be developed to reach an effective overall construction SCM solution for JM.

7.1 Recommendations for JM

Based on the conclusions, the recommendations for JM are:

- Conduct an overview of the framework agreements with materials suppliers that are associated with delivery through the CLC.
    - Many suppliers perceive it a favorable solution to deliver to a CLC, as the conditions are often more convenient for them. However, currently there is little, or none, price gain for JM when using the CLC, it should therefore be savings that JM has not yet been able to benefit from.
- Use the results from TCA to decide which types of materials that should be part of the CLC solution and which material types that are more suitable for direct deliveries.
- Conduct an analysis of different batch sizes between 1 to 5 to find the best solution. It may be that a suitable *one-piece flow* is not to deliver one apartment/day as what has been investigated in the TCA in this study. For instance, something in between one to five, maybe three per delivery every three days could be found to be the best option. The TCA model is designed so that through small adjustments in the model, it should be possible to carry out such an analysis.
- Increase and improve transparency and collaboration with the CLC company to jointly increase efficiency and reduce costs for both actors.
    - Concrete improvement proposals to ensure that a Warehouse Management System (WMS) is used in the CLC to ensure the stability and back-up for JM's projects but also to make the activities in the CLC more efficient.

7.2 Future research

Regarding future research, it would be interesting to add an investigation that helps to evaluate the additional costs that may arise on occasion, for instance, damaged or lost goods. This relates to trustworthy and accurate measurable times and costs for the extra material handling and storage on-site when not delivering via a CLC. A common perception that many researchers and actors in the industry have is that the extra costs that arise for the delivery alternatives via CLC can be saved in later processes. The savings is said to be made in improved production flows, less disturbance, simplified work tasks for supervisors and craftsmen, environment at the construction site etc. It would be of interest to trace actual numbers of these savings that can be compared to the additional costs that are found in the TCA. Currently, numerical proofs of such alternatives are scant.

Another interesting issue for future research concerns batch size in relation to efficient production and various production methods and which alternatives that generate the lowest costs related to logistics. A TCA could help in answering that question as well when including more batch size alternatives, to find the ones with the lowest cost for different materials. Also, an investigation concerning the validity of the TCA-model developed in this study could be carried out when the reference project is completed. The validation could be done by compiling invoices and comparing the results to the TCA calculations. If any differences are discovered, certain parameters can be changed in the TCA model for a more accurate result calculation. Finally, more TCA in relation to various projects could further improve the knowledge and understanding of cost drivers and how costs are allocated in the supply chain in relation to different logistics solutions.

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