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Improving construction supply chains using load carriers

Effects of implementing a load carrier for reinforcement bars to construction sites

Master thesis in the Master Program Supply Chain Management

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Karl Bäckstedt, Philip Nordström and Mikael Persson

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Abstract

Construction sites are characterized by lack of space, uneven stacking surfaces and temporary storage locations. Studies show that about a third of a Swedish construction worker's time is used to find and sort material. Thus, actions should be taken to simplify sorting and handling of material. Delivery of reinforcing bars to construction sites is a cumbersome and time-consuming process, which would benefit from simplified material handling. The goal of the thesis was to investigate how the delivery process of reinforcing bars could be improved by implementing a load carrier in the material flow.

A case study was carried out, involving a reinforcing steel producer, a construction company and a material handling equipment provider. The study investigated the flow of reinforcing steel from the producer to a nearby construction site, with the aid of a load carrier designed by the logistic solutions provider. The material and information flow in the supply chain were mapped and analyzed in order to explore the effects of the load carrier. The mapping of the supply chain was carried out in accordance with the lean framework material flow mapping (MFM).

The findings explored a transfer of activities, from the construction site to the producer. The delivery of material at the construction site was simplified and time for handling material was reduced. However, the production site faces an increase in number of activities and time of order preparation. In addition, the load carrier implementation required reverse logistics to be incorporated in the supply chain.

Resources in the supply chain were affected in terms of requirements and occupied time. The usage of the construction crane was significantly reduced, which was deemed as beneficial, as it was identified as a bottleneck resource. In addition, usage time of the truck was reduced by shorter loading and unloading processes. The load carrier implementation resulted in an increase in man-time at the producing site, while the opposite was experienced at the construction site. Also, the load carrier implementation required significant changes to the information and communication process in the supply chain.

The aim with the analysis was to explore the positive effects of the load carrier and diminish the negative by suggesting a future state map of the supply chain including the load carrier. Thus, negative effects were targeted in the suggestion of the future state map. As so, a future state was presented to further develop the positive effects, while the negative effects were mitigated by reducing the number of activities, warehousing nodes and time in warehousing. Suggestions of changes to the load carrier were presented in order to better fit it into the supply chain's activities.

It appeared possible for the reinforcing bar supplier to expand the load carrier implementation into its value offering. However, a closer mapping of the cost of activities may be needed. Several barriers were identified, such as a supply chain wide understanding of the load carriers purpose, payment structure of transporters as well as strategy alignment of suppliers and customers.

Keywords: Reinforcing bars, Rebar, CAB, Material handling, Construction, Material flow, Supply chain, Load carrier, Packaging, Logistics

Terminology

- BIM-engineer – Building Information Modeling Engineer. An engineer who models and represents buildings in a computer environment.
- Bundle of rebar - A bundle consisting of a set of geometrically identical rebar.
- CAB - Cut-and-bent rebar. Also called C&B.
- Dwell time - the time which a vehicle is stationary during loading and/or unloading.
- VSM - Value stream mapping.

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1 Introduction

The chapter introduces the subject and explains the problem background. Purpose, scope and outline of the thesis are presented.

1.1 Background

Construction companies face fierce competition and customers demand lower costs, at the same time as high quality and short building lead times with precise deadlines are expected (Azambuja and O'Brien, 2008). This is a challenge for construction companies characterized by highly fragmented supply chains, lack of standardization and independent planning (ibid.).

Costs of building construction in Sweden have in recent years increased significantly (Statskontoret, 2009). A study by Mannheimer (2006) shows that about a third of a Swedish construction worker's time is used to find and sort building materials. This makes material handling a crucial and highly important subject. Simplifying material handling activities at construction sites are as such important.

Prefabricated cut and/or bent reinforcing bars, commonly referred to as cut-and-bent rebars (CAB), are customer-specific products which are made-to-order. CAB is designed and produced according to drawings of the specific building where it is to be installed. A study shows that about 40 per cent of the total cost of CAB is related to delivery, handling and installation (Josephson et al., 2011).

According to a technical manager at Celsa Steel Service AB, a construction site of today generally has two alternatives regarding its sourcing of CAB. It is either nearly fully postponed, where final customization is done on-site by construction workers or ordered from a CAB manufacturer who manufactures each item to specification. These two approaches have different benefits and drawbacks in terms of efficiency and robustness. By doing the finalization on-site, miscalculations and other mistakes are more easily mitigated at the expense of efficiency. Conversely, by ordering CAB from a manufacturer, production quality may be increased while man-hour and machine-hour consumption at the construction site are reduced.

In Celsa's current state of operations, Celsa bundles geometrically similar CAB which are to be delivered, in order to simplify handling and installation. Prior to delivery to construction sites, bundles are intermittently stored at Celsa's production site. Once bundles of CAB are ready to be delivered to the construction site, they are stacked onto a truck in sequence of the truck's intended delivery route. When CAB is to be delivered at a construction site, the bundles are unloaded from the truck, one by one, with aid of a crane and simply stored on the ground. This process is usually followed by a delivery inspection. The heavy bundles are arranged in piles when they are unloaded from the truck, which makes delivery inspections difficult. It is common for deliveries to be performed hastily and at unspecified locations due to resource and/or time constraints. In addition, attached documentation containing bundle specifications may get lost among piled material.

The current procedure generates several issues once delivered at the construction site. Pilferage, material handling and material losses generate inefficiencies and additional deliveries to meet specifications. Generally, a construction site is limited in terms of access and warehousing capabilities. This creates an underlying need for organizing materials efficiently. A construction site is a temporary production site. This means that there is an unbalanced flow of materials as material used for logistics purposes needs to be transported away from the site, as it is no longer part of the construction project (Storhagen and Lindqvist, 1998). This makes the logistics to, at and from construction sites complex. In addition, the lack of space for loading and unloading material at the site contributes to the complexity of the logistics operations. Also, construction operations are dependent on delivery precision, as disruptions in the delivery schedule may alter the schedule or even put the construction site work to a halt.

Celsa has, together with a customer within the construction sector, JM AB, referred to as JM, identified that the delivery process may benefit from an introduction of a purpose-specific load carrier for CAB that is to be delivered to the construction site ready for installation, as seen in Figure 1. In addition, Celsa has identified a specific load carrier, developed by Starke Arvid AB, referred to as Starke Arvid, which could be suitable for this purpose. The load carrier would deliver entire orders of CAB to an intended location at the construction site, which could improve the overall delivery process. Celsa considers this as a possibility of differentiation in comparison to its competitors. Implementation of new load carriers has been studied, in for example Jahre et al. (2006). They conclude that implementations come with benefits as well as challenges, which need to be contextually evaluated.

Figure 1 - The intended load carrier.

1.2 Purpose

The purpose of the project is to identify and analyze possible effects in a construction supply chain when implementing a load carrier dedicated to reinforcing bars. Based on the analysis, recommendations regarding an implementation of a load carrier will be presented as decision-support.

1.3 Scope

The scope of the thesis involves evaluating the physical and informational flow through the supply chain of CAB, from the supplier's production output to the construction site's addressed location for installation, as seen in Figure 2. This evaluation includes loading and unloading at each respective location as well as eventual reverse logistics of the load carrier.

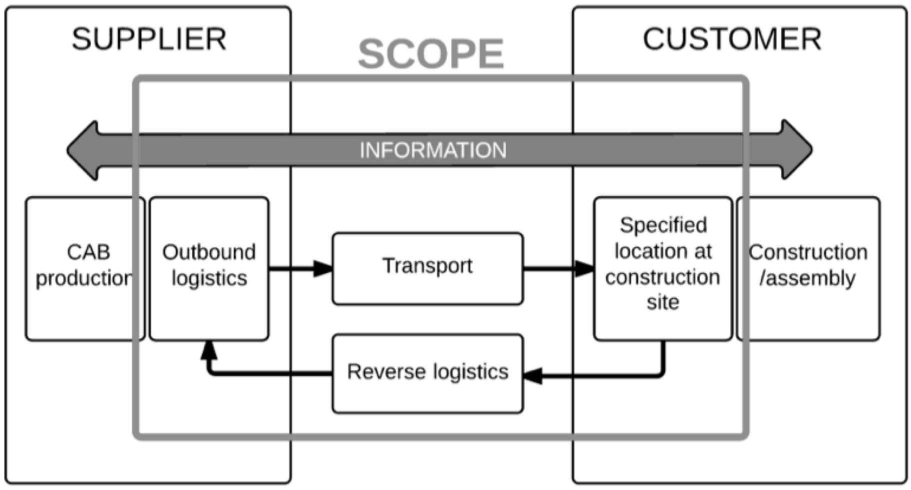

Figure 2 - Scope of the thesis. The thesis does not regard actual production/assembly features at individual actors. Note that reverse logistics is only applicable in an implementation of a load carrier.

The thesis aims to provide suggestions regarding specifications and performance requirements of the load carrier, but does not intend to alter the given load carrier design but rather give input regarding issues of the carrier. The report will not go into the product development process of the load carrier, except possible improvement suggestions or requirements found during the process.

1.4 Outline of the thesis

This section provides an overview of the thesis and explains what is covered in each chapter.

Chapter 2 - Empirical context presents the three involved actors in the case study, Celsa, JM and Starke Arvid. Industry context, competitors and revenue amongst other are presented to provide an understanding of the empirical context.

Chapter 3 - Problem analysis defines the problem that is to be addressed and presents the derived research questions. The problem analysis aims to shed light on the problem in a scientific context and ends up in the research questions that are to be answered.

Chapter 4 - Frame of reference presents existing research that is to be applied on the empirical findings. The frame of reference provides material for analysis of the problem, to enable answering of the research questions. Theory regarding activities, resources and actors are presented in order to enable an analysis of the supply chain including the load carrier.

Chapter 5 – Method describes the data collection methods and analytical tools are presented. It describes how the case study was structured and performed. A distinction is made between current state of operations and the load carrier as implemented, referred to as the pilot project. The thesis uses the analytical lean-tools *value stream mapping* and *material flow mapping*, which enables an analysis of the supply chain, in order to assess its performance.

Chapter 6 – Empirical findings presents the findings of the case study. The findings are presented through supply chain mapping and a map of the information process, along with data regarding activities and resource occupation.

Chapter 7 – Analysis provides an analysis in regards to the frame of reference and the empirical findings. The findings are analyzed to evaluate the performance of the supply chain with the load carrier implementation. In the analysis chapter, the current state and pilot study are compared and a suggested future state of operation is presented.

Chapter 8 – Discussion evaluates the method and empirical findings. The findings of the research questions are discussed in relation to existing literature, together with findings and reflections by the authors. In the conclusion, the thesis is summarized regarding its results, findings as well as suggested further research.

2 Empirical context

This study primarily involves three firms: the producer Celsa, the customer JM and the load carrier supplier Starke Arvid. In order to provide an empirical context to the study, these three actors are briefly described.

2.1 Celsa Steel Service AB

Celsa Steel Service AB is a producer of reinforcing bars in Sweden. Since 2007, Celsa has been a part of the Spanish Celsa Group, one of the largest steel producers in Europe, which has its headquarters in Barcelona, Spain. The Swedish branch has annual revenue of about 700 million SEK and about 170 employees. Celsa has production sites at three different locations in Sweden, Halmstad, Västerås and Vännäs, serving its respective geographical area. At these production sites rebar is designed, cut and bent to customer specification. In addition, sales offices are located throughout the country to serve customers.

Celsa primarily serves customers and wholesalers in the construction and infrastructure industry. As so, Celsa produces several different products and delivers about 100 000 metric tons of CAB yearly to its customers. Different sizes of straight rebar, bent rebar and rebar mesh, amongst others, are in Celsa's product portfolio. Some products are presented in Figure 3.

Figure 3 - Examples of rebar types. From left: Straight reinforcing bars, bent reinforcing bars, and welded reinforcing bars (Source: http://www.celsa-steelservice.se).

The construction segment receives deliveries of 35 000 40 000 metric tons of reinforcing bars every year from Celsa. This segment consists of customers constructing houses, infrastructure and industries. The total amount of rebar is distributed over 5000 deliveries and further distributed in 150 000 different bundles consisting of geometrically similar rebars. These bundles are transported and delivered to 500 construction sites across Sweden.

It is important to mention the relative uniqueness that characterizes the products; almost every CAB is made-to-order. Commonly, parts are made in batches of 5 20 identical pieces. These pieces are unique in terms of customer demand and will have little to no value, beside scrap value, outside the original order context.

Celsa provides sales and engineering support to its customers to aid the specification process. Example of these services are specification of CAB from drawings, BIM modeling, color coding and delivery according to schedule of CAB to simplify the delivery and handling process, specified timely delivery and planning together with control in the IT-platform QR. Celsa is facing competition from the overcapacity that exists in today's European steel market. The major competitors are located in low-cost countries, delivering high quantities of CAB to the Swedish market. Celsa argues that its services extend its value offering to its customers in comparison to its competitors.

2.2 JM AB

JM AB is a construction company focusing on building homes consisting of condominiums in major cities in Sweden, Norway, Denmark, Finland and Belgium. The major markets are the attractive large cities in Scandinavia, such as Stockholm, Uppsala, Gothenburg, and Malmö in Sweden and Oslo in Norway. As so, the main focus of JM is emerging markets in the Nordic area. JM is mainly constructing apartment buildings but do, to some extent, also construct smaller buildings. In addition, JM is engaged in the construction of commercial buildings, mainly in the Stockholm area. The company headquarters is located in Solna, Sweden.

The company has revenue of about 14 billion SEK, 2200 employees and is noted on the NASDAQ OMX Stockholm stock exchange. JM's focus lies on creating value for its customers as well as to utilize its resources as efficiently as possible. JM was founded in 1945 and has 70 years of experience in project management concerning construction. JM has estimated its position as the market leader in private housing, in cities where it is operating, in Sweden and as number seven in Norway (JM, 2015). At the end of 2014, JM had around 29 000 available building rights, a majority of these in the Stockholm region.

According to JM, as it is a building company taking part in the building of well-functioning communities of today and tomorrow, sustainability is of major interest. JM aims to take economic, social, ethical and environmental responsibility for the projects that it is undertaking, including finished dwellings and premises. In addition, JM has signed the UN Global Compact concerning human rights, labor, environment and corruption. (JM, 2015)

The company has an underlying commitment in regards to developing efficient processes, including the logistical process to and within its construction sites. JM emphasizes the importance of improving products and processes through standardization and "lean thinking". The company was awarded the lean prize by *Lean Forum Bygg* 2011 (JM, 2015).

2.3 Starke Arvid AB

Starke Arvid provides the construction sector with products which enhance the ergonomic situation at construction sites. Its main focus is to offer solutions to problems faced by construction companies in everyday operations. Starke Arvid has revenue of about 60 million SEK and employs around 35 people. The company's production and product development is located in Ljungskile, Sweden. Starke Arvid aims at working in close cooperation with its customers in order to achieve deeper knowledge of them and their problems.

Starke Arvid is engaged in three main business areas: development, production and selling of products to the construction industry, handling equipment for snow removal from roadways, and engineering services for a number of clients in the surrounding region (Starke Arvid, 2014). As the business area regarding this project concerns construction products, the following description of Starke Arvid will focus on this business area.

Starke Arvid is a leader in product development in the construction industry serving many large construction companies with products for efficient logistic solutions. Starke Arvid's products for the construction industry are further divided in three categories, namely *transport and handling*, *mounting*, and *recycling*. These three product categories aim to enhance the logistic performance within construction site. Products for transport and handling consist of wagons, carriages and racks to simplify the transportation and handling of material at construction sites. Mounting products consist of smaller elevators and machines for lifting material to simplify installation. Examples of products for recycling are wagons and containers for disposal of products, and various chippers or shredders. Examples of products from the three categories are illustrated in Figure 4.

Figure 4 - From left: Rack for fence storage, plasterboard lift and chipper. (Source: http://www.starkearvid.se).

Starke Arvid's business model is to develop and produce specialized carriers for the construction sector. The products are to enhance the efficiency and the effectiveness of the industry, while at the same time enhance the working environment for the workers in terms of ergonomics and safety. Starke Arvid's aim is to continuously develop its products to enhance performance of its customers. As so, a large part of the profit is reinvested in product development, which is performed in close cooperation with the construction sector, to drive the industry forward.

Starke Arvid is engaged in sustainable development, taking environmental aspects in consideration when developing products. The company holds a diploma regarding environmental issues since 2013, concerning ethical and environmental friendly purchasing routines (Starke Arvid, 2015). In addition, Starke Arvid performs documentation regarding disposal of products.

3 Problem analysis

Celsa is facing competition from a production overcapacity that exists in today's European steel market. A strategy to handle fierce competition is to differentiate the business strategy and the offering of products relative to its competitors (Rothenberg, 2007). By shifting focus from offering a simple product, Celsa is looking into the possibility of extending its value offering, by implementing a load carrier in the material flow. The intent of the load carrier is to simplify the delivery process of CAB.

Implementing a load carrier throughout a supply chain will likely change the way which interactions are made, how resources are utilized and the number and types of activities that are performed. It is necessary to understand how these alterations affect the supply chain performance. Historically, there has been a tendency for packaging system evaluation not to reflect the entire supply chain's performance but rather a single actor, with the risk of sub-optimization as a result (Pålsson et al., 2012). A load carrier implementation may affect other resources' occupation as well as put requirements on additional resources, because of necessary changes within the activity or actor structure.

The structure of activities within and between each actor may change, in response to the implications of a load carrier. The prerequisites of a load carrier may also affect the supply chain's resource needs and their respective utilization. These aspects may be illustrated through the ARA-model, describing activities, resources and actors and their respective interactions. The actor structure refers to involved actors and the information and communication between them. The resource dimension involves physical resources, such as machines, and intangible resources such as know-how (Gadde et al., 2010). The activity dimension is the activities, which are performed by involved actors, for example transportation or materials handling (Gadde et al., 2010). The aim of the model is to present how actors combine resources and activities in their operations within their respective network (Gadde et al., 2010). The research areas and their interdependencies are illustrated in Figure 5. The ARA-model is used to retain a holistic perspective of the supply chain's overall performance and illustrate how resources, their respective utilization as well as undertaken activities for each actor are affected.

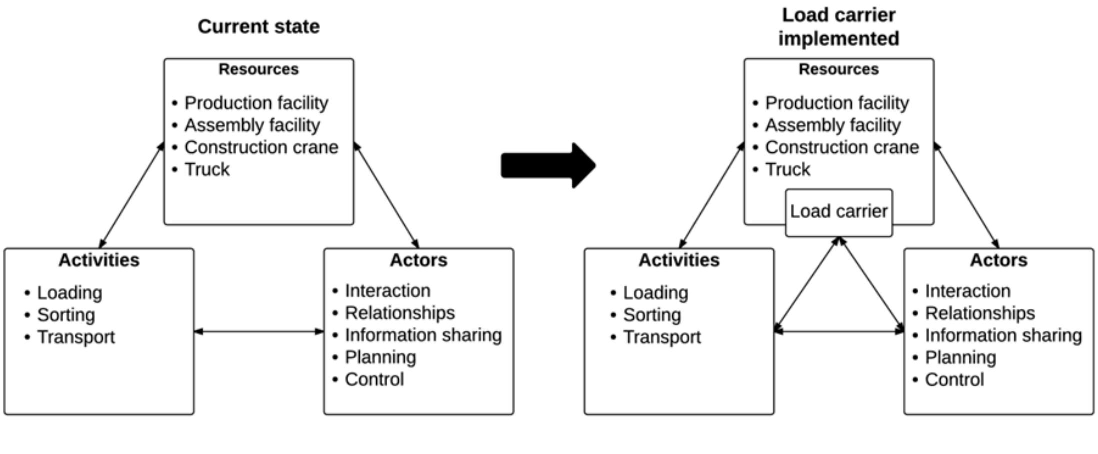

Figure 5 - The ARA-model contextually illustrated. Introduction of a load carrier, illustrated within the ARA-model.

Introducing a load carrier within the current ARA-structure will likely not produce a high degree of fit directly. As so, it is important to evaluate the supply chain performance to enable improvements of the supply chain to better match the load carrier's prerequisites. To study a new resource within an existing context may reveal several benefits as well as challenges. The research questions are divided into the dimensions presented in the ARA-model and serve to assist the thesis in reaching its purpose. In addition, evaluating supply chain performance is considered to span all three dimensions and is thus presented outside the model.

3.1 Effects on activities

Implementing a new resource in a supply chain may affect how existing activities are performed and may alter the division of labor between existing activities among the actors in the supply chain.

An implementation of a resource, load carrier, in the flow of CAB will affect the delivery process as well as require a reverse logistics process. The term 'reverse logistics' is an aspect of the traditional logistics, where waste of products, or as in this case load carriers, are returned upstream in the supply chain (Srivastava, 2008). Reverse logistics tends to require a well-coordinated supply chain and effective communication between the involved actors (Olariu, 2013). As so, achieving a high level of coordination in the chain requires allocation of resources and aligning of activities (Gadde et al., 2010). In this particular case a load carrier, used for delivery of CAB to construction sites, will be transported empty back to Celsa's production sites which implies additional activities compared to a scenario without the load carrier. This requires Celsa and its customers to coordinate and plan the logistics flow to efficiently fit the load carrier into its existing system.

Implementing a load carrier will further change how CAB is handled in the production process, the loading and unloading of trucks as well as in the installation process at the construction site. Due to the heavy and unwieldy nature of the product, rebars are not easily manually handled, which creates problems during inspection of incoming goods. Poor supervision and material retrieval handling may result in insufficient information regarding delivery location and quality. This, in turn, could result in loss of material, necessity of re-ordering or additional administrative work in terms of re-stacking and searching. The bundles from Celsa are delivered with detailed information and barcodes, which remain unused in the receiving process, according to a JM site manager. A load carrier implementation may mitigate issues, such as information handling, by adding traceability as well as decreasing pilferage and throughput time (Andersson et al., 2014).

By introducing a load carrier, CAB may be delivered as a kit to the installation site and improve on-site efficiency. The load carrier loaded with CAB will be delivered to the construction site sorted and prepared for installation. Solving material handling-problems at the construction site may require more upstream activities and enhancement of the level of coordination.

Research questions related to activities

- *How will the configuration of activities change between actors throughout the supply chain with a load carrier implementation?*
- *How are individual activities altered by the implementation of a load carrier?*

3.2 Effects on resources

Celsa, as most production facilities, faces constraints in terms of resources. A high output, given input, is a desired state in order to maximize stakeholder value. Celsa's warehouse is operated by overhead cranes, which serve both the production by sorting and storing as well as outbound logistics by loading trucks. In addition, a load carrier implementation will affect resources in term of requirements and utilization of other resources. The effects on, for example, the occupancy of cranes, available space and operators are therefore important to investigate and evaluate in order to fully understand the impact of this resource implementation.

In order to successfully implement a new resource in a supply chain, it must be compatible with the already existing resources (Gadde et al., 2010). Therefore it is vital to investigate how the load carrier is functioning with already existing resources, such as trucks and cranes, in the supply chain in order to mitigate the risk of having incompatible resources. When introducing new packaging within a supply chain, several requirements need to be fulfilled, such as ability to fit the product, ability to fit the handling equipment, relative size, and cost (Pålsson et al., 2012). A packaging as uncommon as the intended load carrier may put unnecessary strain on the current supply chain and its respective resources and activities. It is therefore crucial to evaluate its applicability and possible improvements.

Given the heavy and cumbersome handling of rebars, cranes tend to be required for sorting and moving. Construction cranes are among the most costly equipment used at construction sites (Zavichi et al., 2014). A construction site crane usually plays a central role of the overall productivity of the site and its utilization may set the pace of the entire project (ibid.). This makes not only utilization rate of a specific construction site's crane important, but also the overall reduction of unnecessary usage. The construction crane may therefore be regarded as a bottleneck resource (Jonsson and Mattsson, 2009). A site manager at JM argues that it is highly desirable to minimizing the utilization of the construction crane in operations, such as unloading a truck carrying CAB.

The limited available space at construction sites contributes to the problems of material handling processes. The outdoor environment, uneven stacking surfaces and temporary storage locations make it difficult to plan and efficiently coordinate operations. Given the circumstances regarding poor storage possibilities, the construction industry has commonly had problems with working in non-ergonomic positions for extended periods of time, including too heavy lifts as well as lifts with twisted backs (English et al., 2006). Bulky, heavy or generally cumbersome construction materials are often the culprits of work-related accidents (Lipscomb et al., 2006). A load carrier intended for CAB may mitigate several of these ergonomic issues as activities of manually handling the material are reduced.

Research questions related to resources

- *How are resources affected when implementing a load carrier?*
- *What are the suggested recommendations and specifications regarding a load carrier in the specific supply chain?*

3.3 Effects on actors

Every interaction requires a certain amount of communication, and with increasing supply chain collaboration the necessity of precise communication tends to increase (Sendhil and Pugazhendi, 2012). Control and information exchange is crucial for the performance of a supply chain's overall performance and effectiveness (Andersson et al., 2014). Implementing a load carrier within the supply chain, resulting in more complex activities and coordination, may require a deeper relationship with higher interdependency between supplier and customer.

When undertaking significant investments to assist customers, additional requirements in the supplier-customer relationship may occur. As for Celsa, it may be necessary to underline the understanding from the customer's point of view that the 'lowest price for a certain good' is not necessarily the best way to acquire material (Gadde, 2004).

Introducing a new resource within a given supply chain context alters the way which its actors perform their activities and relate to their responsibilities. When introducing a load carrier in the supply chain of CAB, activities are likely to be transferred between actors and with that their respective responsibilities. Therefore, it is beneficial to align each actor's strategy towards a common goal (Chopra and Meindl, 2013). One major challenge in supply chain management is to determine how resources are to be controlled and how access to such should be delegated in order to reach supply chain profit maximization as well as mitigate the risk of sub-optimization (Chopra and Meindl, 2013). The allocation of responsibility also includes the future ownership of the implemented load carriers. A load carrier implementation would require additional resources, such as maintenance, making ownership a difficult task.

Construction projects tend to be highly customized and buildings are often specified to customer requirements (Storhagen and Lindqvist, 1998). This implies that the construction industry is a relatively special industry in the sense of unique one-time projects. In comparison to the manufacturing industry, where longer continuity and incremental quality improvements often are possible, one-time projects are unique in these aspects (O'Brien et al., 2008; Formoso and Isatto, 2008). Also, CSCM faces challenges, such as dispersed supplier base and many stakeholders, which complicates coordination and communication. Employing a load carrier would require close collaboration and goal alignment between actors in order to handle the complexity of reverse logistics and reap the possible benefits.

By improving communication and coordination more advanced control concepts may be enabled, such as just-in-time (Vokurka and Lummus, 2000). This may, in turn, may reduce cost and/or increase efficiency. In order to maximize supply chain performance, it is important to investigate how actors initiate their respective material flow, and how it would change with an implementation of a load carrier.

Historically, the construction industry has had few incentives regarding efficiency improvements. This can be derived from the nature of the business, where demand is high during economic growth-intensive periods, which mitigates the need for improvement and the workforce is laid off during recessions with loss of knowledge within the organization as a result (Statskontoret, 2009). With each project often being a one-time operation during a limited period of time involving many separate actors, it is harder to establish long-term supply chain systems with continuous improvement and high efficiency.

Research questions related to actors

- *How will the implementation of a load carrier in the material flow affect existing relationships in the supply chain?*
- *How will control of the supply chain change?*
- *How may the ownership and access to the load carrier be structured within the supply chain?*

3.4 Evaluating supply chain performance

In addition to the research questions related to the dimensions in the ARA-model, it is important to assess the performance of the supply chain in order to understand the effects of implementing a load carrier. When investigating the effects of implementing a new resource in the current structure it may be beneficial to capture the effects through measurements. These measurements may be used to suggest a future supply chain design including the new resource. The following research questions spans over all three dimensions and are therefore presented independently of the ARA-structure.

Research questions related to evaluation of supply chain performance

- *How can the performance of the supply chain be assessed?*
- *How may a future state supply chain, including the load carrier, be designed?*

4 Frame of reference

The frame of reference is divided into four sections, one which aims to provide theory and tools to evaluate and improve supply chains and their performance. Further the following three sections are sorted according to the three dimensions of the ARA-model, as presented in the problem analysis. Thus, the supply chain is analyzed in terms of actors, resources and activities. It is important to analyze the effects on resources and activities, both at each actor as well as in a supply chain perspective. The current supply chain is analyzed in order to enable a comparison with the supply chain with the implemented load carrier. Based on the comparison, a future state suggestion of the supply chain may be presented. As so, earlier research following this structure is presented in this chapter. The structure of the frame of reference follows the logic presented in Figure 6.

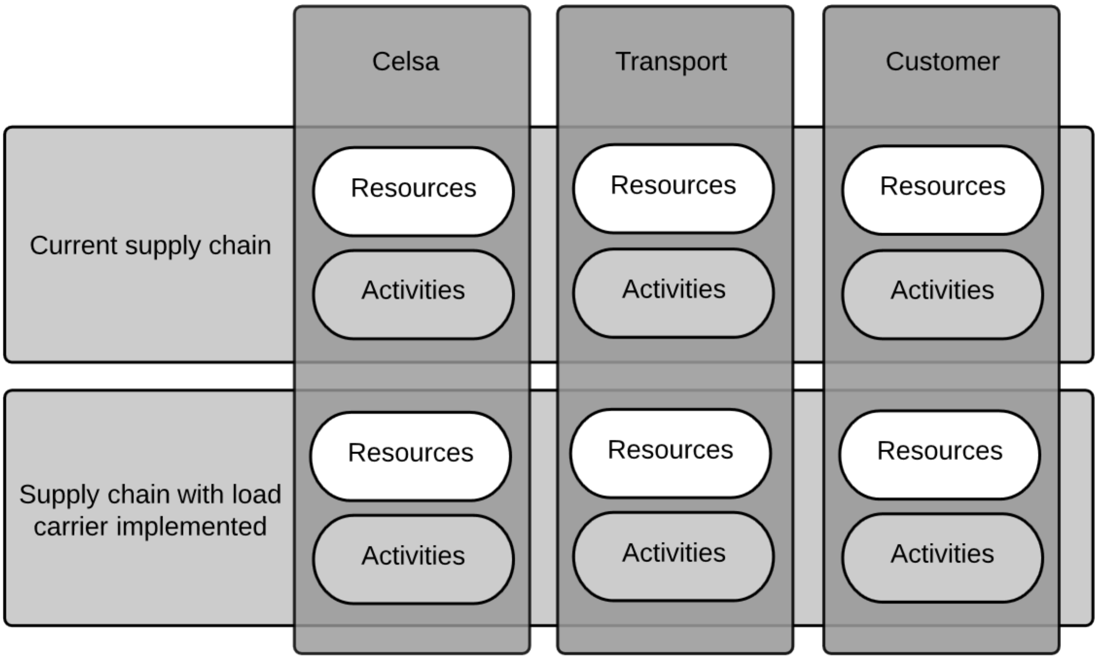

Figure 6 - The analytical perspective of the thesis - applying the ARA-model to rebar delivery supply chain. The model regards both individual actors as well as the supply chain as a whole.

To understand the effects of a load carrier implementation in the supply chain and thus answer the research questions of the three dimensions, relevant research regarding these dimensions is presented. For the activity dimension, literature regarding configuration and alteration of activities when implementing a load carrier is presented. In addition, research how to assess a supply chain's performance is presented. Earlier research regarding load carriers and their implication on existing resources as well as on acquisition of new resources is presented in order to answer relevant research questions. The actor dimension concerns the effects on relationships, control in the supply chain and how ownership of the load carrier may be designed. Hence, earlier research in these areas is presented. The literature is applied on both internal and external communication between the actors, and how activities and resources are affected with a load carrier implementation, at each respective actor as well as the alteration and configuration of activities between actors. As so, the literature is applied on the current supply chain as well as the pilot supply chain involving the load carrier.

4.1 Supply chain performance

Theory and models which span all three dimensions of the ARA-model are presented separately in this section. Evaluating supply chain performance displays common frameworks for analyzing and evaluating supply chain performance. Construction supply chain management refers to the context and challenges which are relatively unique for the industry as a whole. Understanding indirect supply chain costs refers to the assessing of costs associated with supply chain activities. Differentiation concerns the value offering towards customers, enabled by unique supply chain services.

4.1.1 Evaluating supply chain performance

Lean, among other alternatives, is a mindset used to reduce waste and to enhance value flow efficiency in a supply chain. Lean stretches over the three dimensions, including activities, resources and actors.

Lean manufacturing is a systematic approach employed to reduce waste and solely undertake activities that the intended customer is willing to pay for, defined as value. Value stream mapping (VSM) is a commonly employed tool derived from lean. The concept of lean usually includes various tools and models which aim at increasing efficiency and reducing activities that do not create value. Activities that do not create value are defined as waste within organizations and production environments (Liker and Hoseus, 2008).

Generally, non-value creating activities are defined in three categories: muda, muri and mura, which imply waste, overburden and unevenness respectively (Smith, 2014). Focus is commonly on the reduction of waste (muda), which lean manufacturing identifies seven categories of (Hines and Rich, 1997). These are as follow:

- Overproduction
- Transportation
- Unnecessary inventory
- Inappropriate processing
- Waiting
- Excess motion
- Defects

Further, underutilized employees and their knowledge may be regarded as an eighth waste (Womack and Jones, 2007). A lean strategy is employed to reduce or eliminate wastes within organizations. Dolcemascolo (2006) state that a wider perspective, through an extended value stream, may increase the overall supply chain benefit, as more effort is put on cooperation rather than individual cost reduction. When employing lean principles throughout an organization Dolcemascolo (2006) argues that there are four main elements in the value chain which may be improved, namely:

- Communication
- Relationships
- Inventory
- Financial sustainability

Much of the improvements in these areas can be attributed to the long-term focus and cooperation between supply chain actors, which are necessities of an effective lean implementation. Womack and Jones (2007) argue that there is little to be won by solely employing a "need-to-know" basis relationship but rather establish a fixed set of principles addressing the principles:

- Specify value
- Identify value stream
- Make value flow
- Let customers pull
- Pursue perfection

This would be done by deciding on a global supply chain value definition as well as an undertaking of reducing waste within and in between every supply chain actor (Womack and Jones, 2007).

To fully understand the creation of value and the occurrence of waste within this particular supply chain context, lean may be regarded as a powerful toolset. Particularly tools such as value stream mapping and material flow mapping are discussed in *Chapter 5 – Method*.

4.1.2 The construction industry and construction supply chain management

To understand the context of which actors in the construction industry work, the following chapter presents literature regarding the subject. Research regarding construction supply chain management is presented in order to provide analytical tools to answer questions regarding how relationships are handled.

The construction sector is characterized by large projects and involves a large number of different stakeholders. As a result, the power within the supply chain is often fragmented, creating issues regarding coordination, planning and control of the supply chain (Formoso and Isatto, 2008). This implies that conventional supply chain management must be modified in order to be applicable within the construction industry (Formoso and Isatto, 2008).

The limited space at construction sites implies that value adding work should be made off-site, which means that activities should be performed upstream in the supply chain (O'Brien et al., 2008). Many actors are cooperating or working in new constellations for the first time in a construction project, which further complicates the information and coordination process (ibid.). O'Brien et al. (2008) claim that improvements in project performance may be achieved by adapting a more common supply chain perspective on the construction industry.

Poor production planning, common in the construction industry, contributes to the need of holding excess inventory or performing final customization on-site. This may be avoided by well-functioning supply chain management (Azambuja and O'Brien, 2008). In the pre-project plan, the configuration of the supply chain should be involved due to that customer requirements and decisions made in this early phase will affect the total cost and performance of the project (ibid.). In addition, if designers and constructors take independent decision, without applying the perspective of supply chain management, it may harm the outcome of the project in financial terms (ibid.). However, if supply chain management is integrated early on in the project planning phase, problems such as inventory at construction site and other problems connected with uncertainty can be mitigated or avoided (ibid.).

4.1.3 Understanding indirect supply chain costs

In order to gain an understanding of costs associated with complex supply chain activities, research regarding cost drivers in the industry as well as a holistic purchasing perspective is presented. This will enable a greater understanding of the relationships in the industry.

Josephson et al. (2011) have carried out a study on the cost structure of handling reinforcing bars in the construction business. The authors found, through two case studies of building construction, that handling of reinforcing bars represented approximately 40 per cent of the total cost of CAB. The remaining shares consisted of direct material cost, approximately 55 per cent and transportation, approximately five per cent of the total cost. Josephson et al. (2011) state that sorting rebars was time consuming at one occasion, as lower and upper layers were delivered separately. The share of indirect work and pure wastes were further found to be largely varying between different projects but, according to Josephson et al. (2011), the total cost could be reduced by 20-40 per cent by taking actions accordingly. The authors identified the greatest potential of decreasing total costs by increasing cooperation between supplier and customer in order to develop the efficiency of the material flow. Introducing a load carrier in the current supply chain structure may create opportunities for efficiency improvements, higher quality as well as reduced loss of material (Andersson et al., 2014).

As Josephson et al. (2011) state, the strategy with greatest potential in order to decrease total cost, is to increase cooperation between supplier and customer. As so, it is important to understand that it is not only the price of the product itself that is relevant, but also indirect costs, such as goods handling costs, storage costs and administrative costs, that need to be considered (Gadde et al. 2010; Ellram, 1995). Further, Gadde et al. (2010) explain that indirect costs are often more than two times larger than the direct purchasing price. This means that these costs may be a more relevant target for cost reduction than solely the product cost (ibid.). Thus, the perspective should be switched from price and instead be targeted at the indirect costs and how the supplier can help the customer to reduce these (Ellram, 1995).

To enable this change in perspective, more and accurate information regarding the product or service needs to be provided by the supplier (van Weele, 2010; Ellram, 1995). In addition, strategic changes in business models are required (Ellram, 1995).

4.1.4 Differentiation

As the implementation of a load carrier will affect the value offering of Celsa to its customers, it is important to understand the impact it would have on Celsa's business model and as such how it will affect the communication process and relationships with its customers.

A way to increase the value offering towards customers is to add services around a relatively generic product, shifting focus from offering solely a product, that differentiate the offer from that of the competitors (Rothenberg, 2007). This strategy has been successfully implemented in several business-to-business industries and is a possible strategy to gain market shares in a competitive market where a generic product may not perform (ibid.). In addition, it can be argued that services can be linked with a more stable profit due to the differentiation of the product offering relative to the competitors (ibid.).

When a supplier decides to switch to a strategy involving services certain challenges may arise. It is important to continuously build on the company's existing strengths. The design and focus of new services should be based on the expertise within the firm, complemented with acquisition of new skills (Rothenberg, 2007). Contractual agreements will need to be refined and basis for profit revised, as services are implemented in the business model. In addition, incentives for the sales force and communication with customers, need to be aligned with the new goals of the business model (ibid.). It is important to communicate the new business model, both internally and externally to customers in an efficient and clear way (ibid.).

4.2 Activities

Activities are involved in all creation of products and services. An activity is performed, with the aid of resources, to fulfill a purpose. Activities are, for example, undertaken in companies' manufacturing sites as day-to-day operations as well as in the support functions such as human resource management, financing, research and development, and production planning. Individual activities affect other activities which, in turn, are derived from how resources are combined. Activities and their interdependencies are thus characterized by high complexity in this dimension. (Gadde et al., 2010)

The interdependencies between activities play a major role as companies strive to reach high performance by maximizing benefits of the configuration of activities (Gadde et al., 2010). The most efficient allocation of activities may change over time from outsourcing to insourcing or vice versa, depending on a large number of external and internal variables, including the resources available at the customer as well as the supplier (Gadde et al., 2010). According to Gadde et al. (2010), there are two general main drivers to organize and reorganize the activity configuration:

- Improving a single activity.
- Improving the network of activities through coordination.

Improving a single activity may be achieved through economies of scale. This applies not only on transportation and manufacturing but also on purchasing and research and development. Economies of scale, in turn, are achieved through standardization of activities, which implies that heterogeneity and diversity of activities becomes a challenge (Gadde et al., 2010). Thus, there may be a trade-off between efficiency and diversity. In addition, it is necessary to adopt a broad perspective, involving a larger part of the supplier base, in order to mitigate the risk of sub-optimization. Maximizing efficiency in one company might reduce efficiency of its suppliers, due to increasing adjustments in the interface of activities (ibid.).

4.2.1 Forward and reverse logistics including a load carrier

The implementation of a load carrier will affect the existing logistics system in the supply chain and will require reverse logistics of the same. The following chapter presents existing theory regarding forward and reverse logistics of load carriers, to gain an understanding of benefits, challenges and implications regarding activities, which need to be undertaken in order to implement a functional reverse logistic system.

The common definition of logistics involves the flow of materials from point of origin to the point of consumption as well as information (Silva et al., 2012). This procedure may be defined as 'forward logistics'. Extending this terminology, the procedure of returning packaging or other equipment to its point of origin may be referred to as 'reverse logistics' (ibid.).

Research has indicated that, besides the potential cost benefit of switching from a disposable load carrier to a multi-use load carrier, there is a possible benefit of traceability (Storhagen and Lindqvist, 1998). However, it is crucial for the implemented load carrier system to be of high efficiency to motivate its cost and administrative activities (ibid.). Storhagen and Lindqvist (1998) argue that there are at least six dimensions which need to be regarded in terms of implementing an industry wide solution of load carriers. These are:

- Technical
- Organizational
- Administrative
- Structural
- Informational
- Environmental

These dimensions may, depending on situation, be regarded as enablers or prerequisites within the supply chain in order to a load carrier integration plausible (Storhagen and Lindqvist, 1998). As so, not all products may be suitable to be used in conjunction with a load carrier. Also, an industry wide load carrier should be able to handle several different products, like for example the EUR-pallet is able to. In addition, the load carrier should be able to be transported between organizations and be used in their respective operations. The load carrier may reduce recycling of materials at construction sites, which is in many cases costly and cumbersome. Additionally, Silva et al. (2012) define the commonly occurring challenges and issues regarding reverse logistic systems and load carriers as:

- Inadequate or mismatched warehousing capabilities.
- Complexity of return flow of packaging.
- Large uncertainty regarding the return flow of packaging.
- Poor integration of processes within the warehouse and lack of tracking of incoming goods may hinder the speed of outbound shipping.
- High cost of establishing reverse logistics process.

These issues should be addressed to efficiently be able to implement a load carrier in the flow of material. If these challenges can be overcome, they may be turned into a competitive advantage in terms of environmental and economic aspects of the supply chain (Silva et al., 2012).

In addition, Ravi and Shankar (2004) state several aspects which they consider as common barriers of reverse logistics implementations.

- An effective information system to track and trace load carriers.

- Problems with product quality.
- A company-wide understanding of the purpose.
- A general resistance to change without a clear-cut vision of the reverse-logistics process.
- Lack of appropriate metrics.
- Lack of education of personnel.
- Financial constraints.
- Lack of top management commitment towards the reverse logistics implementation.
- Lack of awareness of the benefits from reverse logistics.
- Lack of strategic planning.
- Lack of support from supply chain partners.

Ravi and Shankar (2004) consider an interrelation between several of these factors, where one barrier may correlate with another barrier. However, barriers which they consider to be the strongest are also less dependent on other variables. These are namely lack of awareness of reverse logistics, lack of commitment by top management, problems with quality, lack of strategic planning and financial constraints.

Reverse logistics is performed to return material in the chain by taking advantage of efficient technical solutions (Silva et al., 2012). A reverse logistic system may aim to reduce use of disposable packaging material by implementing a reusable load carrier (ibid.). The authors identify some benefits of an effective reverse logistics system:

- Reuse of material packaging.
- End-of-life products may be recycled in an efficient way.
- Assets may be recovered and returned to stock.
- Reduction of inventory at critical locations.

Twede and Clarke (2004) state that the characteristics of the logistic flow are important aspects in the decision-making process of whether to implement load carriers or not. The length of the logistic cycle and the variability of the logistic cycle are two important aspects that determine the required number of containers (ibid.). A larger pool of containers increases the initial capital investment and thus affects potential payoff. Twede and Clarke (2004) give examples of projects where uncertainty regarding the time of the logistic cycle have been decisive in the decision to not invest in an implementation of load carriers. Twede (1999) argues that the initial investment is the most important cost to evaluate. The author mentions, besides the characteristics of the logistical cycle, standardization of containers as one of the most important aspects, as it will affect the size of the initial investment and the following operating costs. Twede (1999) describes the importance, as well as the difficulties, of having a holistic supply chain perspective when ascribing the benefits and drawbacks of reusable containers. Besides the initial investment costs, implementing reusable containers in the material flow increases operational costs due to extra handling, such as transport and repair, of empty containers. In order to evaluate the true value of such implementation, activity-based costing should be used (Twede and Clarke, 2004).

To be able to assess the performance of a transport system, measures needs to be obtained. The utilization of a transportation system can be defined as economical and physical measures, where the economical aspect defines the rate of which the transport is paid for (Lumsden, 2012). The utilization rate of capacity is calculated as the utilized capacity divided by the available capacity, whereas the utilization rate of time is defined as utilized time in relation to the available time (ibid.). These two indicators are multiplied to derive the overall utilization rate.

The utilization rate, along with increased service and reduced imbalances, are expected to increase as load carriers are implemented in a supply chain (Lumsden, 2012). It is preferable to use as few varieties of load carriers as possible as this, despite decreasing physical load factor, in most cases increases the overall utilization rate (ibid.). Standardization of the loading equipment is necessary in order to ensure high efficiency in a transportation system (ibid.).

Saphire (1994) argues that there are several supply chain conditions which make a reverse logistic system easier to implement. These are:

- Short transport distances
- Frequent deliveries
- Small number of involved actors
- Company-owned transportation

Saphire (1994) continues by stating that these conditions are commonly found in 'closed-loop' systems, where the container is returned to its point of origin for reuse. As so, an effective load carrier solution will be most easily implemented in a steady logistics system with few actors and relatively frequent deliveries.

Beside the necessity of an effective fit between the supply chain context and load carrier, the related costs need to be thoroughly examined. Rosenau et al. (1996) provide an extensive list regarding potential cost aspects related to implementing a reverse logistic system. The most important ones are:

- Material cost
- Damage reduction
- Inbound transport
- Outbound transport
- Sorting
- Ergonomics
- Safety
- Cubic efficiency
- Tracking
- Labor
- Repair

Rosenau et al. (1996) also argue that tracking is a highly neglected, yet important, factor to consider when implementing a reverse logistic system. In order to achieve an effective control system of a load carrier implementation, visibility may be regarded as a prerequisite. Furthermore may a system with high visibility be able to limit its amount of load carriers, given the same performance (Johansson and Hellström, 2010). Rosenau et al. (1996) state that, despite the usually large investments required for a packaging solution, quantitative methods are rarely used in the decision-making process, due to the difficult nature of assessing impacts.

4.3 Resources

To understand effects from the introduction of an entirely new resource within a current supply chain context, research regarding load carriers as a supply chain resource is presented. Furthermore, research regarding contextually significant critical resources is presented, such as the previously mentioned construction crane.

A resource is an asset, for example equipment or workers, which are used to fulfill a purpose. Gadde et al. (2010) divide resources in tangible and intangible resources. These are further divided into two different categories each. Tangible resources are divided into facilities and products, where facilities include machinery, logistics equipment and vehicles while products refers to the physical product that is manufactured. Intangible resources are categorized into organizational units and business relationships (ibid.).

Resources may be regarded as any type of asset which an actor has access to. Resources are not to be regarded as stand-alone assets but rather as how they can be combined with other resources, as this may alter their respective output. Furthermore, due to increasing outsourcing and suppliers' involvement in focal company processes, external resources have become increasingly important and are in some cases even more crucial than internal. It is important to understand the context of both tangible and intangible resources before implementing any additional resources. (Gadde et al., 2010)

Resources can be combined in different ways. As resources are affected by current, previous and future interactions with other resources, this increases the complexity of the interfaces (Gadde et al., 2010). Due to this complexity, it is important to consider the total cost of combining resources, such as adding one resource may require modifications to several others. Similarly, combining external and internal resources requires that compatibility obstacles are avoided. Gadde et al. (2010) provide several examples of compatibility requirements when combining resources. The resources must:

- Fit physically
- Fit functionally
- Fit technically
- Be efficiently manufactured
- Be easily assembled and transported

When combining internal and external resources there are, according to Gadde et al. (2010), mainly three issues that needs to be considered. Firstly, customers' resources must match suppliers' current and future resources, which means that suppliers should not only be chosen based on current external resources, but also how resources may develop. Secondly, division of labor and production facilities must be compatible, including the physical flow between the actors. Gadde et al. (2010) mention that the strategy of physical distribution must be consistent throughout the supply chain. Thirdly, according to Gadde et al. (2010), it is important to fully understand the value offering, products and services of the company. This overall view should be in line with departments such as research and development and marketing, in order to recognize current interfaces between resources and thus the future development potential. The challenges of resource combining often lead to pressure being put on supply chain actors, and as result of this technical development is achieved (ibid.).

4.3.1 Packaging and load carriers

In order to be able to evaluate a load carrier, assess its performance in the supply chain and make recommendations of the features of the same, earlier research regarding packaging and load carriers serve as basis.

Packaging is used to protect, market, and facilitate handling of products. Packaging is commonly divided into three categories, depending on their use and context (Verghese and Lewis, 2007). Primary and secondary packaging is used to store the product until it reaches the customer and for marketing purposes, thus not interesting for the load carrier. However, tertiary packaging, or transport packaging, is the type of packaging used to facilitate and simplify supply chain activities prior to the product reaching end-consumer. As so, the two types of packaging differ in terms of underlying performance drivers. A packaging aimed at individual consumers may need to market the contained product, protect it as well as ease handling and storage, while an industrial packaging is more driven by the latter two. Common examples of tertiary packaging are crates, cushioning material or pallets, where focus tends to be on functional performance.

The relative cost difference between an expendable packaging system and a reusable packaging system appears to be closely related to the size of the packaging, where larger packages are commonly more economically viable for reusable applications (Mollenkopf et al., 2005). Another important factor affecting the relative cost difference of the two alternatives is the frequency of which products are delivered, as higher volumes make returnable packaging more feasible. Mollenkopf et al. (2005) state that cycle time is an aspect with little impact of the overall cost of the system. The cycle time in a logistic system may be defined as lead time, time in depot and time spent as safety stock (Pålsson et al., 2012). As so, the time which a load carrier spends within the supply chain system is not a highly significant factor to consider (Mollenkopf et al., 2005).

Twede and Clarke (2004) argue that an implementation of a load carrier requires an extensive evaluation in regards to several performance areas. The authors suggest a number of technical specifications, which the load carrier needs to reach the minimum requirements of. Relevant to this particular context are:

- Container durability
- Ergonomics

Container durability describes the physical durability of the load carrier by considering its strength and the impact the load has on the container. Secondary and transport packaging are often manually handled and must therefore be ergonomic to handle, load and unload.

The initial financial investment of reusable containers is commonly large, which explains the necessity to evaluate reusable packaging from both an operational and financial perspective (Twede and Clarke, 2004). The financial situation is affected mostly by the initial investments as well as increasing and decreasing costs derived from the implementation of the new logistic process. The commonly occurring costs are thoroughly described by Rosenau et al. (1996). The operational benefits derived from the implementation may include, besides already mentioned aspects, the ability to sort inbound products, better housekeeping and less damage of the products (Twede and Clarke, 2004).

Twede and Clarke (2004) point out the importance to align the use of reusable load carriers with the characteristics and context of the supply chain. The authors found, through case studies, that an explicit supply chain leader is beneficial in order to the implementation of reusable containers in the logistics flow to be successful. In addition, a steady demand characterized by low variability is preferable as it reduces the peak of required numbers of containers (Twede and Clarke, 2004).

Construction companies have historically tended to disregard return logistic systems, as they are deemed as expensive and administratively cumbersome (Storhagen and Lindqvist, 1998). With an increased focus on environmentally incurred costs, alternatives involving unnecessary consumption of resources become less of a viable option.

Pålsson et al. (2012) reason that packaging should be evaluated through six criteria:

- *Packaging fill rate* - refers to the overall fill rate achieved in the supply chain. This involves the consolidation of all three types of packaging fill rates.
- *Packaging material criterion* - refers to the impacts of producing the packaging and the packaging material. This involves costs of one-way packaging in comparison to the investments regarding a reusable load carrier. The investment must include carriers in the return system as well as in an eventual safety stock.
- *Transport criterion* - refers to the impacts of transportation. This criterion involves impacts of aspects such as transported distance, fill rate and necessary empty runs.
- *Material handling criterion* - refers to impacts derived from handling different packaging systems. For example may a one-way packaging system involve less handling.
- *Waste handling criterion* - refers to impact of waste generated due to a particular packaging system, such as required warehousing or recycling of waste.
- *Administration criterion* - refers to economic impacts of managing a particular packaging system, especially regarding return packaging.

Verghese and Lewis (2007) point out the necessity of considering both organizational as well as technical issues regarding packaging specifications, to ensure an effective fit for each party who interacts with the packaging. Further, Verghese and Lewis (2007) consider two major hinders needed to be overcome during a new packaging implementation, resistance to change within the supply chain and costs associated with investments of material and equipment.

Verghese and Lewis (2007) identify several conclusions related to their findings. The implemented packaging solution will need to deliver economic benefits for the entire supply chain, which may require an investigation of current full packaging costs (including for example labor, unpacking, lost revenue). Further, current investments and supply chain infrastructure may be a hinder of renewing packaging. If so, it may be more suitable to revise current packaging during a major supply chain overhaul. Also, it is crucial for a successful implementation to communicate the benefits for each supply chain actor, as these generally try to avoid risks (ibid.).

Olsmats and Dominic (2003) developed a framework called ‘Packaging Scorecard’ to systematically evaluate and compare different load carrier solutions. The underlying idea is to assess drivers and criteria relevant to a particular supply chain context and evaluate performance of each criterion respectively. Different criteria are given different weighting, depending of their relative importance from 0 to 100, and performance is evaluated from 0 to 4 (0 not applicable, 1 not approved, 2 approved, 3 well approved and 4 met excellently) (ibid.). The evaluation criteria are contextual and may therefore differ, but examples are flow of information, volume and weight efficiency, right amount and size and packaging cost (ibid.). As different actors in the supply chain have entirely different needs, the list of criteria may be adapted entirely or partially to achieve a good fit.

4.3.2 Resource occupation

To properly assess and answer how resources are affected, research regarding critical resources, and how to exploit these as efficiently as possible, is presented. It is important to identify critical resources in order to try to reduce the usage of the same as these likely have the greatest impact on supply chain performance. As so, resources identified as bottleneck resources will be targeted in the evaluation of the load carrier's effect on resources.

A bottleneck is a point in which, for example, a production line has lower capacity than the capacity of the other upstream and downstream activities. This congestion point sets the theoretical maximum pace of the entire production line. The activities upstream in the chain should have enough capacity to fulfill demand from downstream activities in order to avoid bottlenecks (Jonsson and Mattsson, 2009). In the event of a present bottleneck, this activity sets the pace of the entire production line or supply chain, meaning that the throughput of production cannot exceed the throughput of the bottleneck resource. However, the bottleneck throughput may be increased, for example by maximizing the capacity utilization by increasing batch sizes and/or reduce set-up times (Jonsson and Mattsson, 2009). Additionally, assigning more available time can increase throughput of a bottleneck resource. Similarly, the pace can be increased by reducing activities undertaken at the bottleneck resource, through efforts such as balancing or kaizen, continuous improvement.

Jonsson and Mattsson (2009) suggest an approach to identify, remove and continuously improve bottlenecks in the material handling in production environments:

1. Identify the constraint. Investigate the flow in order to understand the constraints of the flow.
2. Exploit the constraint. Find the most efficient way of using the bottleneck resource in its current state.
3. Subordinate everything else. Bottleneck and non-bottleneck resources should be synchronized in order to create the most efficient flow. Bottleneck resources should not be idling while non-bottleneck resources create inventory at full uptime.
4. Elevate the constraint. Add capacity, or decrease downtime, if an increase in output is still necessary after step 3.
5. Go back to the first step if extra capacity was added in step 4, which implies that the constraint in the flow might have changed.

Within the construction sector, cranes are usually among the most expensive equipment used at construction sites and often play a key role in the pace of the project (Zavichi et al., 2014). Also, activities using the construction crane are often crucial for the continuous progress of the project (ibid.). The industrialization of the construction sector has changed the way of producing material for projects. The movement from producing material on-site to delivering pre-fabricated material increases the need for transportation and material handling equipment within the limited space at the site (Shapira et al., 2007). This transformation of the industry has changed the crane of a construction project to a critical resource that sets the pace for the project to some extent (Shapira et al., 2007; Zavichi et al., 2014). The crane may therefore be identified as a bottleneck in the aim of achieving higher productivity (Shapira, 2007). Hence, strategies to mitigate the usage of the construction crane, or reduce the operation time of the crane in activities, should be explored at furthest extent possible.

4.4 Actors

Actors are involved in performing activities and controlling resources (Gadde et al., 2010). The actor layer can be seen as the arena where players interact (ibid.). This section aims to provide knowledge and previous research which can assist in the analysis of relationships and control within the supply chain.

The actor layer is dynamic, which means that the combining of resources and activities between actors will continuously change their relative position (Gadde et al., 2010). Gadde et al. (2010) explain three types of modifications in the actor layer. First, the actors in the network change by the activities they conduct and resources they control. Second, activity links and resource ties change the relationship between actors. Third, actors establish new relationships which may cause existing ones to be cancelled, altering the actor layer. According to these three modifications, purchasing behavior and supply management of the firms affect the positions of the actors (ibid.). The same theory also applies for relationship types, for example arm-length relationships and partnerships, which affect the positioning of actors (ibid.). If a supplier creates a value offering to its customers that is superior to that of its competitors, it may transform them to an important and long-term supplier.

Due to technical development in regards to production, transportation and information systems, distribution networks have changed over time (Gadde, 2004). The author mentions the change of distribution strategy from mass production towards postponement, customization and just-in-time deliveries as some of the most significant transitions of supply chain characteristics. As the distribution network evolves, the activity layer changes towards increasing interdependencies, while the necessity of access to external resources between actors increases. These supply chain trends, regarding activities and resources across corporation’s borders, requires closer and more cooperative relationships between actors (ibid.).

The transition towards closer relationships requires extensive resources, as close partner relations are more resource-demanding than those at arm’s length distance. Therefore, an issue that arises with collaborative supply chains is that the management of an actor needs to evaluate and achieve balance between cost and benefit of a relationship with another actor. Despite substantial benefits from each respective relationship, Gadde (2004) emphasizes that an actor needs to restrict its number of partners due to the high cost of these relations. Other issues that arise are the transitions in the relationship atmosphere as the supply chain shifts from confrontational towards collaborative (ibid.).

Gadde (2004) describes that the relationship atmosphere can be explained in three dimensions. These are:

- *Control*. The act of influencing other actors.
- *Power*. Aims at influencing other actors to act in a way that they otherwise would not.
- *Conflict*. Describes the process when an actor is hindered to reach its goals by another actor.

Control is traditionally performed through authoritative control based on ownership, vertical integration and power (Gadde, 2004). As the characteristics of supply chains are altered, requiring a higher level of collaboration, authoritative control become less suitable in favor of contractual and normative control. The latter two, in contrast to authoritative control, are based on incentives and contractual agreements as well as shared visions and trust among actors (ibid.). Power can be categorized as the possession of power and the usage of power. According to Gadde (2004), power was traditionally exercised through forcing or commanding actions. Evolving networks has led to less usage of power while the possession of power becomes an increasingly important aspect in the relationship atmosphere. Gadde (2004) points out that the shift towards more collaboration and less usage of power among the actors not necessarily implies a friendlier environment, but is rather characterized by increasing demands.

There are potential conflicts in all relationships regardless of closeness of involved actors. Depending on how control and power are applied in a relationship, conflicts can be either developing or destructive (Gadde, 2004). In regards to a traditional context, conflicts have been perceived to be a solely negative aspect of a relationship. In a collaborative supply chain, on the other hand, a conflict could be of value for the involved actors if handled properly (ibid.). The conflict should constitute a base for developing a partnership on a long-term perspective, not in day-to-day operations. According to Gadde (2004), close relationships that exploit the full potential of using conflicts as a source of development may be characterized by more conflicts in comparison to relationships at arm's length distance.

4.4.1 Information and coordination

In order to assess the effects of the load carrier on the actor dimension, in terms of information and coordination, relevant literature is presented in this chapter. It is important to relate this to the findings in order to understand the implications on the relationships in the supply chain.

Businesses do not compete individually, but rather as supply chains involving several actors (Lambert and Cooper, 2000). As so, actions taken in a supply chain should be directed to increase the total supply chain surplus (Chopra and Meindl, 2013; Kumar and Pugazhendhi, 2012). This implies that all actors in the supply chain should take mutual decisions and undertake changes according to a strategy or towards the goal of maximizing the surplus. However, this puts prerequisites on the supply chain's coordination and its ability to share information (Chopra and Meindl, 2013). Coordination may be lacking due to poorly aligned supply chain objectives or that the flow of information is disrupted, distorted or delayed (ibid.). A supply chain consists of several stages, where different stages most often have different owners. As actors try to optimize their own objective, it is crucial to align objectives and efficiently, without disruptions, share information to be able to plan and execute the right processes. This means that one major challenge in the supply chain is to achieve coordination despite a dispersed ownership (ibid.).

Lack of coordination may lead to several effects on supply chain performance (Chopra and Meindl, 2013; Kumar and Pugazhendhi, 2012).

- Inventory cost may rise due to stages in the supply chain holding excessive inventory in order to be able to answer to fluctuating demand.
- Material planning will be more difficult due to the lack of information and will contribute to higher replenishment lead times as well as lessened resource utilization, flexibility and customer service.
- Transportation cost may increase due to the variation in demand, which requires actors to hold excessive transportation capacity to cover high-demand periods.
- Level of product availability will be affected by obstructing the material planning process.

Summarily, Chopra and Meindl (2013) state that the lack of coordination will affect the performance of the supply chain by increasing the cost for maintaining the same level of product availability.

To increase the level of coordination, information needs to be shared among the actors in the supply chain and incentives and strategies needs to be aligned (Titus and Bröchner, 2005; Lambert and Cooper, 2013). In the construction sector, information sharing is critical due to the combination of goods and services that need to answer to specific project requirements that is unique for every project (ibid.). In addition, depending on the size of the construction project, a large number of actors may be involved, which emphasizes the need to efficiently share information to involved actors (ibid.). Titus and Bröchner (2005) claim that the construction industry has, for a long time, been behind other industries in terms of innovation, sustainability and supply chain improvements. The construction sector tends to be resistant to change and displays a self-protective behavior, which complicates the multidisciplinary teamwork that coordination requires (ibid.). The background of the employees and their competences, together with attitude against adopting new technologies, may harm the success of implementing a common platform for efficient information sharing. It may therefore be beneficial to the construction industry to study supply chain practices found in other industries, such as car manufacturing, to enhance the level of information (ibid.).

The fundamental communication process may be described using a relatively simplistic model, involving a sender, its message, transferred through a medium before the message is received and the medium's respective noise. As so, Shannon and Weaver (1949) argue that communication should occur through as established mediums, with as many standardized proceedings, as possible while using as few middlemen as possible. This model does not account for the feedback process which may occur, depending on the used medium (Palm and Windahl, 1989).

As in other manufacturing industries, construction supply chain management handles the flow of materials and information. However, regarding the amount of actors involved, such as general contractors, subcontractors and suppliers, the management of the chain is relatively complex (Titus and Bröchner, 2005). Information sharing is crucial in this complex environment and has been facilitated by advances in information technology (ibid.). Due to the unique context of each construction project, with actors and team members working sometimes together for the first time, it is crucial to have a common platform to efficiently share information (ibid.). A common platform where information can be shared and obtained can improve the transparency in the supply chain and enhance the level of coordination (O'Brien and Hammer, 2001). With a common platform for involved actors, precise decisions can be made in a timely manner, in some cases without human interaction, which will lower the cost of the information exchange and the decision process (Titus and Bröchner, 2005).

4.4.2 Control in the supply chain

The implementation of a load carrier may affect the control of the supply chain. As so, it is important to understand and assess how the control of the supply chain is designed today and how it may be affected by the implementation of a load carrier, in order to truly analyze how the access to the load carrier will be handled. Earlier research regarding the ownership structure of load carriers in supply chains is also presented.

Traditionally, planning is viewed as the operation of predetermining an approach to reach certain goals, while control intends to monitor and follow up the execution. According to Formoso and Isatto (2008), planning should be interpreted as an iterative process which is closely connected to the control of production, rather than the first step in a two-staged process "planning and control". In addition, planning may be performed as a cross-company function aligning the performance of the supplier and the demand of the customer. As a result of this perspective, the action of control has changed from monitoring single activities towards controlling the alignment of actors and their goals (Formoso and Isatto, 2008).

The dispersed responsibility of a load carrier may sub-optimize the supply chain's overall performance, making the ownership, responsibility and control of a reusable load carrier a challenging task. Kroon and Vrijens (1995) mention three main principles of controlling a logistics system, including third-party ownership of the carriers. The approaches, as proposed by the authors, are:

- Switch pool systems
- Systems with return logistics
- Systems without return logistics

Switch pool systems means that the sender and recipient of the goods are responsible of maintaining and warehousing a predetermined number of containers. The sender is additionally responsible of not letting the containers become unevenly distributed among the actors. Besides having the sender responsible for the distribution of containers, in switch pool the carrier could also be assigned a number of containers with the aim of exchanging empty with full containers at every exchange point in the chain. Switch pool systems tend to require a lower amount of tracking in comparison with other systems (Johansson and Hellström, 2010).

A system with return logistics has two different alternatives both which involve a central agency responsible of the containers. The first alternative, called transfer system, entails that the recipient temporarily stores all the secondary packaging at its site while the central agency is responsible of the transportation back to the sender. The sender is, in turn, accountable of tracking and tracing, maintenance and administration of the containers. The second alternative, called *deposit system*, entails that empty containers are transported from the recipient to a central depot. The containers are transported to the sender upon request.

In the third approach, system without return logistics, the containers are owned by a central agency but rented by the sender as long as they are needed in the ongoing process. The central agency is not involved in any of the logistics activities and the sender is thus responsible for activities such as transportation, administration, maintenance and storage. This approach is mainly used in order for the sender to reduce its fixed costs, by diminish the investment cost.

Johansson and Hellström (2010) state that these three different approaches likely have different impact and cost of implementation. However, this conclusion is largely based on the context in which a particular implementation is made.

Visibility, as defined by the Council of Supply Chain Management Professionals, is “the ability to access or view pertinent data or information as it relates to logistics and the supply chain, regardless of the point in the chain where the data exists” (Johansson and Hellström, 2010). This is often regarded as a prerequisite for an efficient reverse logistics system (ibid.). However, Johansson and Hellström (2010) continue by stating that a high visibility itself is not enough but rather that management attention is still needed to take proper action in order to achieve greater savings or better performance.

Johansson and Hellström (2007) underline the benefits enabled by an effective visibility system, where total cost of the reverse logistics system may be reduced, for example by using less load carriers (enabled by better knowledge of supply chain behavior) and better decision making through managerial insights regarding demand behavior and supply chain context. Johansson and Hellström (2010) underline this statement by claiming that an effective tracking system may enable a profitable reuse system. This may, for example, be achieved through innovative business opportunities (van Nunen and Zuidwijk, 2004).

Formoso and Isatto (2008), mention several reasons that production planning and control is considered of being ineffective within the construction business. The issues of production planning and control include:

- Not considered as a managerial process.
- Control is often performed as verbal information rather than formal approaches.
- Uncertainty is not properly handled in order to mitigate the risk and its causes.
- The time spent of different planning horizons should be in line with the ‘output’.
- Construction managers do not use systematically collected data sufficiently in the decision-making process.

To facilitate control and handle administration, and fees and maintenance of an integrated load carrier, it is common in the Swedish production environment that an industry-wide organization is created (Storhagen and Lindqvist, 1998). These companies are usually run without profit-maximization and solely exist to reduce the cost of the supply chain. The purpose of this is to incur the producer of the contained product as well as the seller of the product with the cost of the return system and not the end-customer (Storhagen and Lindqvist, 1998).

A pull-based supply chain may be defined as a customer demand initiated delivery process, meaning at products are pulled through the supply chain when demanded rather than pushed through based on speculation. just-in-time (JIT) is a concept which aims to have the right items, in the right place and at the right time, in order to enable a reduction of waste within the supply chain as according to the lean concept (Vokurka and Lummus, 2000). It may be defined as a pull-based supply chain process. The aim of a JIT implementation is to increase the overall supply chain performance (Swanson and Lankford, 1998). This may lead to reduced inventory by producing or receiving items just in time to when it is to be used (Lee and Ebrahimpour, 1987). This means that the movement and processing of material is made as late as possible in the manufacturing process and it should be conducted in smaller batches (ibid.).

If a manufacturing company is aiming to introduce JIT in its operations, certain criteria need to be fulfilled. Swanson and Lankford (1998) explain the JIT concept with five important aspects that needs to be fulfilled to successfully implement JIT, namely:

- Company-wide commitment.
- Proper materials at the right time.
- A reduction of suppliers, which will improve the quality of these relationships by working closely together.
- Quality control must be based on prevent rather than on detecting defects.
- Involving personnel to become experts in the processes of the JIT solution.

The whole organization needs to commit to JIT and this will have to start with top management and be communicated throughout the company. This includes training personnel of the concept, to efficiently apply it to the companies' processes. A JIT-implementation may reduce inventory levels and thus free up space that can be used for value adding activities instead of storage. However, in order to gain advantages of JIT, material delivered is required to be of good quality, on-time and at a reasonable cost. Swanson and Lankford (1998) state that a possible step into JIT manufacturing is to reduce the number of suppliers. This may increase the quality of the relationships with the suppliers through more frequent interaction and thus enable an increased quality of material and delivery plans. Another advantage of a smaller supplier base is a reduction of administrative work by less interaction with different actors (ibid.). However, it is important to engage in deeper relationships with suppliers who frequently can deliver material of high quality, are reliable and that has the possibility to deliver in smaller batches. The buying firm and its suppliers will engage in partnerships and the primary focus is the profit margin for both firms and equal sharing of rewards (ibid.).

4.4.3 Organizational learning

The activities and resources will be affected by the implementation of a load carrier in the supply chain. To assess the impact on the resources and activities it is important to understand the learning progress within an organization when implementing a new procedure. In order to be able to answer how activities are altered, it is necessary to gain an understanding of how activities are learnt and improved during their respective implementation phase. To ensure this, relevant literature on the subject is presented in this chapter.

Newly set-up production lines with manual assembly will produce the first unit inefficiently (Fioretti, 2007). The learning process will over time lead to reduced cycle times, as the experience of the process increases. This is called the learning curve, which states that the time of production will decrease with cumulative production (Fioretti, 2007). The decrease in production time is achieved by 'learning by doing'. The learning curve is the most common in situations where a number of items can be combined in several different ways. Organizational learning refers to when an organization captures knowledge and uses its experience to maintain or improve performance of their processes (Lopez et al., 2006). Lopez et al. (2006) conceptualize organizational learning in four dimensions:

- Knowledge acquisition
- Distribution
- Interpretation
- Organizational memory

Knowledge acquisition refers to how knowledge is found. Knowledge may be acquired in an external context or internally in the organization by for example experience of processes. External knowledge may be acquired through hiring of new personnel or acquisition of other companies. Distribution refers to how the knowledge is spread throughout the organization. The spread of knowledge requires well-functioning communication channels and close collaboration between business units. The way individuals share and use aspects of their knowledge that is not known to all of them, is referred to as the interpretation dimension. The interpretation dimension affects the shared understanding and thus coordination of decision-making within the organization. The organizational memory dimension refers to how knowledge is stored in the organization's memory. The knowledge may be contained through an organizational system designed to store information or by setting up rules, procedures or other standards. (Lopez et al., 2006)

The dimensions, as discussed by Lopez et al. (2006), need to be addressed and considered in order to facilitate organizational learning (Lopez et al., 2006). An organization's competitive advantage can be found in the capturing and applying of knowledge. The organization consists of individuals and it is thus important to understand the complexity and how to enhance organizational learning in order to grow the competitive advantage (ibid.).

5 Method

In order to understand the current structure of the supply chain and explore the effects on changes to the same with an implementation of a load carrier, a case study was performed. A case study only provides a single instance of observation, which may limit the significance of its statistical and numerical results. A case study was performed of the supply chain in its current state as well as the pilot state including the load carrier, which enabled assessment of supply chain performance. The case study served as a foundation to facilitate answering of the research questions. Following the analysis of the current state of operations as well as the pilot study, recommendations and an estimation of possible future state of operations was given.

In case studies, data may be collected both by qualitative and quantitative methods (Dubois and Gibbert, 2010). A major difference from other research methods is that a case study does not try to control the context in which the data are collected. This provides the researcher with the possibility to study a process in a real-life setting, which may contribute to a more viable result (ibid.). The project required qualitative judgment in order to assess the perceived effects and outcome of the implementation of a load carrier. Quantified studies complemented this assessment regarding resource occupation and activity configuration. This enabled the study to better evaluate the load carrier implementation's effects on supply chain performance.

To support the findings in the observations, interviews were performed with managers as well as workers and operators in the involved companies. With the aid of analytical tools and theoretical frameworks, the material flow was assessed and analyzed in order to present results from the case study and draw conclusions.

5.1 Case description

The delivery process of CAB to construction site is cumbersome and time-consuming, which occupies the construction crane for an extensive period of time. During the start-up phase of this project, a group consisting of representatives from the involved actors identified that the delivery process of CAB for floor level installation would likely benefit from being performed with the aid of a load carrier. The load carrier would simplify handling and reduce the time needed for the delivery process. The weight, quantity and characteristics of the orders made them relatively suitable for a load carrier. The orders contained a mix of straight and bent rebars, which all fitted the intended load carriers. When constructing floor levels, CAB is divided into a lower and upper layer. Once the two layers of reinforcing bars have been installed, it is filled with concrete. The installation of the upper and lower layer occurs separately, which makes it appropriate to have them separated prior to installation. The load carrier may enable this. It is also suitable for the delivery at the site, where the aim is, according to the site manager, to lift the load carrier directly from the truck up to the level of the building where the CAB is to be installed. Hence, only orders of floor reinforcement were part of the case study. Figure 7 illustrates how floor reinforcement is installed at the construction site. In the figure, the lower layer of CAB has been installed and ventilation and electric systems are in place. Once all tubing and wiring has been installed, a second layer of CAB is installed. After that the floor is covered in concrete.

Figure 7 - Lower layer of floor reinforcement installed at a JM construction site

An evaluation from such an implementation was needed to be performed in order to understand the effects in the supply chain. The study intended to scrutinize the flow of CAB between Celsa's production site and the appointed location within a construction site of one of its customers. The Celsa production site that produces CAB in the case study is located in an industrial area outside the city of Västerås. The production consists of cutting and bending customized rebars and rebar mesh used in constructions. The raw material of rebar is delivered by ship from corporate group's steel factory in Rana, Norway, in rolls or straight pre-cut lengths, depending on gauge and is then fed into the cutting and bending section of the factory. Once there, the rebar is cut and bent depending on order specifications and packaged as bundles with lifting straps. It should be noted that the current way of delivery involves no packaging besides lifting straps. The bundles of CAB may be tagged with an appropriate color coding, which is used to simplify sorting and handling during delivery and installation at the construction site. Once every part of an order has been produced, the rebar is transported by overhead crane to a transport bed which transfers the material from the production area to the storage area. At the storage area, the orders are prepared for loading onto incoming trucks. The production site and the movement of material are illustrated in Figure 8.

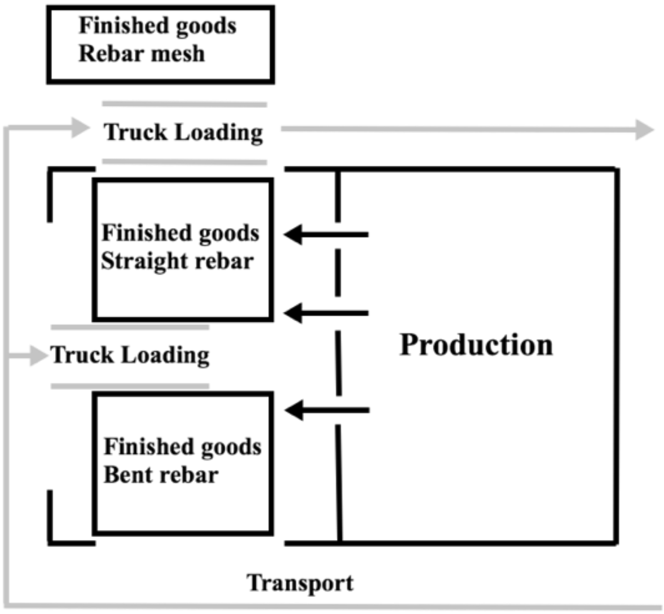

Figure 8 - A map illustrating Celsa's production facility in Västerås

According to the production manager at Celsa Västerås, the production site measures performance mainly on two criteria, namely machine time efficiency, which refers to the up-time of the machines, and truck load factor. Production management thus arranges production to maximize these measures while maintaining the promised lead time of ten working days.

Regarding this particular study, a construction site of JM in Stockholm, Västända, was analyzed. The analyzed construction site of JM is located in Årsta, in the city center of Stockholm. A major area consisting of several apartment buildings are to be constructed. The site is, according to the site manager, characterized by lack of storage places. Hence, the project would benefit from improvements in the delivery and handling process. The project site, at the time of deliveries, is illustrated in Figure 9.

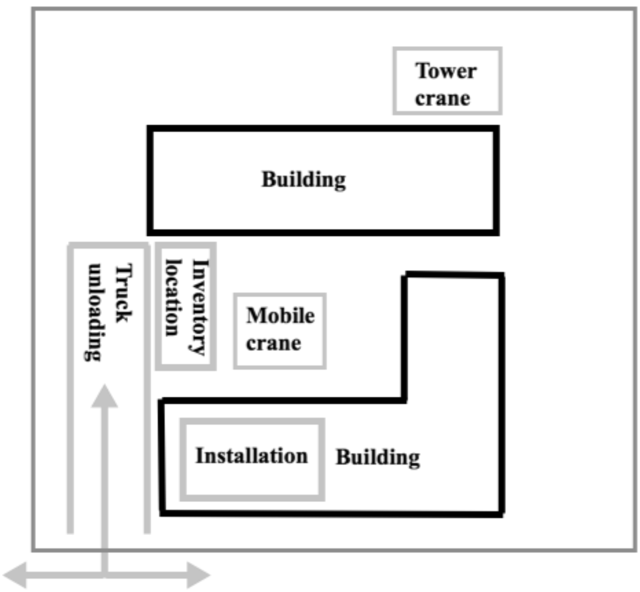

Figure 9 - Schematic overview of the layout of the construction site at Västända, Stockholm.

The material flow was empirically investigated. This was done both for current state of operations as well as for the pilot study. In order to assess the benefits and drawbacks of a particular supply chain solution, it is necessary to map, compare and evaluate its performance in comparison to current state as well as other possible solutions (Andersson et al., 2014).

In the case study, a load carrier from Starke Arvid was used in the pilot study and compared to current state. An already developed load carrier by Starke Arvid had been chosen to reduce lead time and cost of the initial study. The load carrier can be seen in Figure 10. However, the load carrier may, in case of a full-scale implementation, be developed further to suit the needs of Celsa and its customers.

Figure 10 - The load carrier implemented during the pilot study (Source: http://www.starkearvid.se)

The load carrier was designed to handle straight rebars in six shelves and bent bars in the bottom compartment. It can be lifted by both crane and forklift. The load carrier weighs 400 kilograms and is able to carry 4.5 metric tons of reinforcing bars. Table 1 presents specifications data of the load carrier.

Table 1 - Technical specifications of the currently implemented load carrier

Max load	4500 kg
Width	1100 mm
Length	3000 mm
Height	1700 mm
Weight	400 kg

CAB is delivered by a local transport provider who utilizes regular heavy trucks. The trucks are commonly equipped with a crane capable of lifting about two metric tons, meaning that the trucks are not capable of lifting a loaded load carrier, which weighs up to 5 metric ton. Celsa contracts the transport provider to perform its transportation, meaning that Celsa is in control of transportation to its customers' construction sites.

5.2 Data collection

Primary and secondary data were collected through interviews and observations at production and constructions sites. Collected data were assessed and analyzed with the aid of an analytical framework developed from relevant literature and existing toolsets regarding supply chain evaluation.

5.2.1 Interviews

Interviews took place in order to evaluate the implementations of the load carrier from an operative perspective. Primary data were collected through interviews with representatives from Celsa and JM in order to get a deeper understanding of the problem with today's situation and the effects of the pilot project including the load carrier. The data were also used to get input on the design of the load carrier and how to improve the loading and handling of the same. Qualitative methods enabled a different, non-quantifiable perspective. The interviews were of open-ended question structure to reduce the risk of missing other aspects of the problem. In addition, interviews also served as a tool to map the information flow in the supply chain.

The load carrier and the effects of its implementation were discussed with:

- Technical manager at Celsa
- BIM-engineers at Celsa
- Production manager at Celsa
- Production operators at Celsa
- Transport planner at Celsa
- Truck drivers at transport provider
- Site manager at JM
- Construction workers at JM
- Logistics manager at JM
- CEO at Starke Arvid

Group meeting were held on a biweekly basis, to disclose the progress of the study to relevant actors at Celsa, JM and Starke Arvid, which enabled them to provide input and feedback. This may in turn have ensured a higher validity of the undertaken study and analysis.

5.2.2 Observations

Observations were performed to collect primary data from Celsa's production site in Västerås, transportation and JM's construction site in Stockholm, respectively. The case study was performed by observations of the material flow from Celsa to the construction site of JM. The material flow was recorded and document with video camera. The authors played a passive role in the documentation of the material flow in order to reduce the risk of influencing the results.

The case study was divided into three separate studies, which involved one study of the current state of operations and two studies of the pilot project including the load carrier. This enabled a comparison of the two states, which was deemed as appropriate in order to accurately assess and evaluate the performance of a load carrier in the supply chain.

The current state of operations as well as the pilot study was observed during six occasions. This was done to gain a sufficient understanding of empirical context as well as data regarding the undertaken activities and resource occupation throughout the supply chain. The observations were performed at the following dates:

- 2015-02-12 General overview at Celsa’s production site in Halmstad
- 2015-02-19 General overview at Celsa’s production site in Västerås
- 2015-02-19 General overview at JM’s construction site in Årsta, Stockholm
- 2015-03-31 Measurement of pilot study
- 2015-04-10 Measurement of current state
- 2015-04-22 Measurement of pilot study

5.3 Data presentation

Data from the case study are mapped and presented in terms of resource occupation, cycle time, number of activities and total activity time. In addition, number of inventory points, storage time and area, and fill rate of truck are presented. The data was compared in order to find the changes in activity structure, alteration of individual activities, resource occupation and to assess the overall performance of the supply chain. To map the supply chain, lean analytical tools in form of value stream mapping and material flow mapping serve as a method for mapping and analysis of the empirical findings.

The data are presented per bundle to make it independent from dimensions which do not reflect the nature of demand or activities undertaken in the supply chain. It may be argued that observations should be made on the basis of a single piece of rebar as to make a fully generalized comparison. However, as the nature of the rebar consumption is per bundle, where a set of geometrically similar rebar are installed in adjacency, will the demand in the future still be defined as per bundle. Further, despite rebar generally being sold by weight, this is not considered as a valid dimension of reference, since activities often are performed in regards to each specific bundle rather than weight. For example, a single order of a 100 kg bundle would still require both overhead and construction crane time very similar to that of a 1000 kg bundle. By presenting the data per bundle of rebar, generalizations are made possible between different order sizes. This enables comparisons between likely states of operation, such as the current state and the pilot study, despite differing order sizes. It is important to bear in mind that the studied orders differed somewhat in size, which may affect the result. This implies that activities, where the total activity time is independent of the number of the bundles, such as the transport between the actors, differ in regards to the cycle time when comparing current and pilot study due to the varying sizes of the shipments.

5.3.1 Mapping of supply chain

Mapping of the supply chain was performed in order to understand the current processes and evaluate the performance of the flow, in current state as well as in the pilot project. Value stream mapping and material flow mapping are lean tools to identify and eliminate waste in order to achieve a pull-based and efficient value flow. As so, the two tools are applied on the “snap-shot” of the supply chain.

Value stream mapping (VSM) is a lean tool designed to assist in change processes. This is achieved by describing the current state of products and production facilities and comparing these to an anticipated future state (Rother and Shook, 2005). This enables the mapper to evaluate the benefits and drawbacks of performing the change process. If the future state is deemed as sufficiently better than the current state, the next step is to formulate a specific action plan, which serves to aid in changing the system (Rother and Shook, 2005).

Common practice in value stream mapping involves several steps to assist the mapper in getting the correct overview of the system and to illustrate how the flow of today occurs (Dolcemascolo, 2006). The following procedure is presented by Dolcemascolo (2006) when mapping an extended value stream:

1. Identify and select the value stream that is to be mapped.
    a. Group products into families.
    b. Select which products/product families that are to be analyzed.
    c. Follow the value stream from the downstream point (customer) back to the materials in receiving.
2. Map the current state of the value stream.
3. Map a suggested future state using a set of lean tools and principles.
4. Create a plan for implementation of the future state map.

The symbols used in the value stream mapping are presented in Appendix E - Value stream mapping symbols.

By following this procedure, it is possible to see which activities are undertaken as well as their respective attributes (Dolcemascolo, 2006). The data that have been extracted from such analysis involve:

- Man-time
- Cycle time
- Types of inventory (raw material, WIP and finished goods)
- Throughput time
- Resource occupation

According to Dolcemascolo (2006), communication is a common culprit for waste in value streams. It is therefore necessary to reveal possible delays in information flow as well as to eliminate or simplify possible steps of communication. Illustrating the flow of information enables relevant actors to quantify information as well as generate ideas of how to improve it (ibid.).

Hines and Rich (1997) present an approach which categorizes activities within three types: *value adding*, *non-value adding* and *necessary but non-value adding*. The first non-value adding category includes pure waste that should be eliminated, whereas the second category represents waste that can only be eliminated through large-scale changes of the operations. The classification of non-value adding activities are based on the seven wastes originating in the Toyota production system (ibid). Some of these wastes are not experienced or relevant for the studied supply chain, such as faster-than-necessary pace and correction of mistakes. However, six of the wastes are targeted in the designing of a future state map. These five wastes are:

- Waiting
- Transportation
- Processing
- Excess stock
- Unnecessary motion
- Defects

By identifying such waste, the activities may be targeted for improvements.

Value stream mapping serves as a suitable tool for analysis of the flow of reinforcement bars in this case study as it enables a visualization of wastes in the flow, and hence has the ability to provide a viable comparison with the pilot study including the load carrier. As so, in the supply chain context of Celsa to its customer, it was suitable to examine the value stream of the current state of operation and compare it to the value stream of the implemented pilot study. This enabled the possibility to evaluate its benefits and drawbacks as well as draw additional conclusions and recommendations regarding the load carrier's applicability and possible future implementation.

Material flow mapping (MFM) is a tool developed to analyze and understand the value stream flow in between supply chain actors (Langbeck et al., 2012). This is done to improve the entire value flow within a supply chain. The established, traditional process of VSM is a powerful tool when analyzing processes within organizations, but an extended scope may often be needed to be able to simplify flows with waste and cost reduction as a result. Analogous with traditional VSM, MFM follows the same steps of mapping current state, suggesting future state and a specified action plan to create the future state (Langbeck et al., 2012).

As MFM shifts focus from manufacturing and individual actors' activities to the processes which occur between actors, less focus is put on manufacturing aspects in comparison to VSM. Focus rather lies on activities which link actors together, such as transportation, labeling, sorting and loading (Langbeck et al., 2012). The method strives to reduce sub optimization throughout the supply chain by illustrating all actors and their respective waste (ibid.).

Langbeck et al. (2012) recommend that several aspects within the supply chain should be regarded to simplify flow between actors to reach a desired future state:

1. Real customer demand?
2. Constraints in the value flow?
3. How can more smooth flow between entities be achieved?
4. How can the internal flow be simplified?
5. How to achieve a pull system?
6. How can the supply chain's flow be synchronized to the customer's demand?
7. How can the supply chain be improved further?

To assist in evaluating the supply chain's current and future performance, Langbeck et al. (2012) suggest several performance measures that are deemed as generally:

- Throughput time, internal
- Throughput time, external

- Time in warehousing
- Number of activities, handling
- Number of activities, transport
- Number of activities, administration
- Number of warehousing nodes
- Number of products in the flow
- Transported distance, internal
- Transported distance, external
- Man-hours/product
- Machine hours/product

Langbeck et al. (2012) emphasize the importance of time in warehousing (3), number of activities (4-6) as well as number of warehousing nodes (7) as these tend to give a good understanding of the overall supply chain performance while not undertaking man-hour measurements.

Similarly to the VSM protocol, the supply chain performance should be measured and estimated for current as well as for future state before arriving at an action plan, which is designed to simplify and assist the change transition. Employing the framework of VSM and MFM within a case study may generate timed results which are less than ideal in terms of reliability, due to limited access to data. However, despite unreliable timings, MFM may be used to gain an understanding of the activity and resource structure within the supply chain. Data from the case study are mapped with these tools.

A case study enables the possibility of investigating a particular context while reducing the chance of measurement errors in terms of a faulty study design. However, a case study does not necessarily provide sufficient reliability to generalize results outside the context of the study.

6 Empirical findings

This chapter presents the empirical findings of the study. The current state followed by the pilot project is presented. For each state, a material flow map (MFM) is presented, which is later used for comparison and analysis. The data are presented as cycle time per bundle, man-time per bundle and number of activities. Furthermore, activities and how they interact are described. Occupied storage area, storage time, fill rate of the truck, and resource occupation are also presented. In addition, the information and communication process between Celsa and JM are presented and developed in order to improve supply chain performance.

6.1 Current state

The current state of operations is presented in this section. First, a mapping of the supply chain is presented following the MFM framework. Second, activity structure and resource occupation are presented in order to enable a comparison with the pilot study. Third, the mapped information and order process are presented. The section also displays the findings from the technical preparations of an order.

6.1.1 Mapping of the supply chain

Production is initiated through production planning after an order from JM of floor reinforcement. Once the material is produced within Celsa's production facility, it is sorted and transported, by either conveyor or overhead crane, to the finished goods inventory storage. At the delivery point in the inventory storage area, it is picked up by another overhead crane and transported to its designated storage location. The straight and bent reinforcing bars are stored separately, despite being of the same order, to simplify handling and storing. It is approximately 30 meters between these two locations to simplify loading of trucks. The rebars commonly await pickup in storage for 2-3 days, although material is occasionally delivered directly from production onto trucks.

The transport is performed by an external actor contracted by Celsa, which means that Celsa is in control of the transportation to its customers' sites. Celsa pays a fixed amount per truck and day, which implies that Celsa wants to achieve the highest fill rate possible on the trucks. The cost is dependent on which truck Celsa acquires, such as crane-equipped trucks. The transport planning department at Celsa performs the ordering of trucks and contact with the transport provider.

Once the truck arrives at Celsa's storage site, the driver and the crane operator decide in which order the bundles should be loaded onto the truck, in respect to the delivery route of the truck. This is decided with the aid of order documents. The material is sorted and loaded onto the truck in a number of overhead crane lifts performed by the operator. The material is secured on the truck by the driver. The finished goods storage location can be seen in Figure 11. The operator scans the bundles while they are being lifted onto the truck. The scanning procedure is done to assure that all parts of the order are included and loaded. It is then transported, in sequence, to respective customers. The customers are usually located in the Stockholm and Västerås area.

Figure 11 - Bent rebars at finished goods warehouse at Celsa.

Reinforcing bars are delivered by truck to a specified entrance of the construction site intended for material deliveries, specified by JM. During the case study, material was unloaded from the truck with the aid of the truck's own crane. CAB is an ergonomically cumbersome product that is difficult to handle. In the current state, a construction worker stands on the ground and guides the bundles of CAB into the right position. This includes working in an ergonomically awkward position to be able to assist in the delivery process. Figure 12 illustrates how the construction worker guides the bundles into the right position.

Figure 12 - Ergonomic situation for construction worker while unloading truck.

After unloading of CAB, it is stored on the ground awaiting lift to the floor level where it is intended to be installed. The temporary storage location at the construction site is illustrated in Figure 13.

Figure 13 - Temporary storage area at the construction site

The bundles are lifted, with the aid of the construction crane, to the floor level where the CAB is intended to be installed. Construction workers assist the crane operator when attaching as well as receiving the CAB bundles, on the ground as well as on the floor level respectively.

The empirical findings of the material flow in the current state of operations are illustrated in Figure 14. The results are presented, as defined by the VSM procedure, describing the control and order initiating process in the supply chain. The following data are presented to enhance the evaluation:

- Number of bundles
- Cycle time per bundle
- Man-time per bundle

The total number of bundles represents the number of bundles included in the studied order. Cycle time and man-time represents the consumed time for each activity per bundle and consumed time by involved operator or construction worker per bundle, respectively. The mapped material flow from Celsa to JM is illustrated in Figure 14.

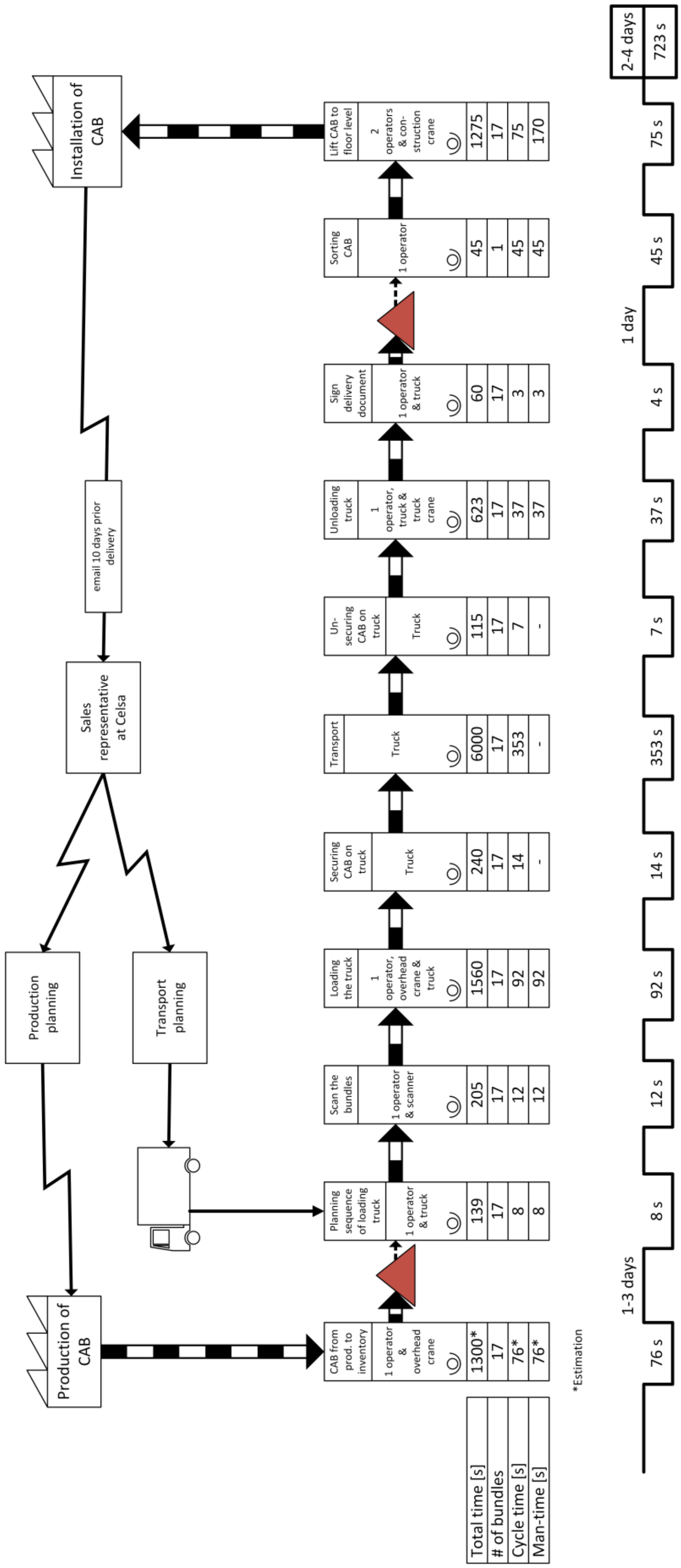

Figure 14 - Material flow mapping of current supply chain. Activities without man-time are denoted with a '-'.

The transportation is performed by an independent carrier with extensive experience working with Celsa, as they perform several daily transports of CAB between Celsa and its customers in the Mälardalen region. The drivers provided input of their perceived work environment of the current state, as well as effects such as potential risks and problems of implementing a load carrier in the material flow. During the case study there was no queuing of trucks at production sites. However, according to the driver, there are often queues of up to three other trucks awaiting loading, meaning that each truck may have to wait several hours before it is loaded and can depart.

According to the site manager at JM, orders of CAB are occasionally incomplete. The underlying reason being that bundles are unintentionally delivered to the wrong site caused by mixing on the truck bed. Furthermore, the construction workers experience that sorting of rebars is time consuming and non-ergonomic. It is usually necessary to move and lift bundles to locate a particular set of rebar. Also, the rebar storage location at the construction site commonly has to be moved, as it may be interfering with construction operations or be an obstacle for other deliveries. They may also be moved to make room for other equipment or construction material, which is a crucial in order to utilize the limited space.

The drivers state that they occasionally have to wait at construction sites for crane availability. A driver points out that he usually uses the truck's crane for unloading CAB, which implies that crane availability is not necessary in these cases. This procedure still requires a construction worker's attention as a receiver.

Storage time and storage area are presented in Table 2. Storage time represents the time that CAB is stored in inventory, while the storage area is the area that is occupied for storing CAB. The storage area is limited at Celsa's production sites. The storage area at the construction site may be regarded as a critical resource.

Table 2 - Storage time and area for a single delivery.

Storage	Storage time/delivery [d]	Storage area/delivery [m^2]
Celsa	1-3*	25
JM	1	20

During the current state study, several orders were included in the shipment, with one being voluminous rebar mesh. Because of this, the truck was only loaded with 8 metric tons of rebar before being constrained by volume. This resulted in the fill ratios displayed in Table 3. The fill rate includes all orders that were loaded on the truck, not only the studied order. The truck itself had the ability to load 13 metric tons. In more common scenarios, without rebar mesh, the truck is usually constrained by weight. The trucks that are used by Celsa are varying in regards to capacity of weight.

Table 3 - Estimated fill rate of the truck

Estimated fill rate	Fill rate [%]
Weight	~ 60
Volume	~ 100

6.1.2 Activity structure and resource occupation

This section presents time of activities and resource occupation of delivering a bundle. The transport time between the production facility and the construction site is excluded in the presentation of activities, as it is not affected by the load carrier implementation. The measured order in the current state contained 17 bundles of CAB. This normally differs from order to order.

As seen in Figure 15, the material flow is divided into activities, which are further divided into time per bundle. The throughput time for a single delivered bundle was:

- 203 seconds at Celsa
- 167 seconds at JM

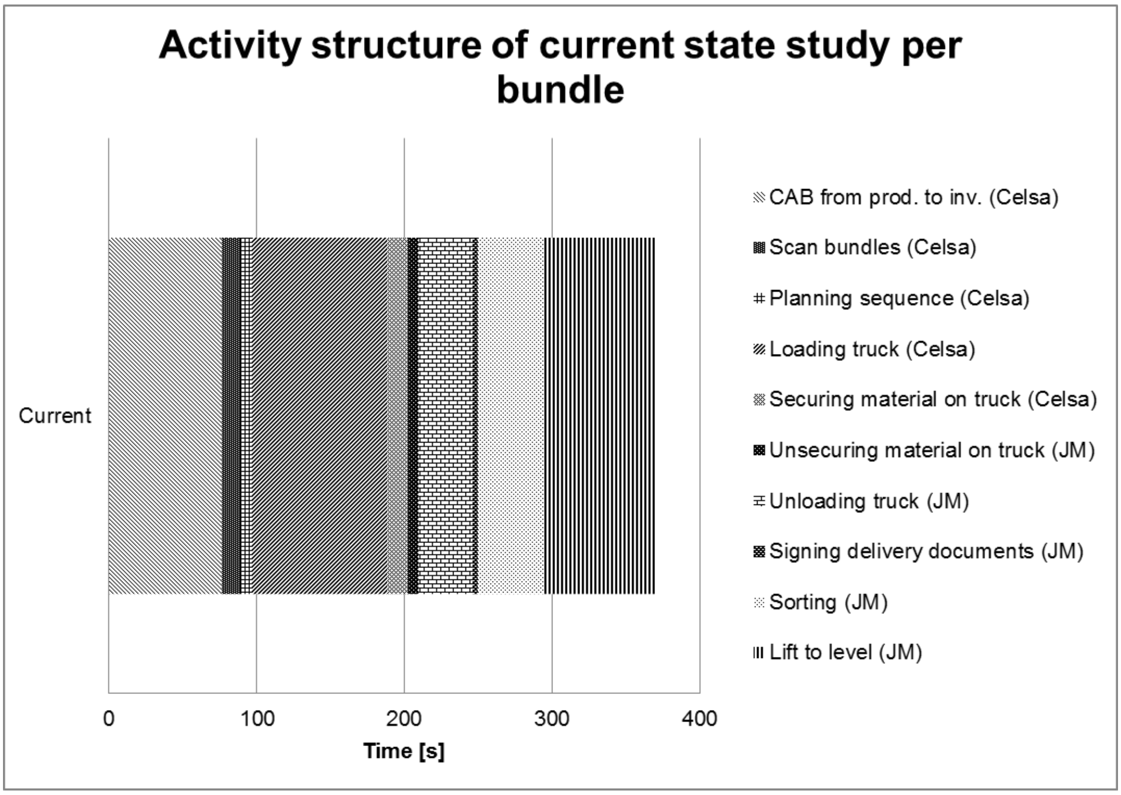

Figure 15 - Total activity time per bundle in current state.. The activity structure is the same as in the value stream map (Figure 14).

As described, the activities are evaluated in terms of their respective amount of repetitions, illustrated in Table 4. This may provide an indicator of how labor intensive a certain activity is without the uncertainty of time measurements.

Table 4 - Number of repetitions within each activity as required per bundle.

Activity	Repetitions	Repetitions per bundle
Planning Sequence	1	0.06
Scan Bundles	17	1.00
Loading truck	5	0.29
Lashing	1	0.06
Unlashing	1	0.06
Uloading truck	7	0.41
Sign delivery documents	1	0.06
Sorting	1	0.06
Lift to level	6	0.35

The measurements in Figure 16 represent the actual time a given resource is occupied in the delivery process. An occupied resource implies that it cannot be used for other purposes.

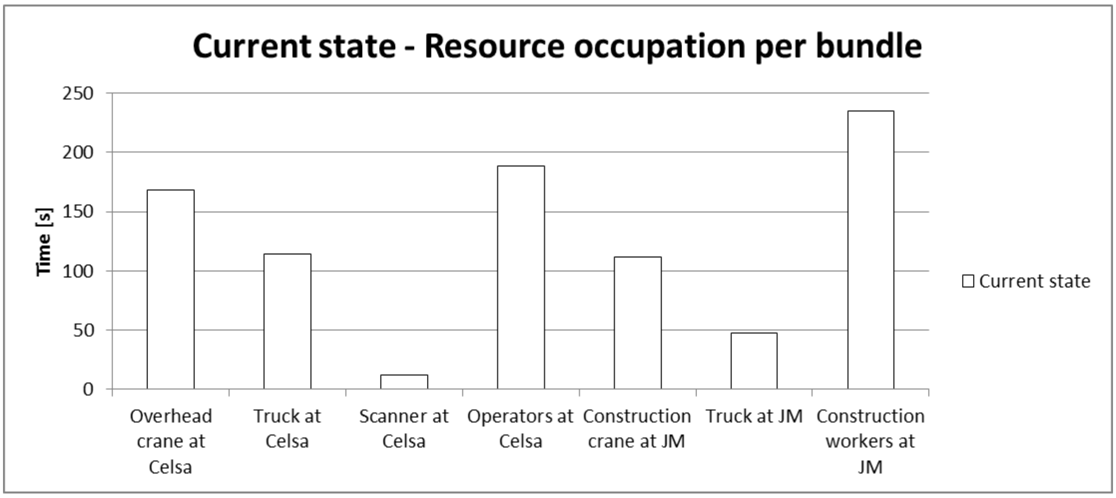

Figure 16 - Resource occupation per bundle as measured in the current state of operations

The measured time of the overhead crane was the consecutive time for moving and loading activities of rebars. The truck was timed during all activities where the truck or its driver was included. Resources mentioned in Figure 16 may be interconnected with other resources and may as much occupy those capacities as well. One example is the resource interrelation between the driver and the truck, as it is perceived as permanent. Regardless of the activity that the driver performs, the truck cannot be used for other activities. This means that these two resources may be regarded as one resource when evaluating the supply chain.

6.1.3 Information and order process

The information and order process within the empirical context may be described as in Figure 17.

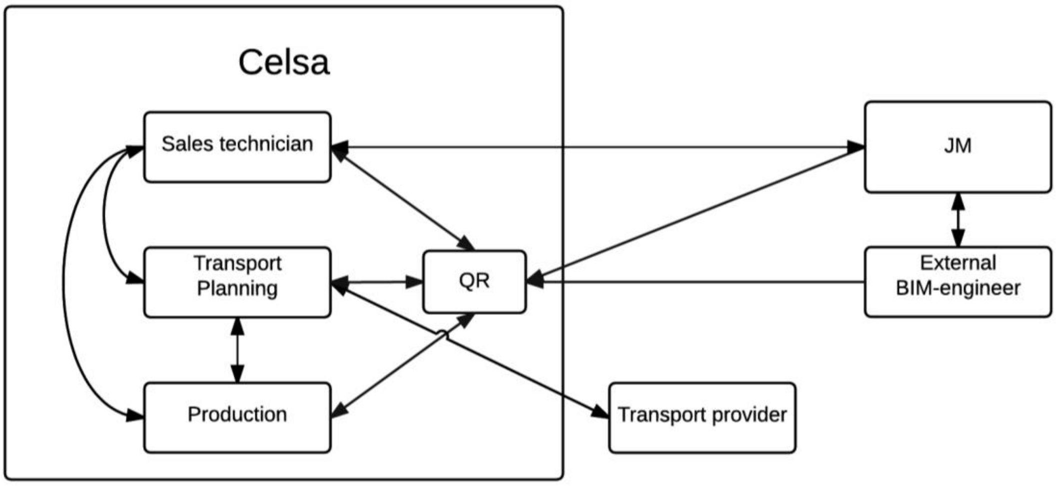

Figure 17 - Information flow of orders in current state.

Celsa signs a contract with a customer, commonly running for two to three years, as supplier of reinforcing bars to projects during the contract time. In this contract, prices for material and services are set. During the contract time, whenever a project is in a start-up phase, an initial meeting is held between the two parties. It is commonly held between Celsa representatives and representatives for the customer. The initial meeting is commonly formed by a BIM-engineer and the regional manager from Celsa as well as the site manager of the construction customer. The meeting concerns the purpose of the project, in terms of reinforcing bar material. During the meeting a delivery and time plan is agreed upon. This plan includes what and when CAB is to be delivered to the construction site throughout the project. In addition, technical solutions regarding CAB will be decided upon. The customer may also want Celsa to perform additional services, such as 3D-modelling of drawings or color coding of the reinforcing bars. Contact persons during the project are also decided upon. All aspects decided during the start-up meeting, is documented in a so called “start-up protocol”, which serves as basis for delivery of CAB during the construction.

As a service, Celsa provides an IT-platform called QR. The customer may use QR to create and organize its specifications of CAB, inspect drawings and enable wireless communication to, for example, simplify delivery inspection. In addition, the customer may use the platform to observe the delivery plan and make changes if necessary, for example by adding color coding to a delivery. It is not uncommon that the information in QR is insufficient or that the customer’s site manager is not using the platform.

After the initial meeting and establishment of the primary delivery plan, final orders are placed by the customer by phone or email ten work days prior to delivery, throughout the project. The orders are received by a sales technician, who releases the order to the production facility and to the transport planning. All involved actors have access to information about the order in QR, but the order is placed through email and thus not distributed through QR.

6.1.4 Technical preparation of the order

From building drawings, CAB has to be specified in order to enable production. A specification includes details of how many of each type of bar that is to be produced. The specification of the order is derived from drawings of the reinforcing bars for the specific area of installation. There are two ways to prepare an order for production.

- A BIM-engineer at Celsa performs the specification of CAB.
- The specification of CAB can be performed by an external actor, contracted by the customer, in this case JM. The specifications are sent to a Celsa sales representative by email and are inserted into the production planning.

During the case study, the specification of CAB had been performed by an external actor, meaning that the BIM-engineer at Celsa did not spend any time on specifying the order. Instead it was simply inserted into the production planning by the sales representative. An order of the size as in the case study is estimated to about four hours of work.

6.2 Pilot study

The pilot study was performed during two measurement occasions. Observations and qualitative input from both cases are presented and explained in this chapter while the measurements and value stream map is derived from the second observation.

6.2.1 Mapping of the supply chain

Similar to the current state scenario, once the CAB was produced, it was transported and sorted by overhead crane at the finished goods storage area. The day before pick-up, two operators loaded, using the overhead crane, CAB onto the load carrier, in a specific order designed by the BIM-engineer. Operators secured the CAB for transportation on the load carrier by lashing it with straps. The load carrier awaited pick-up overnight and was loaded onto the truck the following morning, with the aid of the overhead crane, and transported to the construction site.

According to the production manager at Celsa, the option of moving finished reinforcing bars directly onto the load carrier, located in the production area, was examined. This turned out to be unfeasible due to constraints of the production layout. Therefore, the load carrier was used solely within the area of finished goods.

During standard procedure, CAB is not allowed to be scanned prior to the loading procedure to increase the reliability of the deliveries. However, as the CAB were considered loaded once on the load carrier, they were scanned as they were loaded onto the carrier.

When loading the carrier, all reinforcing bars could not be fitted onto the carrier due to the intricate and voluminous design of some of the CAB. In the first case study, one bundle of larger type of bent bars was delivered on the side of the load carrier. As so, the truck was loaded and unloaded with two separate lifts, one lift with the loaded carrier and one lift with the single bundle. In the second case a EUR-pallet, containing one particular design of CAB, was also delivered aside the carrier. As in the first case, this resulted in two separate lifts.

After the operator had loaded the bottom of the load carrier, straight rebars were transported, with aid of the overhead crane, to the area next to the load carrier and spread on the ground in piles consisting of the same colors tags. This was performed to simplify loading of the carrier and to get an overview of what was included in the order. The rebars were put in order to simplify for construction workers, when picking rebar from the load carrier, as designed by the BIM-engineer. During the second study, the BIM-engineer had assigned color-coding to simplify operations for all parties.

After loading of straight rebars, the operator secured the cargo by lashing it with straps. This activity was time consuming. The operator did not have any standardized procedure for this, which may have been the underlying cause of the significant time consumption. Concurrently, the filled load carrier was tested for weight distribution as well as load securing. This task was time consuming and needed to be performed several times. Once the test was completed, the carrier was stored awaiting truck pick up the following day. The loaded load carrier is presented in Figure 18.

Figure 18 - The loaded load carrier.

When the truck arrived at Celsa's storage, the carrier was lifted by overhead crane. The load carrier was placed and secured on the truck's bed. Additional orders, unrelated to the study, were loaded as well. At arrival at the construction site, the driver removed the securing straps from the load carrier and prepared it for pickup. During the first case study a, forklift was used to lift the load carrier from the truck and as so did not occupy the construction crane. During the second case study, the load carrier was unloaded with the aid of the construction crane. During both occasions, the load carrier was stored on the ground for about a day before it was lifted to its intended floor. After the rebar on the load carrier had been consumed, the load carrier was placed in an area with limited activity awaiting pickup to Celsa. The value stream map for the pilot study is presented in Figure 19.

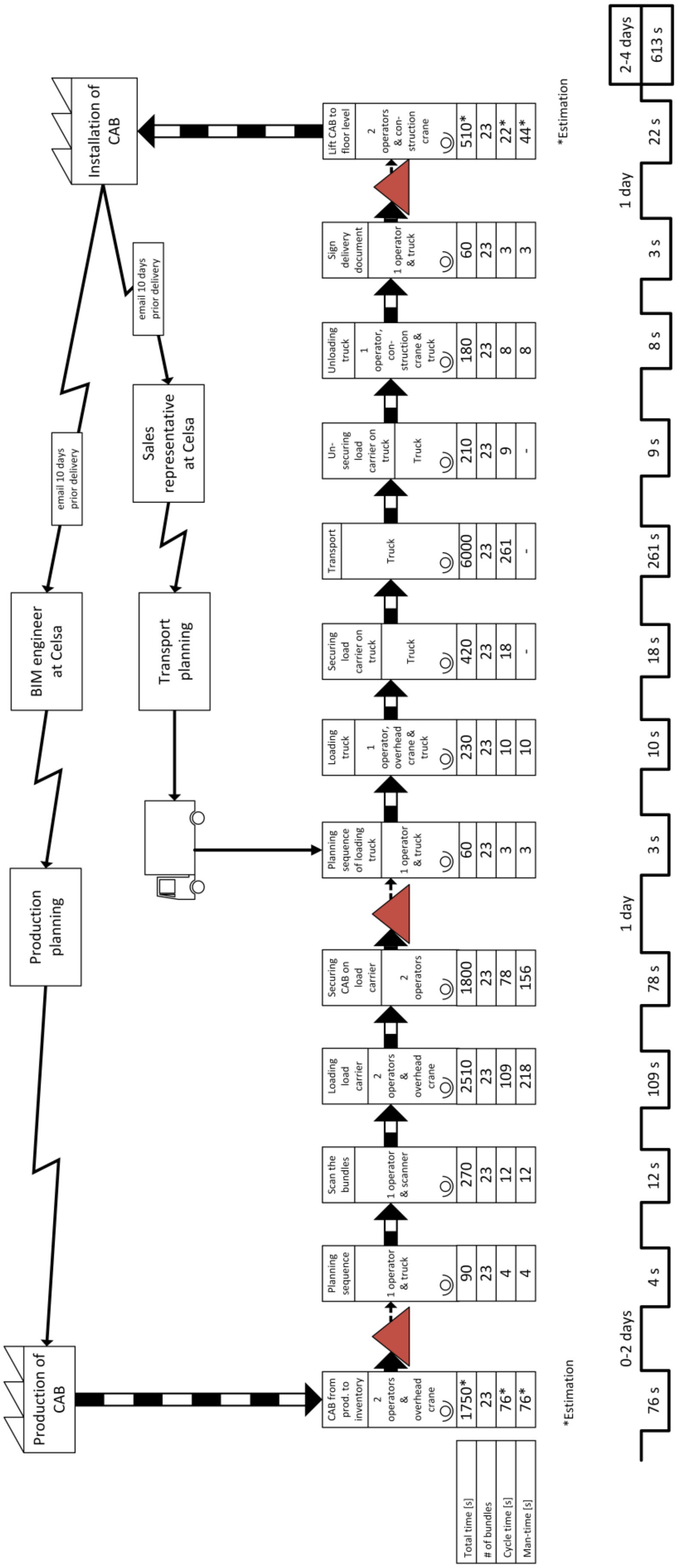

Figure 19 - *Material flow mapping of the pilot study.*

The storage time and storage area of CAB presented in Table 5 involves only the load carrier when loaded. Thus, the empty load carrier's storage time is not included.

Table 5 - Storage time and area for CAB in the pilot study.

Storage	Storage time/delivery [d]	Storage area/delivery [m^2]
Celsa	1-3*	9
JM	1	9

The fill rate of the truck is presented in Table 6. As mentioned, this includes all orders that were loaded on the truck, not only the studied order.

Table 6 - Fill rate of the truck, including all orders. The change of fill rate depends largely on other orders on the truck

Estimated fill rate	Fill rate [%]
Weight	~ 65
Volume	~ 50

6.2.1.1 Reverse logistics of the load carrier

When CAB is unloaded from the load carrier and installed at its intended location, the load carrier is lifted down to ground level using the construction crane. It is stored, awaiting pickup, for transport back to Celsa's production facility. When a truck has delivered an order to the construction site, the load carrier is lifted onto the truck with the aid of a construction crane or forklift. It is secured and transported back to Celsa. At arrival to the production facility, the load carrier is unsecured and lifted of the truck by overhead crane or forklift. The carrier is stored and awaiting loading of CAB for another order. Mapping of the reverse logistic process is illustrated in Figure 20.

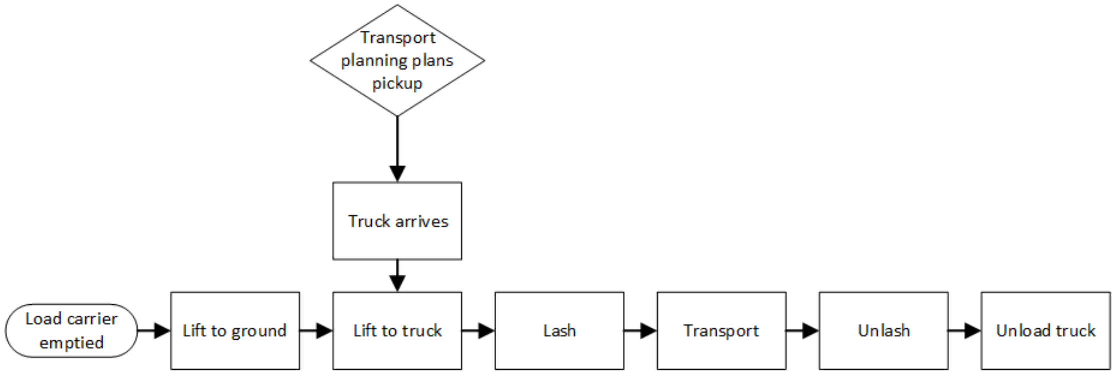

Figure 20 - Flowchart of the reverse logistics process, as implemented in the pilot project

Additionally, retrieving the load carrier from the construction site required some effort from transport planning, to coordinate the pickup between the foreman, crane operators and truck driver. Little other effort was required due to the limited amount of load carriers.

6.2.2 Activity structure and resource occupation

This section presents the activities as well as resource occupation

- Load the carrier with CAB.
- Secure the CAB on the carrier.
- Secure the carrier on the truck.

As seen in Figure 21, the transport time to the site is excluded in the presentation of activities as it is seen as fixed and is not affected by an implementation of a load carrier.

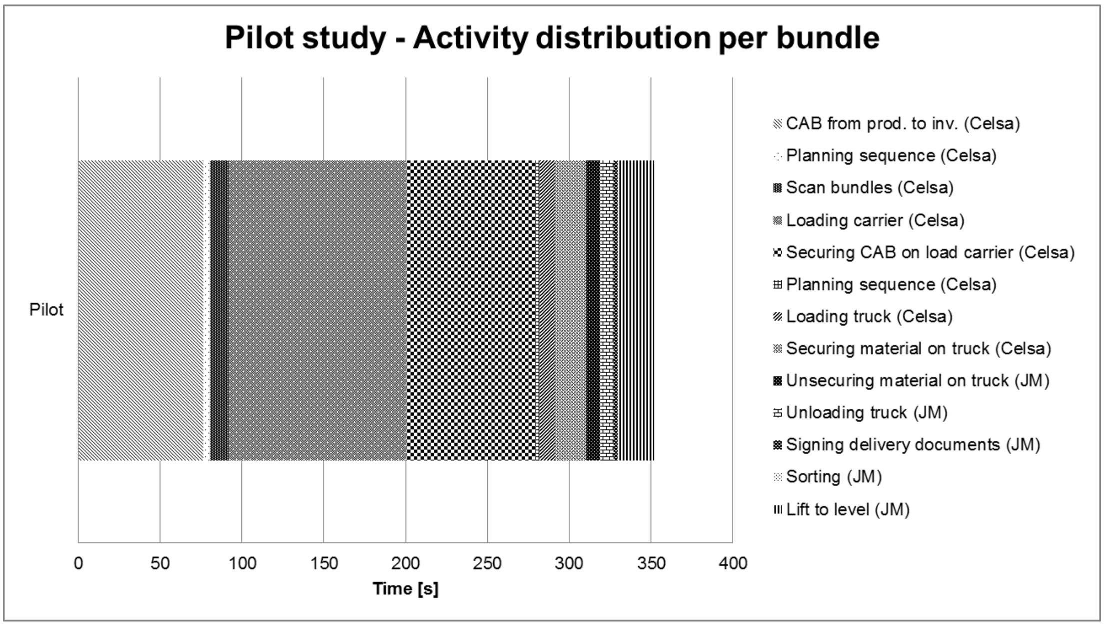

Figure 21 - Total time of activities. The transport time is excluded in this data, due to it being fixed and does not change with an implementation of a load carrier.

Table 7 presents the number of repetitions per bundle.

Table 7 - Number of repetitions for each activity during pilot study.

Activity	Repetitions	Repetitions per bundle
Planning Sequence	1	0.04
Scan Bundles	23	1.00
Loading carrier	14	0.61
Lashing carrier	1	0.04
Planning sequence	1	0.04
Loading truck	2	0.09
Lashing	1	0.04
Unlashing	1	0.04
Unloading truck	2	0.09
Signing delivery documents	1	0.04
Lift to level	2	0.09

Occupation of resources is presented in Figure 22, similarly to the current state scenario. As the weight of the loaded carrier surpasses the truck's maximum lifting capacity of 1-2 metric tons, it is not possible to lift the carrier off the truck by its own crane. Instead there is requirement for a construction crane at the construction site to lift the load carrier to the level where it is to be installed. However, when returning load carriers to the production facility, trucks equipped with cranes would be capable of lifting the empty load carrier.

The time in Figure 22 represents when a resource is occupied and thus not available for other activities. As mentioned, resources may occupy additional resources, such as when the overhead crane is in use, the overhead operator is also occupied and thus not able to sort or scan other rebars.

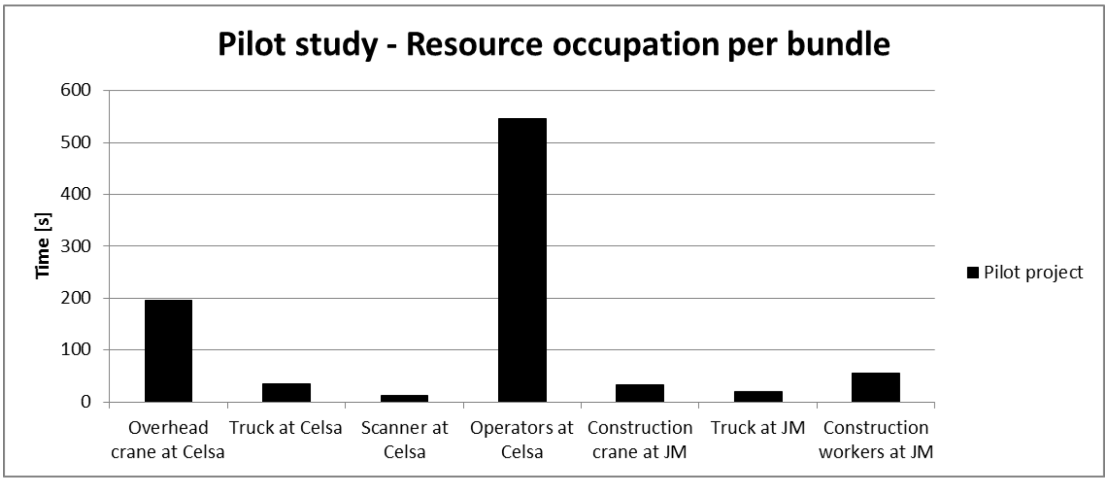

Figure 22 - Resource occupation per bundle during pilot study.

6.2.3 Information and order process

This section describes the information and order process which was undertaken during the pilot study. As the load carrier was going to be used for delivery of CAB, a load scheme was to be prepared for loading the carrier. Thus, a BIM-engineer was included in the order process together with a sales technician. JM placed the order by email to a sales technician and the BIM-engineer. The BIM-engineer designed a load scheme and made necessary changes to the design of CAB in order to fit it on the load carrier. The new specification of CAB was communicated to production planning. The sales technician communicated the order to transport planning, who communicated and planned the delivery process with the transport provider. The information flow of the pilot study is illustrated in Figure 23.

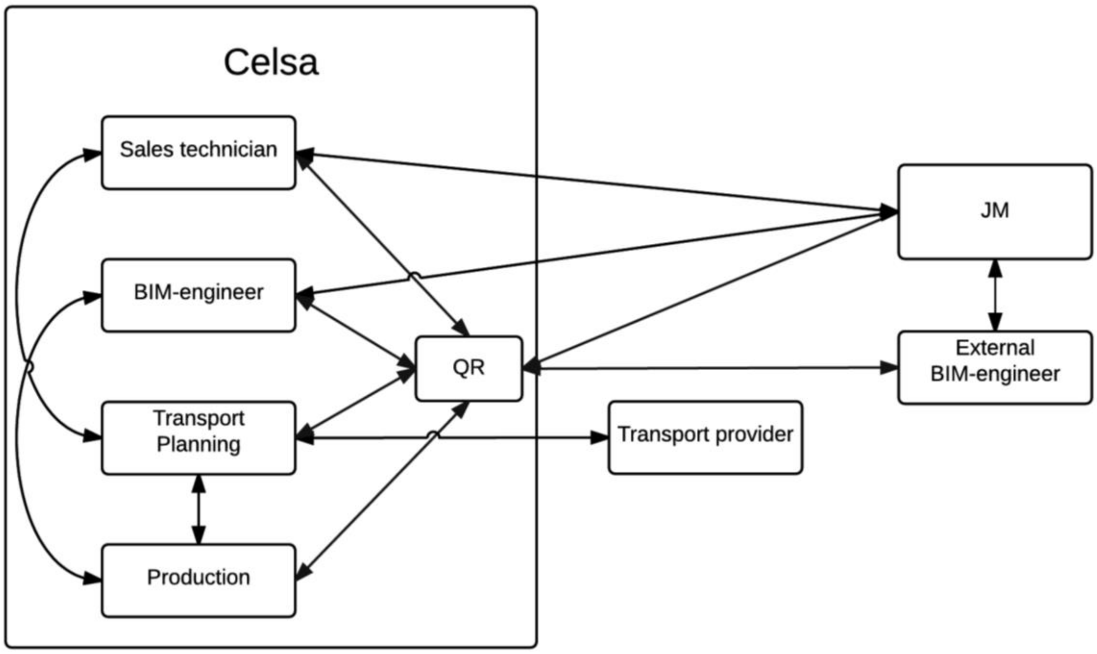

Figure 23 - Information flow chart for the pilot project.

6.2.4 Technical preparation of the order

According to a BIM-engineer at Celsa, using the load carrier in the supply chain required extra administration for technicians at Celsa. The extra work was needed to adjust CAB specifications to better fit the geometry of the load carrier. Reinforcing bars can often be divided into smaller parts compared to the initial drawing and then spliced during the installation. Reducing the size of the reinforcing bars was also in line with the preferred type of operations at the construction site, as large rebars are cumbersome to handle and install. Planning and designing a load scheme for the load carrier was also performed by the BIM-engineer. It included the process of finding a suitable center of gravity for the load carrier as well as matching the load carrier's shelving with the customer's requests, in this case separating the upper and lower layer of rebar. The load scheme for the load carrier in the first case study can be seen in Appendix A - Developed load schemes. Adjusting the reinforcing bars and designing the load scheme for the load carrier required several hours of the BIM-engineer. The load scheme was attached to the load carrier to simplify the unloading of the same for the construction workers.

During the second case study, reinforcing bars were tagged with color according to the load scheme of the load carrier. Each color represented a specific shelf on the load carrier where the bundled was to be loaded. The specific place where it was to be loaded was also marked with the color on the load carrier. This was done to simplify loading for the operator at Celsa and to make it more clearly for construction workers looking for a specific bar. By specifying the location of rebars on the carrier, the correct center of gravity of the load carrier was easily calculated by the BIM-engineer. This reduced operator testing time. The load scheme for case study two is presented in Appendix A - Developed load schemes. It was also attached on the load carrier.

6.2.5 Perceived effects of the load carrier

In this section, a summary of the input from operators at Celsa and construction workers at JM is given. Input was received during the observations regarding a future implementation of a load carrier from personnel that are involved in the material flow.

The perceived effects from the operator's perspective at Celsa of the implementation of the load carrier was, as a result of the extra lifts to load the carrier with CAB, that it required extra work to load the truck. Two of the operators stated that the load carrier had potential but the extra lifts required were seen as redundant. It was the loading of the carrier that was time consuming and significantly increased the number of required lifts.

From the operators' perspective, the load carriers should be filled directly from production to gain the most benefit. Due to the design of the load carrier, this would require bent rebar to be produced prior to straight rebar. Additionally, according to the operators, it would require that production and planning are better incorporated in the delivery process.

Suggested by both operators and truck drivers, the load carrier could be used solely within construction site, meaning that the trucks at Celsa are loaded as in the current state. Once at the construction site, CAB would be unloaded directly onto the load carrier from the truck. The load carrier would then be lifted up to the floor level where it is to be used. This would give the construction workers the same ergonomic benefits as in the case study. However, it would not simplify the unloading of the truck at the construction site. Further, the procedure may mitigate issues of poor fill rate and higher coordination requirements, while still retaining the simplicity for construction workers.

A truck driver expressed concern regarding the safety issues associated with the load carrier, as he stated that it suffered from lack of sufficient securing possibilities. In addition, the driver was hesitant of transporting heterogeneous goods, mixing load carriers with single bundles of CAB, as he stated that it would affect fill rate significantly. The other driver stated that an implementation of the load carrier will counteract the possibility to use the truck crane, implying that the time of unloading the vehicle will in general increase. He further argued that lack of shielding of the load carrier towards the driver's cabinet was a safety concern. It should be noted that this driver was generally negative towards the entire concept, which may reflect upon his opinions and statements.

The involved construction workers at JM were satisfied with the load carrier and how it was loaded. It facilitated the installation of CAB and mitigated non-ergonomic lifting of heavy bundles and simplified sorting and fetching of material. They did not have any specific suggestion for changes. They had a positive attitude regarding the concept as a whole.

Conversely with the site manager's intent, the foreman did not perceive that the CAB delivery process would benefit significantly from just-in-time, due to low delivery reliability of complete orders. As so, the foreman orders CAB to be delivered the day before installation, to reduce the risk of missing material.

The delivery of rebars with the load carrier at the construction site was in line with the expectations of the personnel at the construction site. A construction worker, together with the site's foreman, perceived the implementation of the load carrier as a significant improvement. They argued that it would increase the probability of complete deliveries and also facilitate the control of the unloaded CAB. The foreman stated that he preferred to receive the order a day prior its intended consumption to reduce the risk of material deficit. He further believes that return logistics is not a large issue in regards to the warehousing space at the construction site.

7 Analysis

The analysis is divided into two main sections and aims to analyze the empirical findings with the aid of literature presented in the frame of reference. First, the pilot study is analyzed in comparison to the current state. This includes the activity structure and resource occupation that have changed with the implementation of the load carrier. Second, a suggestion for a future state of operations, including the load carrier derived from earlier research is presented.

7.1 Current state and pilot study comparison

The current state and pilot study are compared in order to analyze how the processes change with an implementation of a load carrier in the current flow. Analysis of the current state scenario aims to provide a view of how the delivering process of CAB may be improved. Non-efficient processes are identified and analyzed to increase supply chain performance. It is important to question and analyze the current process in the supply chain in order to understand the challenges and obstacles that an implementation of a load carrier may face. In the pilot study, the load carrier is implemented in current operations without major changes to current processes. The activity structure and resource occupation are, amongst other aspects, analyzed in order to see the positive and negative effects of the load carrier implementation. The analysis is divided in activities, resources and actors in accordance with the problem analysis.

7.1.1 Activities

The following chapter will provide an analysis of how activities are altered within and among actors when implementing a load carrier.

Administrative work

As in the investigated supply chain, few involved actors facilitate the implementation of a load carrier, in accordance with Storhagen and Lindqvist (1998). The implementation is, however, hampered by the characteristics of the product, as bundled CAB often is a voluminous and non-standardized product, cumbersome to handle and stack. This property makes it less than ideal for a standardized carrier, as advocated by Storhagen and Lindqvist (1998). This issue may, to some extent, be mitigated by BIM-engineers at Celsa through better design of CAB to match the load carrier's limitations. This preparation proved to be a time consuming process, as the BIM-engineer had to spend several hours correcting and adapting already completed CAB specifications. In this particular scenario, the customer had already specified the ordered CAB, which resulted in redundant work. With a more clear communication process, this could have been avoided.

According to Storhagen and Lindqvist (1998), one of the dimensions that need to be regarded in terms of implementing a load carrier is the administration. As discussed in the comparison between the current state and the pilot study, with administrative work being performed twice, this dimension crucial in order to mitigate redundant work and reduce the preparation time of the load carrier. This issue may be reduced or mitigated by using Celsa's in-house services.

Material handling

The activity structure in the material flow changed with an implementation of the load carrier, which led to additional activities at Celsa.

- An extra planning sequence before loading the carrier
- Loading the carrier
- Securing the CAB on the carrier

Figure 24 illustrates the activity structure and activity time per bundle at Celsa and JM for the current and pilot study respectively. As mentioned, activities that were added to the operations at Celsa contributed to the increased total time of the activities. Securing CAB on the carrier was perceived as a time consuming process. As seen in Figure 24, the activities *loading carrier* and *securing CAB on load carrier* makes up 55 per cent of the accumulated cycle time in the pilot study. On the other hand, the activities at the construction site are less time consuming and completed using fewer repetitions.

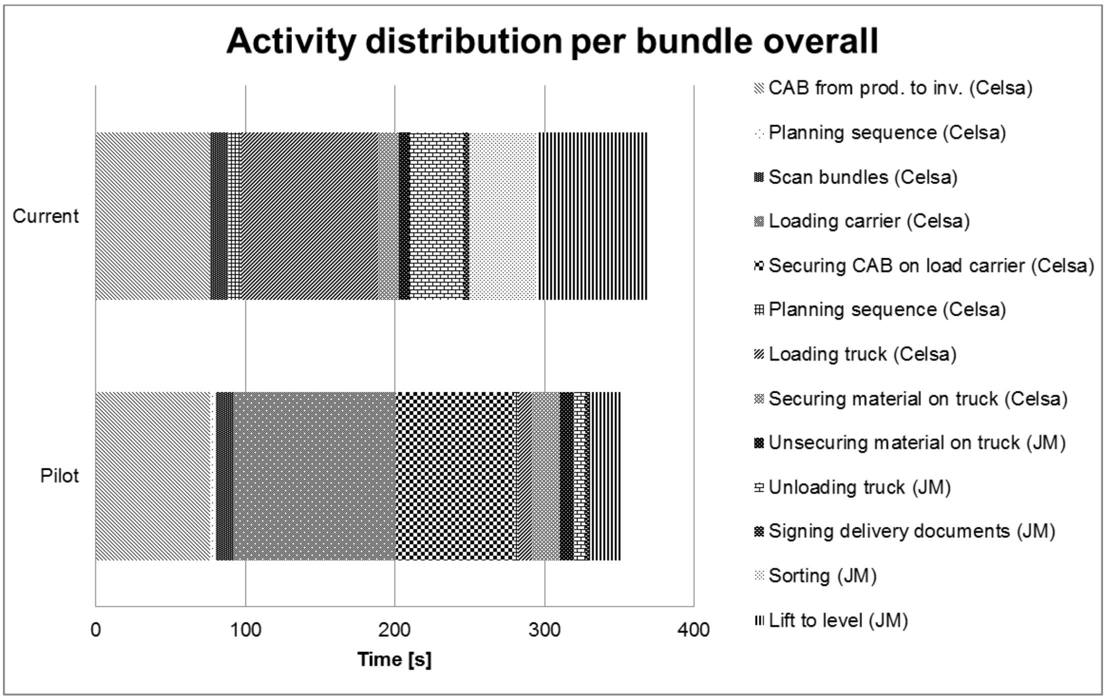

Figure 24 - Activity structure and accumulated cycle time of supply chain. The transport time is excluded in this data, due to it being fixed and does not change with an implementation of a load carrier

The material handling process in the pilot study shows significant negative impact on the activities undertaken in regards to *the material handling criterion*, as defined by Pålsson et al. (2012). This is in line with Langbeck et al. (2012), who argue that the numbers of activities, as well as time spent undertaking activities, are important aspects when evaluating supply chain performance.

Organizational learning

Being an entirely new way of performing these tasks, it may be reasonable to assume that the additional activities were performed in a less than ideal way, in accordance to Fioretti (2007). Over time the learning process will set in and reduce the total activity time. As Lopez et al. (2006) state, the knowledge acquired from experience should be effectively distributed throughout the organization and stored in the memory of the organization through routines or standards. During the two studies, different working shifts performed the loading and securing of the load carrier. There had been no significant communication between operators to distribute acquired knowledge of the working process, which may explain why no reduction in time was seen. As mentioned, knowledge should be distributed throughout the organization to enhance a continuous improvement of processes. Distributing the knowledge captured during the first case study to relevant operators, would have likely been beneficial. The four dimensions of organizational learning presented by Lopez et al. (2006) were thus not fulfilled in their entirety during the two studies at Celsa.

Loading and securing the load carrier represent a significant portion of the entire time of activities. As presented previously, the cycle time of routine activities will likely decrease over time, in accordance with Fioretti (2007). If the cycle time for these time-consuming activities can be reduced, it will have a significant impact on the total activity time.

As seen in Figure 25, the loading of the truck is significantly decreased in the pilot study. Loading time of the truck was reduced by approximately 90 per cent. Time of securing the load carrier on the truck had increased with 30 per cent compared to securing the material in the current state, which also contributes to the longer total time. The time of lashing the load carrier may likely be reduced through development of standards and routines, in line with Lopez et al. (2006).

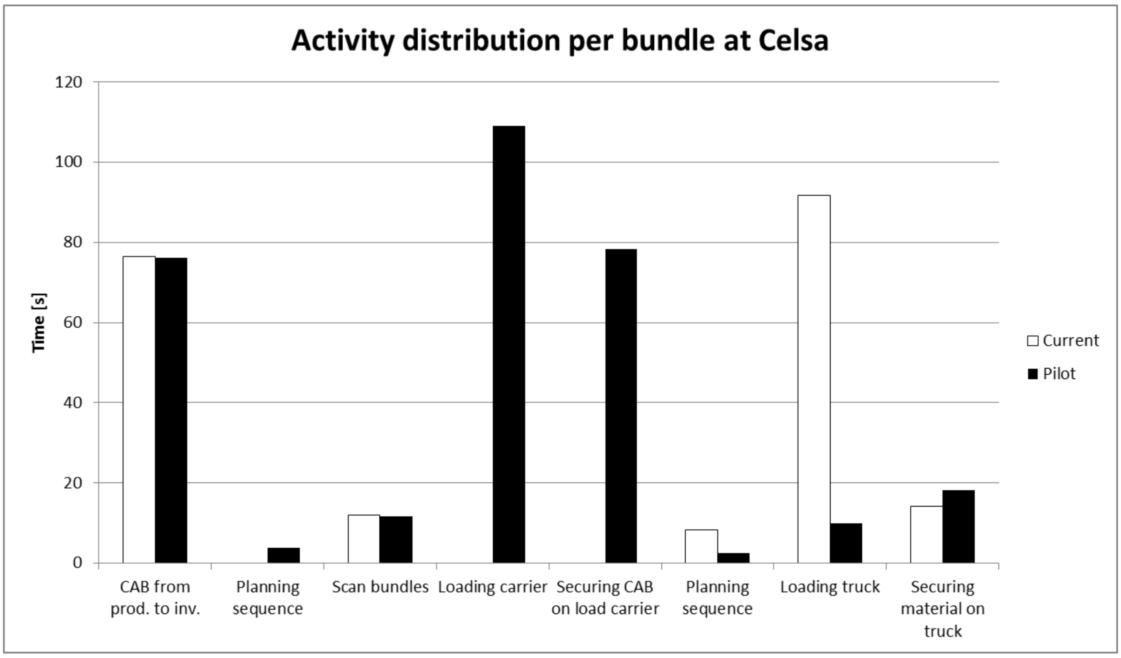

Figure 25 - Activity structure at Celsa, separated by type of activity. The current state categories 'loading carrier' and 'securing CAB on load carrier' are set to zero, since these activities do not exist.

The ergonomic situation for the operators at Celsa was negatively affected by the implementation of the carrier. In the current state, operators had to do little bending or heavy lifting. In the pilot study, the amount of heavy lifts that the operators had to perform increased. Additionally, securing the load carrier was performed in ergonomically poor positions. Thus, loading of the carrier was not in line with the requirements presented by Twede and Clarke (2004). The load carrier should be ergonomically to load, as this often requires significant manual handling.

Another aspect to consider is the contingency of faulty/missing orders. Operators at Celsa mention the risk of missing order lines, which is only discovered during the loading of the truck, resulting in necessary corrective shipments. Due to the nature of the load carrier loading process, CAB can be scanned prior to truck loading, which gives additional time to assess the correctness of the order and take actions accordingly.

The benefits of the changed activity structure are mainly achieved at the construction site. As seen in Figure 26 the main time reduction can be assigned to *unloading* and *lift to level*. These times are reduced by 73 per cent. By performing only one lift, the time which the crane is occupied is reduced as well as the need for construction workers to assist the crane. As mentioned, reducing the usage of the construction crane is crucial in building projects according to Shapira et al. (2007). This is regarded as highly positive, in accordance with Zavichi et al. (2014) and Shapira et al. (2007). Additionally, the results are in line with Shapira et al. (2007), who state that reduction of construction crane usage should be explored. However, *unsecuring material on truck* took longer than of bundles of CAB, which increases the accumulated cycle time for this activity. The reason for this is unclear, but may be reduced over time through learning.

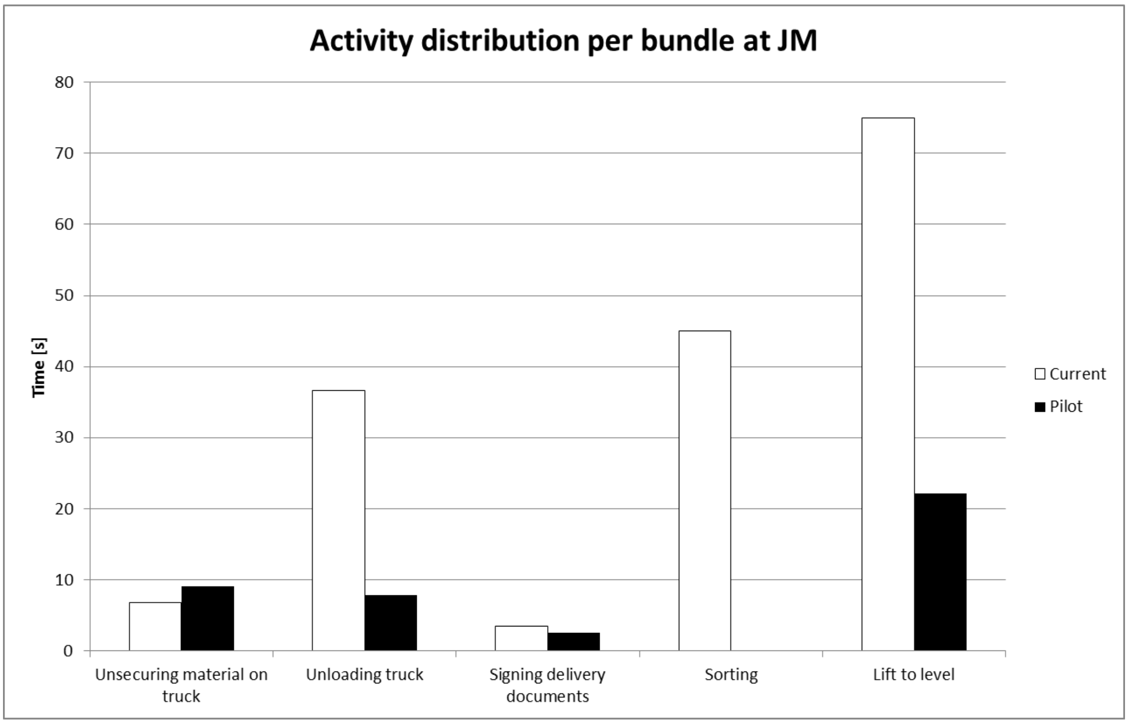

Figure 26 - Activity structure at JM, separated by type of activity.

The load carrier may be lifted with one lift up to the level where it is intended for installation. In the current state, bundles are lifted by the construction crane in several lifts.

Ergonomics at construction site

In the current state, a construction worker guided the lifts of the bundles to storage on the ground, which required extensive manual labor and bending. In addition, when bundles of CAB are lifted up to the level it is to be installed, they are again spread on the floor. This further contributes to the non-ergonomic situation for the construction workers.

The load carrier reduced the construction worker’s physically tasks to solely securing and unsecuring the load carrier during lifting rather than handling and lifting bundles during the unloading procedure. When using the load carrier, bars were picked at a more ergonomically friendly height, which reduced bending and need of working on knees. The amount of cumbersome lifts was also reduced, as the bars were picked from the load carrier rather than from the ground. The load carrier is thus more fulfilling of the requirements regarding ergonomic suitability by Twede and Clarke (2004).

Reverse logistics

After using the load carrier as a rack during installation of CAB, the emptied load carrier was lifted down to the ground with the aid of the construction crane. This is an additional activity which does not exist in the current state of operations. The lift was performed when the crane was not highly occupied, due to the lack of critical time requirements. As such, it did not contribute considerably to usage of critical resources, as defined by Zavichi et al. (2014). The carrier was stored on the ground awaiting pick-up to be transported back to the Celsa production site. The carrier had to be loaded onto a returning truck with adequate free space. This was done concurrently with the next delivery of CAB. This procedure put pressure on Celsa's transport planning, to ensure that a delivery to the construction site was performed in a sequence which enabled the load carrier to be loaded onto a relatively empty truck. In addition, it required communication between the drivers, the construction site and transport planning. The load carrier was loaded onto the truck by either the truck's crane or the construction crane. It was transported back to the Celsa production facility in Västerås and lifted off the truck with the overhead crane and stored, awaiting next delivery.

The process of reverse logistics of the load carrier do not require any extra transport, as the truck is returning empty to Celsa. The extra activities that are added in comparison to the current state are:

- Lifting empty load carrier to ground level at construction site
- Lifting empty load carrier onto truck
- Lashing load carrier on truck
- Unlashing load carrier on truck
- Lifting load carrier to ground level for storage at Celsa

As so, some of the challenges defined by Silva et al. (2012), are not valid in this particular case. The return of the carrier may not be regarded as resource demanding, as the truck is either way driving empty back to Celsa. Similarly, the reverse logistic process does not require additional investments. On the other hand, it will require an administrative process that is, according to Storhagen and Lindqvist (1998), driving higher costs. Thus, the benefits of the load carrier will need to justify its additional administrative activities and cost.

Control

The nature of the business context, where each order is made-to-order, is inherently pull-based. More so, the control of the supply chain, in its current state, is rather how the flow is achieved and coordinated than initiated. The part of the supply chain that is studied between Celsa and its respective customers is relatively short, making monitoring the current system comparatively easy. Once an order has been placed, it is planned and pushed through the production and transportation before being delivered to the customer. However, in the pilot study, the element of reverse logistics comes into play. This requires an active role which coordinates and enables the readiness of the load carrier. The coordination process involves communication of the load carrier's current status, determining when it is needed as well as the entire activity of returning it to its point of origin. These activities were handled by Celsa's transport planning in the pilot study.

As discussed by Silva et al. (2012), many aspects of the logistics process become more challenging and have to be mitigated when implementing the load carrier in the pilot study. Activities related to material handling and loading will increase in variability, making cost assessment more difficult. Forecasting also becomes more difficult as it involves more variables and, as discussed earlier, visibility becomes less clear. As so, the pricing of the load carrier service becomes more difficult.

7.1.2 Resources

The feasibility of an implementation of the load carrier must be evaluated in regards to technical, economical and contextual aspects. This chapter will provide an analysis of how resources are affected, evaluation of the technical fit of the load carrier in the supply chain and consideration how the requirements of other resources are affected in regards to the load carrier.

Load carrier and its fill rate

During the study of the implementation, loaded CAB amounted to about 3000 kg each time, giving it an overall fill rate of about 67 per cent, in regards to the load carrier's weight constraint. As so, the load carrier is fulfilling the order in terms of weight. However, in both studies the load carrier was constrained by volume as the bottom of the carrier, used to carry geometrically intricate CAB, was fully loaded in regards to volume. As a result of this, some CAB had to be delivered separately. Had there been more straight CAB, the load carrier would have been able to fulfill a higher weight ratio. And similarly, had there been less intricate CAB, the load carrier would not have been constrained by volume. This is, however, dependent on these particular cases and may not be representative for general operations.

Comparing the load carrier's performance in relation to the current state scenario, as defined by Pålsson et al. (2012), is not deemed as valid, since the current state solution has a "secondary packaging" weight to volume ratio of 100 % inherently. However, a more valid comparison is possible by studying entire truckloads. As mentioned, the trucks carrying the load carrier were also loaded in the traditional sense concurrently, enabling a higher flexibility. This resulted in higher weight fill rates than if only load carriers had been employed.

When considering the current state of operation, load factor of the truck and the nature of the product make weight almost exclusively the limiting factor. CAB is loaded onto the truck until all orders of the route have been fulfilled or until the maximum loading weight has been achieved. By using a load carrier during transportation, the maximum capacity of carrying goods decreases as the carrier occupied both weight and volume. The load carrier weighed 400 kg, which represents about 3 per cent of a 15 metric ton capacity the truck.

Given the studied cases of the load carrier implementation, neither scenario was the truck fully constrained in regards to volume, meaning that it was still capable of fulfilling its orders or be loaded in regards to the weight constraint. However, considering a more large-scale implementation utilizing more than one load carrier or generally larger orders (by weight or volume), the risk of fulfilling the volumetric constraint, while not fulfilling the weight constraint, increases. Main reasons are that the load carriers cannot be stacked onto each other and that the securement of the load carrier occupies more volume compared to securing single bundles material. In addition, the fact that load carriers are loaded as a discrete number, rather than continuously, restricts the possibility to fulfill the constraints efficiently, in comparison to current state. As seen in Figure 27, the load carrier reduces the truck's ability to deliver CAB by weight and weight. The constraints given by the vehicle in question may be described as:

*n * weight of load carrier + CAB < Weight constraint of truck*

*n * volume of load carrier + CAB < Volume constraint of truck*

When evaluating the actual utilization rate of the fully constrained truck it is necessary to only include the material which is to be delivered. As so, the utilization rate of a load carrier implementation is still be described as

CAB / Weight constraint of truck [%]

CAB / Volume constraint of truck [%]

Or, similarly expressed through a total fill rate perspective

*Load carrier fill rate by weight * Truck fill rate by weight [%]*

*Load carrier fill rate by volume * Truck fill rate by volume [%]*

More so, the load carrier implementation will, inherently, display a worse fill-rate in regards to weight than its non-implemented counterpart. A lower fill-rate requires additional shipments, which in turn results in more negative impacts, such as administrative work and environmental impact. The worsened load factor may, given the assumption that the truck is fully constrained by weight, be described as

*n * weight of load carrier / Weight constraint of truck [%]*

Or, conversely, the best possible load factor may be described as

*1 - (n * weight of load carrier / Weight constraint of truck) [%]*

It is important to note that the nature of the business context, rebar is sold by weight and is also generally the constraining factor. This creates a resistance to change for worse, despite possible benefits within other areas, such as in the delivery process.

Given the context of the implemented load carrier, it may be difficult to quantify a load carrier's impact on the truck's occupied volume. In the two case studies, the constraints depend on the nature of the remaining rebar. Despite a possible heavy volume usage from using a load carrier, it does not limit the delivered weight as much as one would anticipate, as illustrated by Figure 27. Another aspect, which may be crucial, is the occupied volume derived from the necessity of securing the load carrier, which in turn may limit the possibility to further load the truck.

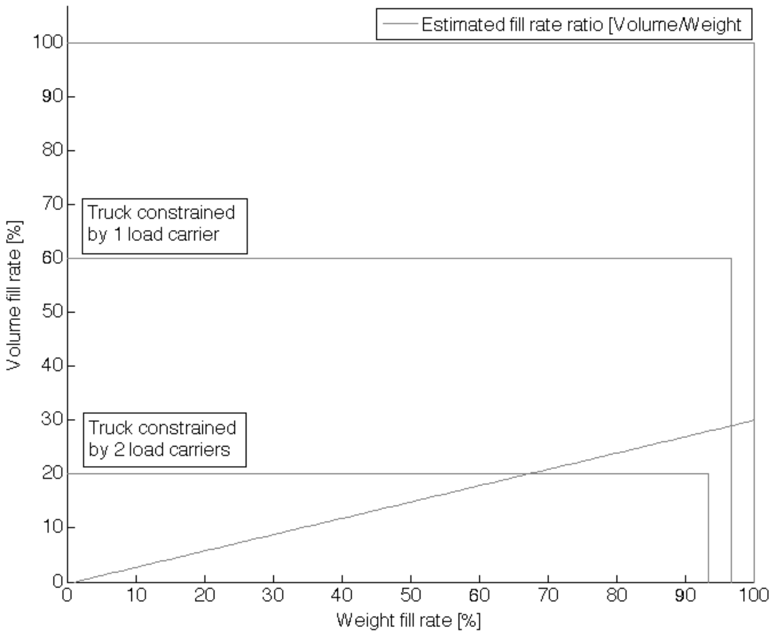

Figure 27 - Conceptual graph depicting the relation of fill rate constraints. Volume fill rate, given that the truck was constrained by weight without load carrier, was assumed to 30 per cent.

Products delivered by Celsa that do constrain trucks by volume, such as rebar mesh, would not be feasible to combine with the load carrier at all, which reduces flexibility and increases the necessity of transport planning. The pilot project indicates a challenge of compatibility, in regards to combining current state packaging with the load carrier, during transport, as illustrated in Figure 27. Additionally, as concluded, the load carrier does inevitably reduce the fill rate in regards to maximum weight and volume. These findings are in line with Gadde et al. (2010), who stress that combining resources must be viable from a total cost perspective as an implementation of new or external resources might require adjustments of already existing resources. The authors state that the combined resources must fit physically, technically, functionally and should be easy to manufacture, transport and assemble. With increasing non-compatible resources during transport, additional, more extensive, planning of transportation may be required. In line with the argumentation of Gadde et al. (2010), existing resources may need to be adjusted to better comply with the load carrier, whereby the cost of these adjustments needs to be considered. Further, it is also important to question the applicability of the currently used trucks. By switching the trucks used, a better fit between resources may be enabled.

Investments

Assessing the economic impact of a pilot implementation is difficult, as capital investments have to be put in relation to actions and activities within the supply chain (Rosenau et al., 1996). The initial investment has to be put in context to the effects within the supply chain, and their respective changes to the cash flow of the actors (Rosenau et al., 1996).

Introducing a reverse logistics system in a supply chain should be economic viable for the overall supply chain (Pålsson et al., 2012). From the perspective of the investor of the load carriers, in the studied case Celsa or an external agent, there must be an economical pay-off. Implementation of load carriers or reusable containers in a supply chain often requires large initial investments but does also affect the operating costs in different manners (Twede, 1999; Twede and Clarke, 2004; Verghese and Lewis, 2007). Verghese and Lewis (2007) stress the importance of evaluating the benefits and additional costs from a total supply chain perspective. When implementing a load carrier in the supply chain, the interfaces between activities, resources and actors change. As so the following paragraphs will focus on how the load carrier affects other resources and how the requirements of other resources change.

Celsa's supply chain is characterized by high variability and non-steady demand as the customers expect customized made-to-order CAB delivered to one-time projects. Therefore, the orders that Celsa receives are heavily altering in both regards to size and configuration. Twede and Clarke (2004) argue that the supply chain should be characterized by stable demand with low variety and also involve a clear supply chain leader in order to facilitate a load carrier implementation. Thus, in contrast to the conclusions drawn by Twede and Clarke (2004), the investigated supply chain involving Celsa and JM is not characterized by some of the variables that the authors emphasizes as particularly important for this purpose. Additionally, the lack of standardization and predictability in the construction business makes it more difficult to use the load carrier in a broader manner. Construction equipment, such as the load carrier, that is compatible with a large range of other resources benefit from the possibility increase the utilization of time, as argued by Lumsden (2012). This is also in line with Twede (1999), who argues that reusable containers should be used in a standardized environment in order to be useful among several actors and products. On the other hand, Mollenkopf et al. (2005) stress that investments of reusable containers are more likely to be economically viable the larger the size of the container. If a load carrier was to be implemented, the mismatch of the supply chain characteristics and its products therefore implies additional requirements. For example, high variability requires larger number of load carriers to handle time periods with high demand. This will in turn require a larger initial investments and higher logistics costs.

Johansson and Hellström (2010) state that an effective tracking system may give managerial insights enabling the reduction of load carrier in the reverse logistics system. However, considering the context of a small initial implementation, this may likely be disregarded initially.

Differentiation

According to Rothenberg (2007), offering additional services around a product might be a viable way for a supplier to differentiate it from its competitors when the product itself is fairly generic. Extending the value offer through services often lead to deepened relationships between the supplier and customer, and does also reduce the risk for the supplier of being copied by competitors (Rothenberg, 2007; van Weele, 2010). Thus, implementing a load carrier in the supply chain can be regarded as a differentiation in comparison to Celsa's competitors.

Resource occupation

When investigating how the load carrier affected other resources in the supply chain, it was found that the occupation of resources such as cranes and trucks were diminished. The occupation of resources during the case studies is seen in Figure 28. The time of the truck at the sites respectively is measured as the time the truck is involved in activities that can be derived from the specific investigated order.

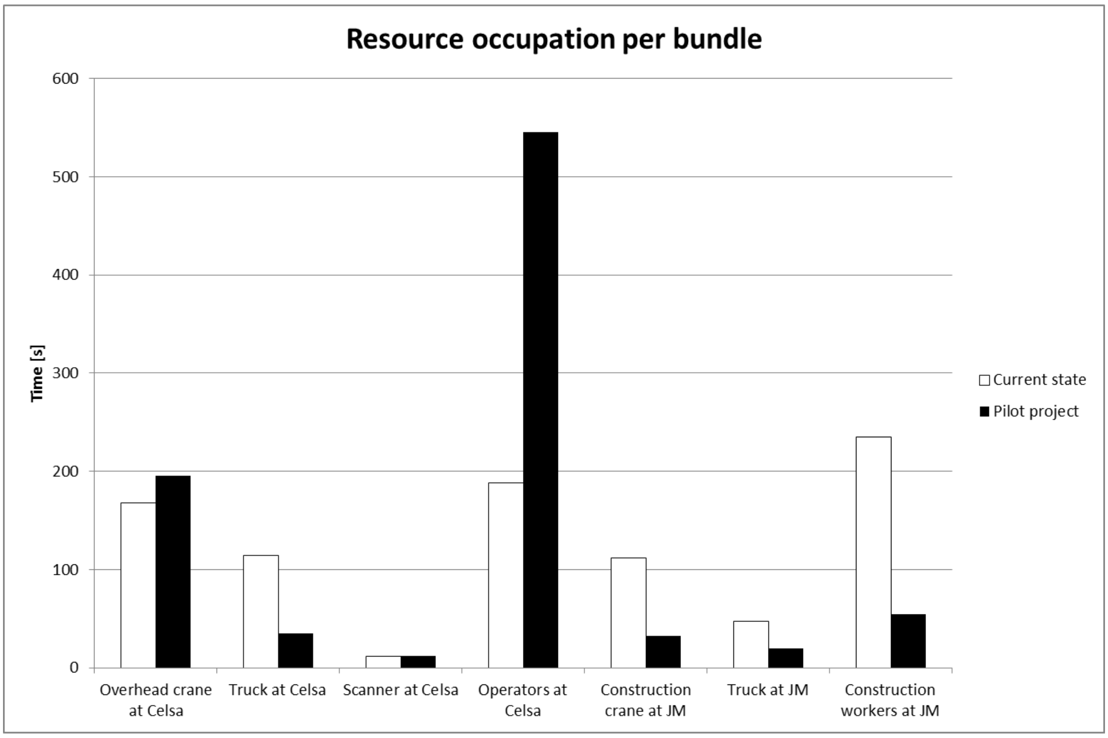

Figure 28 - Comparison of resource occupation per bundle

As seen in Figure 28, delivering reinforcement bars with a load carrier reduces the required utilization of several key resources at JM. When implementing the load carrier in the supply chain, the use of the onboard crane of the truck is reduced. This is due to the weight limitations of said crane. As so, the flexibility of the delivery process is reduced to larger on-site cranes, making it necessary to utilize a construction crane. As a result of this, there is a potential risk that waiting times to unload goods at the construction site will increase.

Resources that are used in the delivery process are presented in Figure 28. Some of these resources are identified as bottleneck resources. When using the load carrier, the crane occupancy is reduced due to fewer numbers of repetitions. This may lead to reduced idling time of other operations waiting for crane availability (Zavichi et al., 2014). According to the site manager at JM, reduction of the occupation of construction cranes can be regarded as valuable improvements, as these are key resources and often become bottlenecks at the construction site.

It should be noted that CAB for floor reinforcement is usually intended for higher floor levels, which puts an absolute requirement of the usage of high capacity lifting equipment at the construction site, such as construction cranes. However, this final lift may be done by the construction site crane during lower intensity periods. In comparison to the current state of operations, it will reduce the number of lifts considerably. This is line with the opinions of the site manager and the foreman at JM, who both argue that the average waiting time regarding a construction crane may be reduced significantly with decreasing time of the unloading activity. The reason being that activities which are time consuming and require a crane must be planned beforehand, whereas activities only requiring a few lifts can be performed in-between other activities, and thus increasing the crane utilization.

The focus on changing the supply chain to decrease the involvement of construction cranes is also in line with Jonsson and Mattsson (2009) that state that activities and resources in the supply chain adjacent to a bottleneck resource should be subordinated with the purpose of creating a more efficient flow. In terms of output from Celsa's production facility in Västerås, the overhead crane may be regarded as a bottleneck resource. The queuing which, according to the empirical findings, tends to occur when several trucks arrive at Celsa awaiting pickup of CAB amounts to as much as three hours. The estimated dwell time, when employing load carriers, may be reduced considerably as extensive preparation of the material can be performed prior to the truck's arrival. This enables queues to be reduced and, as so, trucks reaching customers quicker. The reduced overall utilization of the truck as well as the occupancy at the production and construction sites may lead to lower costs for transportation as additional deliveries during a working day may be enabled for each truck. This is in line with the method of reducing or removing bottlenecks, as suggested by Jonsson and Mattsson (2009), where a constraint has been identified and elevated. Reducing the queues lead to a reduction of the waste waiting, as defined by Hines and Rich (1997).

The limited flexibility imposed on trucks and their operators, in this particular context, regarding working hours and total daily operational time may reduce the positive effects of short loading and unloading times enabled by the load carrier. Implying that, when taking all effects into account, at the end of the day less material will have been moved given the same effort from Celsa and the transporter.

The conditions, in which the load carrier was delivered and used, enabled JM to limit its storage of rebar. Furthermore, the load carrier enabled relatively easy and swift moving in case of the storage area intervening with other activities. This ability addresses one of the main issues discussed by Azambuja and O'Brien (2008) of the construction sector holding excess inventory. This finding is also in line with Hines and Rich (1997), in terms of waste reduction.

7.1.3 Actors

The load carrier implementation in current operations requires extensive activity coordination and increasing access to external resources among actors. In line with Gadde (2004), this would require relationships between the actors to become stronger and closer. Increasing collaboration between Celsa and JM facilitates further improvements of activities as, according to Gadde (2004), closer relationships enables conflicts to be constructive and developing. Through shared visions, additional pressure is being put on existing relationships, information sharing and communication, in order to achieve improvements. The analysis shows that some issues need to be addressed and designed to better fit with the load carrier. This sections aims to bring light on some of these issues.

According to Shannon and Weaver (1949) and Titus and Bröchner (2005), communication is less likely to be susceptible to misinformation if it occurs through established mediums and procedures. The current state of operation has an established communication and information process through which customers place orders and communicate with Celsa. These are mainly Celsa's sales technicians and BIM-engineers and in some extent the QR-system. The currently unstandardized procedure for the load carrier may have put strain on the communication routine, in terms of standardization as well as differing anticipated outcomes, respectively. An aspect which may be attributable, in line with Titus and Bröchner (2005), is that the construction sector tends to be cautious of implementing new technology. With the amount of actors involved in a construction supply chain and the unique context of each project, it may be beneficial for a construction company to have simplified and efficient way of dealing with dispersed information (ibid.). A common platform for information sharing could contribute to this and would be beneficial for the customers.

In the pilot study, orders were placed by email to Celsa with specifications of CAB. These specifications were designed by an external actor, which contributed to extra work which the BIM-engineer had to perform for the CAB to fit the load carrier. In the case studies, the BIM-engineer spent significant time preparing the CAB to fit the load carrier and to design a load scheme. This time may be reduced if the BIM-engineer performs the specification of CAB to fit the load carrier initially, as it would create a more efficient process. However, it may at the same time be beneficial for the customer to contract an external actor to deliver all specifications of reinforcing bars throughout the whole project, as was the case in the pilot study. In case of a load carrier implementation, a way of dealing with this needs to be agreed upon between Celsa and the customer early on to mitigate redundant work.

A start-up meeting, involving Celsa and its customer, is held before each project is about to start. The purpose of the meeting is to set a delivery plan and decide on what services that should be performed. However, start-up meetings are occasionally not held, or held in an insufficient manner, meaning that terms of the project are not necessarily clear for all involved parties. As Titus and Bröchner (2005) argue, information sharing should be used in a standardized and precise way, to mitigate miscommunication.

During the two studies of the implemented load carrier, the BIM-engineer managed to streamline the process significantly, reducing administrative work as well as provide useful instructions to the overhead crane operator. These findings support the principle of Lopez et al. (2006) and provide an indication that the process can be streamlined further. Since the same BIM-engineer performed the specification of CAB and preparation of the load carrier enabled the knowledge to be gained and used, however, the physical loading of the carrier did not have any advantage of the knowledge from the first study.

Ravi and Shankar (2004) state that there is often a lack of vision or purpose with a reverse logistics implementation, as required by the load carrier. As for this particular context, the underlying purpose is perceived as well-defined. In accordance with Ravi and Shankar's (2004) main criterion regarding successful logistics implementations, enablers within the organizations do believe in the proposed solution, which may serve as an important role in the project's future success.

The resistance to change observed within the supply chain is as expected (Ravi and Shankar, 2004). It is necessary to deduce the constructive aspects given by these knowledgeable actors even though they may be negative to the concept. The current state of operation rewards the transporter through a fixed price per truck and day, which in turn may be in conflict with the concept of a load carrier. The case study of the implemented load carrier shows a reduction of transport time and, as such, it is necessary to devise measurements which truly reflect performance within the scope of a load carrier. Doing so may spur change among the supply chain actors.

7.1.4 Summary and comparison of effects in case study

When evaluating the impact of a particular implementation, it is important to assess the different criteria given by the supply chain and its respective actors' context. A particular actor may value one type of performance differently than another. By anticipating these, and creating a load carrier solution which caters to as many needs and criteria as possible, the chance of creating a high performance supply chain increases. This is captured by the packaging scorecard developed by Olsmats and Dominic (2003), where performance is evaluated from 0 to 4 (0 not applicable, 1 not approved, 2 approved, 3 well approved and 4 met excellently).

Table 8, Table 9 and Table 10 present summaries of the perceived performance of the load carrier in the pilot study in comparison to the current state. The criteria for each actor were chosen to reflect their underlying performance criteria. It should be noted that different actors may have entirely different criteria. The estimated performance measures were derived from the empirical findings as well as relevant literature frameworks, such as Pålsson et al. (2012) and Rosenau et al. (1996). It should be noted that the weighted importance are estimated in a more conceptually manner and should be revised, foremost in regards to monetary aspects that were not accessible nor known during the thesis. A full conceptual methodology of the evaluation is shown in Appendix D - Packaging scorecard.

Table 8 - Packaging scorecard for Celsa. 'Importance' has not been assessed, and is therefore estimated without semi-quantitative figures. As so 'relative importance' has not been calculated. 'Performance' is semi-quantitatively evaluated.

Criteria	Importance [0-10]	Relative importance [%]	Performance current state [0-4]	Performance pilot study [0-4]
Information	Medium		1	3
Volume efficiency	Medium		4	2
Weight efficiency	Medium		4	3
Correct size	Low		3	2
Packaging cost	Low		4	0
Handeability	High		2	2
Dwell time	Low		1	4
Ergonomics	High		3	2
Sum		**100%**		

Table 9 - Packaging scorecard for transporter. 'Importance' has not been assessed, and is therefore estimated without semi-quantitative figures. As so 'relative importance' has not been calculated. 'Performance' is semi-qualitatively evaluated.

Criteria	Importance [0-10]	Relative importance [%]	Performance current state [0-4]	Performance pilot study [0-4]
Volume efficiency	High		4	2
Weight efficiency	Medium		4	3
Handeability	Medium		2	3
Dwell time	Low		2	4
Sum		**100%**		

Table 10 - Packaging scorecard for JM. 'Importance' has not been assessed, and is therefore estimated without semi-quantitative figures. As so 'relative importance' has not been calculated. 'Performance' is semi-qualitatively evaluated.

Criteria	Importance [0-10]	Relative importance [%]	Performance current state [0-4]	Performance pilot study [0-4]
Information	High		1	3
Correct size	Medium		3	1
Handeability	High		1	4
Dwell time	High		2	4
Occupied storage area	Medium			
Ergonomics	High		1	3
Sum		**100%**		

It is important to point out that not all effects should be assessed equally. As mentioned, according to the site manager at JM, Zavichi et al. (2014) and Shapira et al. (2007), the construction crane is a critical resource, which implies that a decrease of construction crane occupancy is an important aspect. Therefore, it could be perceived as an effect that motivates a negative effect on other aspects. Decreased occupancy of resources, such as the construction crane and overhead crane, is enabled through increased handleability of the carrier compared to the current state. Increasing handleability also results in decreasing dwell times, which is perceived as highly desirable. However, due to the payment structure of the truck services, it was found that there were few incentives neither for the truck company to reduce dwell time nor for Celsa to reduce its queues at the production site. As the handleability enables several other aspects to be improved, this is perceived to be of high importance both at Celsa and JM.

With a load carrier implementation, the material is handled in a more structured manner, which facilitates information sharing between actors. The majority of negative effects are realized in Celsa's operations and, conversely, the majority of the positive effects are realized at the construction site.

Correct size, receiving an appropriate amount of material relative to its intended purpose and consumption may be seen as an important factor. By delivering rebar in bundles, the size of the package can be made near optimal. Conversely, the large load carrier is only suitable in orders nearing multiples of 3-4 metric tons. The current weighting is subject to change, if the supply chain context was to change. In case of a just-in-time implementation, employing the correct size of packaging is likely highly important for every actor.

7.2 Future state

The future scenario is derived from literature and the comparison of the two scenarios in order to present a viable and high performing solution for the supply chain involving a load carrier. Critical aspects and effects identified in the comparison are targeted when suggesting a solution for implementing a load carrier in the supply chain.

7.2.1 Assessing the supply chain's performance

It is difficult to reliably assess a supply chain's performance given limited data collection. This chapter provides tools and frameworks to assess a supply chain's performance. With this as basis, a future state of operations is suggested and motivated.

The majority of the perceived negative effects of the load carrier implementation were realized among Celsa's activities. As so, these are the main focus of the future state. Additionally, the flow at the construction site is also developed to enhance the performance in comparison to the pilot study. The suggestions on future specifications of the load carrier are mainly based on the evaluation adopted from Pålsson et al. (2012) and Rosenau et al. (1996). The information and coordination process between Celsa and its customer is analyzed and developed in line to improve supply chain performance (Chopra and Meindl, 2013; Kumar and Pugazhendhi, 2012).

The effects and respective costs of a load carrier implementation may be assessed further using frameworks developed by Rosenau et al. (1996), Pålsson et al. (2012) and Olsmats and Dominic (2003). However, when considering an entire supply chain, a more holistic perspective is required, as achieved by Langbeck et al. (2012). This framework utilizes relevant factors, as presented in the literature review.

The future state intends to increase the value flow in the supply by simplifying the flow of material and information. The aim is to create a more smooth flow by enabling a wider pull-system. This is achieved, according to Langbeck et al. (2012), through twelve performance measures that assess the supply chain's current and future performance. Not all measures are deemed as applicable or relevant for this material flow. Langbeck et al. (2012) emphasize the importance of three performance measures, namely, *time in warehousing*, *number of warehousing nodes* and *number of activities*. Some of the positive effects of the load carrier implementation are:

- Reduced usage of construction crane

- Reduced construction worker man-time
- Reduced dwell time of truck
- Reduced material handling at JM

Some examples of negative effects from the load carrier implementation are:

- Increased overhead crane usage
- Increased operator man-time
- Increased number of activities
- Increased number of warehousing nodes.

In order to explore the positive effects in the pilot project to a greater extent and mitigate the negative effects, the three presented measurements serve this purpose. These three measures are applied to suggest a future state map. It is, at the same time, important to understand that an increase in number of activities may not be regarded as entirely negative, as an additional activity may reduce time or complexity in other activities. Therefore, the future state aims particularly at reduce resource occupancy.

7.2.2 Future state material flow mapping

In line with the MFM-methodology, a future state map is derived from the pilot project. The future state is achieved by analyzing and improving the current state and pilot project based on a number of aspects in line with Langbeck et al. (2012).

The supply chain in the current state and pilot study is characterized by a pull-flow as the customer initiate the production of reinforcing bars at the supplier's facility. However, the material flow, from production until consumption, is characterized as push-flow. During the case study, JM placed orders weekly. More smooth flow of reinforcing bars between Celsa and JM is hindered by, among other reasons, lack of sequence planning of the construction process at JM. This means that the precise sequence, in which rebar is installed is not decided in advance. Formoso and Isatto (2008) state that production planning in the construction sector is ineffective due to several reasons. Examples of these reasons are that uncertainty is not handled properly in order to mitigate risk and that construction managers do not systematically collect data to assist the decision making process. Thus, JM would likely benefit from a more effective planning process in order to sequence its operations, enabling a smoother flow of material. The geographical distance between the supplier and customer further complicates more frequent delivery due to cost and environmental reasons.

Major constraints in the current state and pilot project were perceived to be the warehousing space, both at the production site and construction site. In the storage location of finished goods at the production site, the limited space created disorder, meaning that operators had to spend time searching for intended material for certain orders. The desired future supply chain of reinforcing bars is designed as seen in Figure 29. In the future state map, cycle times are assumed to be the same as in the pilot study for activities which are not affected by the suggested changes. Instead, the main difference between the future state and pilot state consists of activities being altered or discarded due to design differences of the supply chain. A comparison of the altered activity distribution between the different states is shown in Figure 30. As seen in the figure, the total activity time is lower in the future state compared to current and pilot state. This is mainly achieved by the future state combining the benefits of the load carrier implementation in the pilot state, such as reduced loading time, and the ability to directly fill the load carrier from the production facility. The activity time at JM is reduced due to the removal of redundant lifts, enabled direct lifts to the floor level.

The future state intends to reduce wastes in order to create a more efficient material flow. Due to the load carrier implementation, there are primarily five out of the seven wastes derived from lean, mentioned by Hines and Rich (1997) that are possible to reduce. These are:

- Transportation
- Unnecessary inventory
- Waiting
- Excess motion
- Defects

The wastes of transportation and unnecessary inventory are likely reduced as a result of the changed structure of activities. Having the load carrier filled directly from the production facility would free up warehousing space at the production site while reducing the number of handling activities. The reinforcing bars are, as in the pilot project, scanned when they are loaded onto the load carrier. The difference is that, in the future state, rebars are scanned at an earlier stage in the flow, meaning that information of missing pieces will be announced at an earlier time, in line with Ravi and Shankar (2004). This increases the possibility to complete the order prior delivery, reducing defect rates.

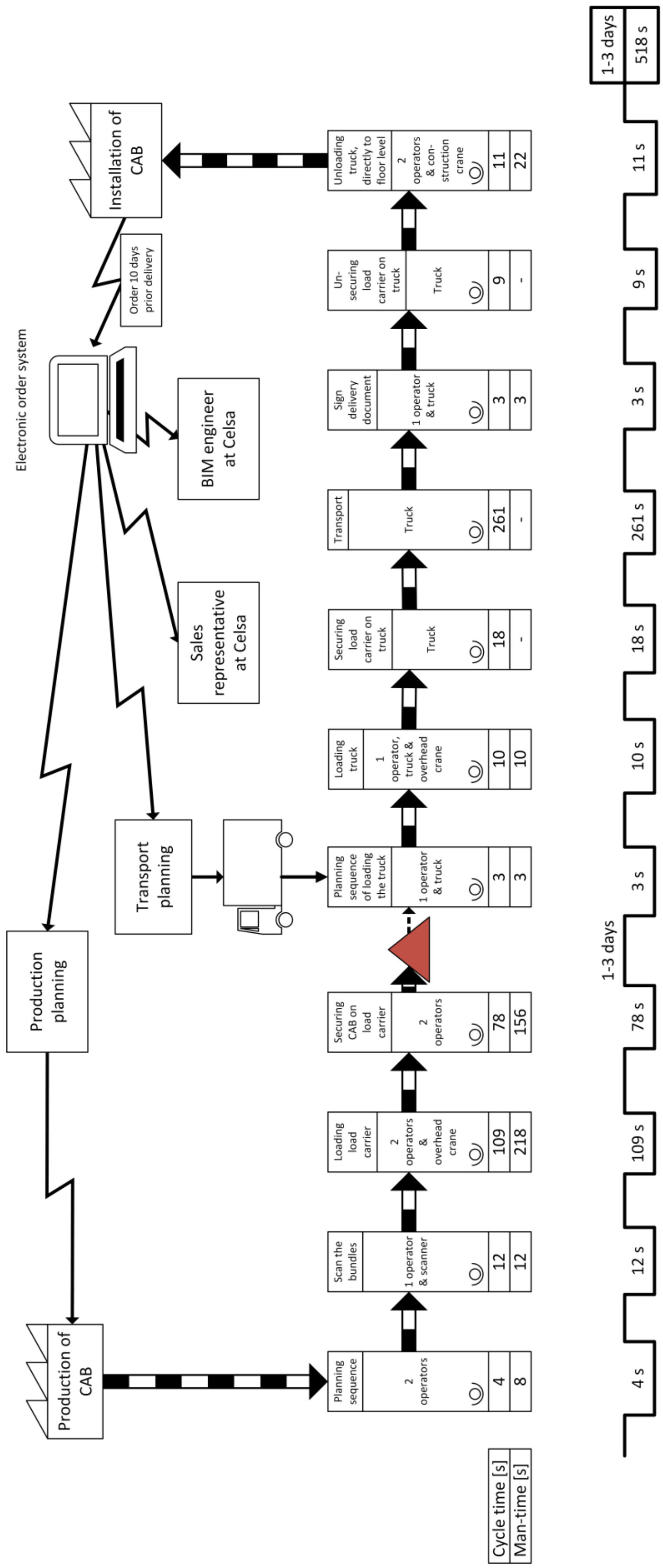

Figure 29 - Estimated material flow mapping of future supply chain

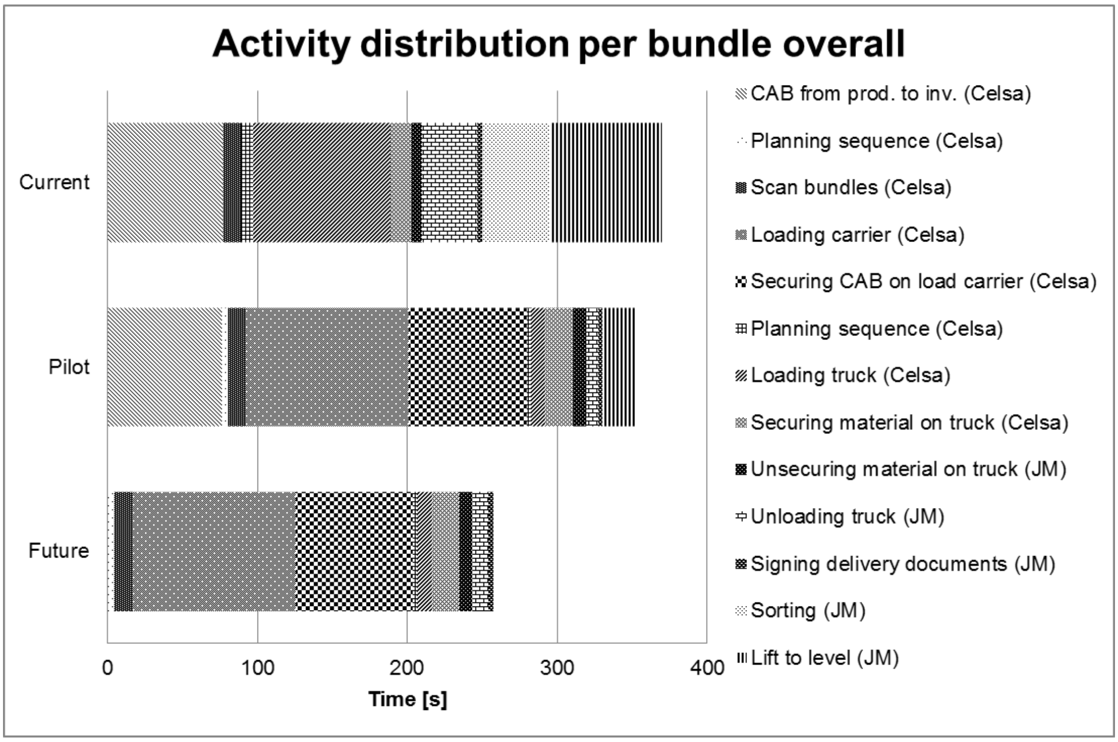

Figure 30 - Activity distribution per bundle comparison. The figure illustrates the activity distribution regarding the three analyzed states. The red line denotes the separation of activities between Celsa and JM.

Activities such as *loading truck* or move *rebar from production to inventory* are critical in order to free up space for other trucks or goods, respectively. Thus, filling the load carrier directly from the conveyor must, in regards to the current production layout, be done immediately as the finished rebar is delivered to the warehouse. The work intensity for Celsa's operators was found to be unevenly distributed throughout the day and securing the load carrier may, unlike previous mentioned critical activities, be done during periods with fewer operational tasks. Increasing the possibility of performing activities in-between other activities provides the potential to reduce the waste of waiting.

As seen in Figure 31, comparing the current state and the pilot project, a significant difference regarding occupancy of operators at Celsa may be seen. This is partly explained as the loading activity involved two operators during the pilot project while only one operator was involved during the current state. Employing two operators during the loading process may not be necessary and the activity may therefore be rationalized by reducing the number of operators.

With its current design, the load carrier is most easily loaded from the bottom to the top, meaning that bent rebar should be loaded prior to straight rebar, in order to avoid heavy and unergonomic lifts. This is not in line with the current production procedure as the straight rebar is often produced prior to bent rebar, according to input from operators at Celsa. As reinforcing bars would be loaded directly from the conveyor in the future state, it may require more extensive production planning to achieve a suitable material loading sequence, unless production design is changed.

A significant potential future improvement of the material flow at JM lies within the possibility of lifting the load carrier directly to the intended location of installation. Lifting the load carrier directly to the intended location does not reduce warehousing per se, but it reduces the number of activities and the occupation of resources, as fewer lifts are required. The latter can be seen in Figure 31. A JIT concept in the supply chain, according to Swanson and Lankford (1998), requires changes in the relationships between actors, company-wide commitment, and high quality of products amongst other. In order to increase the overall supply chain performance through a JIT concept, it would thus require a stronger and tighter relationship between Celsa and its customers, in line with Gadde (2004). As the close cooperation between Celsa and JM intensifies, it will most likely amplify the characteristics of the relationship atmosphere among the actors towards a relationship based on shared visions and normative control, in comparison to the current arm's length relationship. This enables constructive use of conflicts and power as means of further development and improvement of interdependent operations, as in line with Gadde (2004).

Strategies such as JIT have to be beneficial for all involved parties, from the production at Celsa to the installation at JM. Construction workers at JM display a restrictive attitude towards just-in-time deliveries, arguing that receiving orders a day earlier reduces the risk of material deficit. This is in line with Titus and Bröchner (2005), who explain the hesitant attitude in the construction sector towards new technologies and concepts as a barrier for efficiency improvements.

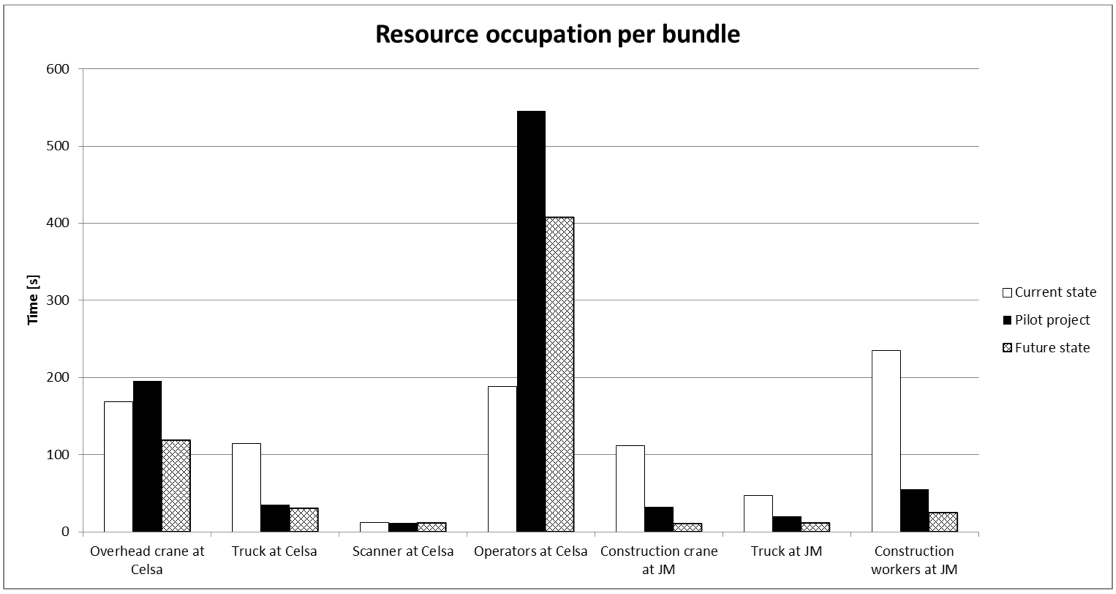

Figure 31 - Comparison of resource occupation, displayed per bundle and arranged by resource.

7.2.3 Information and coordination

The information and communication in the order process in the pilot study was mapped in order to assess its performance and suitability for a load carrier implementation. The suggested information and communication process for a future state involving the load carrier is presented in Figure 32.

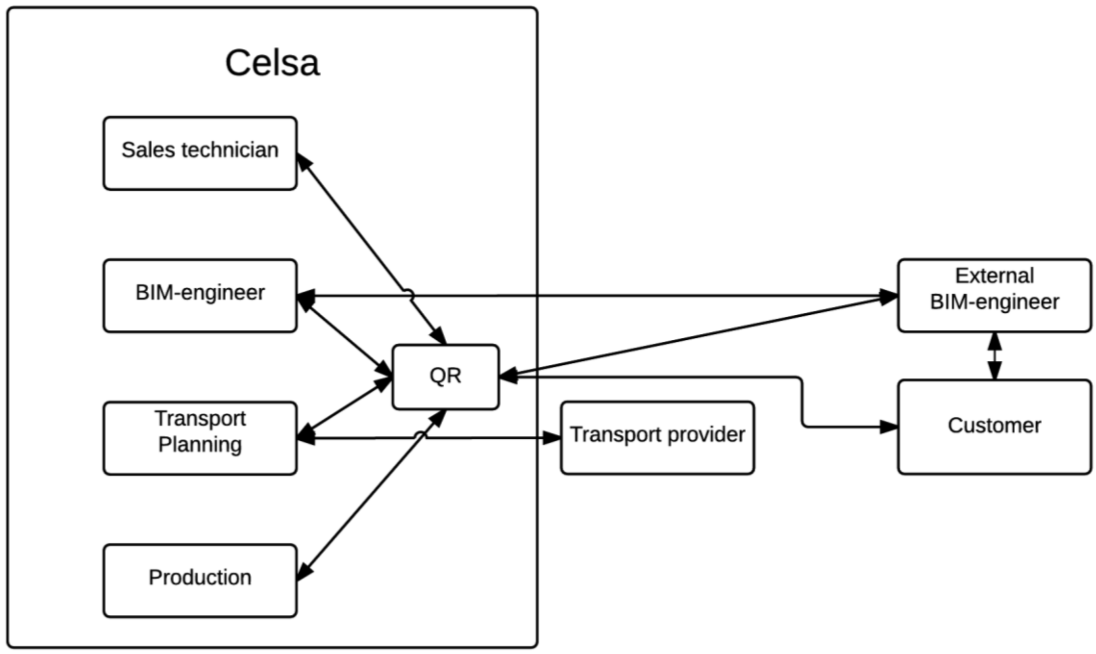

Figure 32 - Conceptual information flow in future state of operations.

An aspect that was identified as a drawback in the information flow process was the amount of middlemen which information passed through before reaching its intended receiver. As Shannon and Weaver (1949) state, communication should occur through established mediums, in a standardized way and with as few middlemen as possible. Thus, the aim was to reduce the amount of middlemen in the information flow.

The customer may use an external actor to perform the CAB specification, as it may benefit within other areas of operation by doing so. However, if an external actor is to be contracted by the customer it should communicate with the BIM-engineer at Celsa, to enable the specification to be designed to fit the load carrier. This would reduce the redundant work the BIM-engineer at Celsa had to perform in the pilot study. Further, if the load carrier is to be implemented, standards should be set up regarding how to design CAB to fit the load carrier. This would enable the external BIM-engineer to design CAB accordingly, without communicating as closely with technicians at Celsa. This change is in line with Shannon and Weaver (1949), as a middleman is eliminated in the communication process. In addition, according to Chopra and Meindl (2013), strategies and goals should be aligned in the supply chain to maximize supply chain surplus.

QR, the online platform for Celsa and its customers, may have potential to be developed further. Today it is used to register projects and specify services and orders, which can be assessed by all involved actors. In the future state, it is regarded as a tool where orders are placed by the customer, which all units and individuals at Celsa can access. This will simplify the process for the customer, thus reduce its communication mediums. As Titus and Bröchner (2005) state, in a construction supply chain with many involved actors, actions should be taken to simplify the information and communication process. In line with O'Brien and Hammer (2001), QR would serve as a common platform that stores and distributes information to the involved actors. It would improve the transparency in the supply chain and enhance the level of coordination. QR would eliminate the communication channels between the sales technician and transport planning and the communication channels between the BIM-engineer and production, as the information would be distributed in real time through QR.

If QR is developed to be used as a common platform in the communication process, it would simplify the planning process of reverse logistics. It could provide information to transport planning that orders are to be delivered with the aid of load carriers as well as when the load carriers inventory is planned to be depleted. Thus, planning of reverse logistics can take place simultaneously with the forward logistic planning process, in conjunction with the transport provider, mitigating or reducing additional communication processes.

The start-up meeting of each project is an opportunity for Celsa to explain, or in some sense market, the services it is offering while at the same time establish relationships with involved managers for the specific project. With an implementation of a load carrier, the construction company may be informed about this service and how they would benefit from it. As so, accurate information about the service and benefits for the customer's operations should be communicated, as in line with van Weele (2010) and Ellram (1995). If the customer would decide to make use of the load carrier, the protocol from this meeting should state terms of the service and how CAB should be delivered with the aid of the carrier. If this is decided upon at an early stage, it would simplify the usage of the load carrier throughout the project. Furthermore, the protocol would also serve as guidelines for the construction company how the communication with Celsa is to be handled. Hence, the start-up meetings should be given a higher priority and always be held and documented to capture these effects, in line with Azambuja and O'Brien (2008).

At the start-up meeting, Celsa would explain its service and communicate the benefits for the customer. Thus, it is important for Celsa to be able to communicate the real cost of purchase for the customer (Gadde et al., 2010; Ellram, 1995). The load carrier service will be of higher direct cost for the customer, but indirect costs will likely decrease, as the benefits are captured. As Gadde et al. (2010) state, indirect costs are often higher than the direct costs and therefore a relevant target for cost reduction efforts.

It would likely be highly beneficial to further develop learning and communication routines within Celsa's organization prior to implementing a load carrier. A plan how to acquire, distribute, interpret and keep the knowledge in the organization effectively is recommended, as in line with Lopez et al. (2006). The knowledge of performing tasks could be distributed through regularly held meetings in the production. In addition, the knowledge should be stored in memory by setting up routines or standards concerning the load carrier.

The management of Celsa and the customer are positive to the implementation of a load carrier. Top commitment needs to be strong when implementing logistic processes according to Ravi and Shankar (2004). In addition, it is crucial that it is communicated throughout the organization to strive towards a goal, in this case a successful implementation and to change the value offering. If the decision of a larger load carrier implementation is made, it should be done continuously and with significant effort. It is necessary to retain this higher commitment during the entire change and implementation process.

7.2.4 Load carrier

Control

To increase the possibility of successfully implementing a load carrier, a reverse logistics system should be designed with high visibility in mind, in accordance with Ravi and Shankar (2004) and Johansson and Hellström (2010). This includes a clear responsibility structure for tracking, administering, maintaining and storing load carriers. As so, it is deemed as important to fully assess the administrative work impact of transport planning and production planning prior to a larger scale implementation to mitigate the risk of failed deliveries as well as misplaced carriers.

The ownership of the load carriers is an aspect that needs to be considered. In the construction industry, it is common that an external actor owns the equipment while the construction company rents equipment for each specific project (Storhagen and Lindqvist, 1998). This is designed to enhance the flexibility for the construction company while reducing the tied up capital in expensive equipment. This strategy, defined as *system without return logistics* by Kroon and Vrijens (1995), is applicable for the load carrier if Celsa prefers to reduce required investment and thus rent the load carrier to a variable cost from a central agency. Celsa would in this case be in control of the entire logistic process, such as transportation, administration and storage. This strategy enhances the flexibility, reduces load carrier in storage, reduces investment and simplifies the process of production and logistic planning. Alternatives to the mentioned strategy are that Celsa invests in load carriers or outsources parts or the whole logistic process, as mentioned by Kroon and Vrijens (1995). As Celsa already has a functioning logistic system, the findings suggest a system without return logistic or that Celsa accomplish the investment after careful cost analysis.

As discussed by Hellström and Johansson (2010), it is necessary to have an effective tracking system to ensure visibility throughout the logistics system. It is deemed as appropriate to integrate the load carrier into the current bar-code system to avoid additional expenses. However, due to the lack of routine procedures anticipated at the differing customers, a more manual approach is suggested for follow-up and tracking at the customer's construction site. This may be achieved through routine communication between the customer and the responsible actors within Celsa. As mentioned earlier, it would be preferred if communication could occur through a common communication platform, such as QR.

A large-scale implementation of load carriers would require an increase in resources and activities in terms of administration. A crucial aspect of a reverse logistics process is to monitor and control the return flow. There is a need to have a minimum of load carriers at the production site awaiting delivery as well as have enough of load carriers to be able to have them present at the construction sites during the customers operations. The load carriers requires an effective system be able to track and plan the forward and return logistic of carriers, as in line with Ravi and Shankar (2004) and Johansson and Hellström (2010). QR may be developed to serve as a tool in such a system.

Dwell-time reduction

Celsa currently pays a fixed amount to the transport provider for a truck with driver an entire day, which means the reduction in truck occupation will not manifest itself in reduced transport billing. As so, it may be beneficial to employ a more flexible payment structure, such as payment per hour or similar.

The total truck time was reduced due to reduced dwell time at the sites respectively. Therefore it is important to analyze the total dwell during a working day to understand potential improvements. The total dwell time is affected by the number of deliveries which in turn is affected by the distance between supplier and customer.

Load carrier compatibility

An effective load carrier solution appears to be beneficial for the transporter, in terms of dwell time and occupied resources during loading and unloading processes. The major challenge faced by the transport provider is its constraints regarding volume and weight. A load carrier occupies weight as well as volume. In order to reduce the negative effects that the load carrier has on the occupation of truck volume, the possibility to stack load carriers is deemed as appropriate to evaluate. The load carrier should further be designed to fit as well as possible with each interface within the supply chain. As different actors have access to different resources as well as facing different constraints, an adaptability or ideal middle way should be established.

In line with Gadde et al. (2010), improvements of the load carrier can be achieved in regards to its physical configuration in order to increase compatibility in the supply chain. Loading and securing the load carrier were the activities that were found to be most time consuming. During the pilot project, securing the load carrier was done ad hoc. The activity of lashing the load carrier would instead benefit from increasing the standardization of the procedure. Further, the drivers expressed concern regarding securing steel on steel, as it does not create enough friction. This could be improved by applying an outer layer material, such as rubber or wood. The loading activity could be improved in regards to ergonomics and time consumption by allowing the shelves to be foldable. In general, a better ability to modularize the load carrier could mitigate the risk of a mismatch in a load carrier implementation, discussed by Twede and Clarke (2004), and better suit the characteristics of a construction supply chain. Modularization could create the opportunity to achieve better compatibility in different environments, towards different customers and in regards to characteristics of different orders.

During the pilot project, trucks with cranes were used to transport the load carrier. As the crane cannot be used to lift the loaded load carrier, it would be beneficial to use trucks without crane in order for the load carrier to better comply with the trucks characteristics and to increase the utilization of resources. Furthermore, a load carrier carrying long rebar may occupy space on the truck which hinders the entire truck bed to be utilized. As so, it may be suitable to adapt the load carrier or the used truck beds to fit geometrically.

The benefits of reduced number of repetitions due to the implementation of the load carrier were to some extent diminished by the fact that not all material could be fitted onto the load carrier. The size of orders varies significantly and increasing the size of the load carrier would likely increase the probability to fit an order entirely. This would, however, create a trade-off between capacity, fill rate and flexibility.

8 Discussion

This chapter addresses and discusses concerns regarding the method, findings and validity of the report as well as the fulfillment of the earlier stated research questions. To be able to structurally discuss the thesis' aim to reach its purpose, it is discussed through the dimensions activities, resources and actors. This enables the method, findings and validity to be included in the discussion. The discussion concludes with a section discussing the future state map and how it may be implemented, as well as how Celsa can fit its overall operations to better suit a load carrier implementation.

Discussion regarding following research questions is presented below:

- *How can the performance of the supply chain be assessed?*
- *How may a future state supply chain, including the load carrier, be designed?*

As commonly stated, evaluating an overall supply chain's performance may be a difficult task. The activity performance within Celsa will likely change, as routines of operation set in, making the measured times in the findings less representative. The conclusions from the study regarding supply chain performance are not entirely clear. The findings show that perceived effects of the carrier are in line with the intended purpose of Celsa's interest. However, it requires several changes in the supply chain and related processes at Celsa in order to be effectively implemented. Once such changes are in place it will be possible to fully assess the performance of the supply chain.

Changes in Celsa's current operations are likely required to fit the load carrier effectively. The future state map presents how a future supply chain may be designed. In the suggested future state, CAB would be loaded on the load carrier directly as it is transported from the production area to the storage area, thus eliminating an inventory node. It is important to question the procedure of bundling CAB when produced, even though it is convenient in the current state of operations. An alternative procedure may be to place the load carrier within the production area and load CAB directly onto the load carrier. This would likely require additional work for the operators, as the load carrier would have to be moved between machines within the production area several times. On the other hand, it would likely reduce transport within the finished goods storage. Thus, it would reduce the occupation of the overhead crane. In the finished goods storage area, the load carrier could be secured during periods of low work-intensity. The overhead crane usage would be reduced to only lifting the load carrier onto the truck.

To achieve an efficient flow of material, one-piece flow may be the target. However, it is deemed as difficult to deliver CAB piece-by-piece to the construction site. The load carrier implementation will likely enable a more efficient flow, albeit not as smooth in terms of inventory, given that construction operations can be planned to a greater extent. As for now, the customer only knows which day it intends to install CAB. If planning can be done at a higher resolution such as which sequence and time it should be installed, a better pull flow may be achieved. For example, if the customer knows the installation sequence, the load carrier can be loaded accordingly. Knowing this is, according to Langbeck et al. (2012), crucial in order to understand the underlying customer demand. By understanding the true customer demand, the possibility of implementing a smooth value flow increases. In current state, the customer only knows that it will install the lower layer prior to the upper layer and load carrier can only be loaded with respect to this.

Another aspect, enabled by more accurate planning at the construction site, is to accomplish deliveries made just-in-time. The load carrier could be loaded and prepared for transportation at Celsa and delivered to the construction site once material is needed. If the planning is accurate, the load carrier would be unloaded from the truck and lifted up to the floor level where it is to be installed. This would enable construction workers to access material more effectively and reduce the occupation of the construction crane. In the current state, all bundles are not lifted to the floor level simultaneously, as it would occupy a larger area as well as require extra sorting and handling. The load carrier occupies a smaller area at the intended location, the material is easier to access and no sorting is required, thus enabling the JIT concept. Summarily, the load carrier could be delivered JIT, loaded in sequence for installation in a pull-based flow.

8.1 Activities

The following chapter is a discussion regarding the activity-related research questions. These research questions were expressed as following:

- *How will the configuration of activities change between the actors throughout the supply chain with a load carrier implementation?*
- *How are individual activities altered by the implementation of a load carrier?*

As mentioned, the case study only provides a "snap-shot" of the supply chain. The investigated orders were also of different size, 17 bundles in current state in comparison to 23 bundles in the pilot study, which affected the result in terms of resource occupancy per bundle and cycle time. Because the orders differ in size, some of the activities, which are volume independent, are affected in a non-representative way. For example, planning sequence for loading of the truck and signing of delivery documents are such activities. However, these activities represent only a fraction of the total time.

As the load carrier was implemented in current operations without adjustments, the inexperience and ad hoc approach likely affected performance. The findings suggest that organizational learning took place in the technical preparation of the order, as in line with Lopez et al. (2006). This organizational learning will naturally continue if the load carrier is further evaluated and, thus, the findings should not be seen as a static. It should rather serve as a guideline of how configuration of activities changed and how single activities were altered between actors. The findings also suggest that Celsa may need to revise its methods of distributing information throughout the organization, as in line with Lopez et al. (2006). The attitude towards the load carrier may have affected the result, as some individuals in the chain possess a strong negative attitude towards the carrier. Therefore it is of great importance to communicate the effects of the load carrier, both externally and internally, in order for all involved actors to understand the purpose. Celsa will likely benefit by more clearly communicating the purpose and potential of the implementation.

In the pilot study, more activities are added to the operations at Celsa while the number of activities at the customer's site is reduced. However, time of critical activities, such as loading the truck at Celsa, unloading the truck at the customer and lift to floor level for installation at the customer, were significantly reduced. It is also important to understand that an increase of number of activities at one actor is not necessarily negative through an overall supply chain perspective, as it may reduce activities at other actors. Hence, the findings suggest that the extra sorting and handling of material taking place at Celsa in the pilot study, reduces the time per bundle at the customer with more than 65 per cent by reducing or eliminating activities downstream in the supply chain. As so, the load carrier serves its purpose in terms of differentiation, in line with Rothenberg (2007). A concluding remark is that a supply chain reconfiguration by implementing a new load carrier has diverse effects on various parts in the supply chain and on different actors. These effects can be intentional in order to provide some value for the customer, as was the case in this study. However, there were also unintentional effects that need to be handled in the supply chain by the involved actors.

8.2 Resources

The following chapter is a discussion regarding resource-related research questions. These research questions were expressed as following:

- *How are resources affected when implementing a load carrier?*
- *What are the suggested recommendations and specifications regarding a load carrier in the supply chain?*

Existing resources are affected in terms of time usage and requirements. For example, trucks with built-in cranes cannot be used when implementing the load carrier, as it is too heavy. The findings suggest that it would be beneficial to use trucks with better fit with the load carrier, such as larger beds and/or without cranes, to better utilize the space on the truck. This would make the unloading activity more efficient as all load carriers, independently of delivery sequence, could be reachable without rearrangement of material on the truck's bed. This is in line with Gadde et al. (2010); resources should fit together in order to maximize resource utilization. The load carrier appears to fit effectively at the construction site, given that the project is in the phase of building floor levels. At this point in time, there is always a sufficient crane available.

The major change in terms of resources is the reduced occupancy of the construction crane, identified as a bottleneck resource. Another aspect is the faster loading and unloading of the truck, which reduces time that the truck is occupied, as such the analysis suggests that Celsa may need to reevaluate its contract terms with the transport provider in order to capture the positive effects of the load carrier. As for now, the transport provider is rewarded by a fixed amount per truck per day. By changing this, Celsa may face a lower cost for transportation.

The load carrier may be designed differently, to better fit and interrelate with other resources. The findings identified some improvements of a future load carrier, including better securing possibilities and better methods to fit intricate CAB. The load carrier could benefit from being modularized, as orders differ in size and distribution of bent and straight rebars. These findings are in line with Twede and Clarke (2004), as modularization would likely provide higher adaptability.

8.3 Actors

The following chapter is a discussion regarding actor-related research questions. These research questions were expressed as following:

- *How will the implementation of a load carrier in the material flow affect existing relationships in the supply chain?*
- *How will the control of the supply chain change?*
- *How may the ownership and access to the load carrier be structured within the supply chain?*

The findings point out the importance of changes in relationships between Celsa and its customers. The current communication procedure is not sufficiently effective for a load carrier implementation and would benefit of being revised, in order to efficiently implement a load carrier in current operations. As so, it may be argued for a simplified communication process through a common platform, eliminating middlemen. This may reduce the risk of miscommunication. Sharing information throughout the supply chain is likely to be highly beneficial in an implementation of a load carrier, as implementing it would require more coordination, planning and communication. Enabling a higher level of coordination is critical according to O'Brien and Hammer (2001).

The findings suggest that every supply chain actor's strategy should be aligned, in order to maximize possible supply chain surplus, as argued by Chopra and Meindl (2013). For example the amount of redundant work, done by Celsa's BIM-engineer, could be mitigated. It is deemed as important for the customers to revise their methods concerning CAB-specification, to ensure a beneficial tradeoff regarding load carrier efficiency and other benefits within their respective organizations. As so, the specification of CAB may be performed by Celsa's BIM-engineer or by an external actor who receives information how to specify CAB in accordance with the load carrier's requirements. If Celsa designs a standard of how to design CAB for the load carrier, it would be beneficial for all parties. In addition, as mentioned, company-wide commitment and understanding of the purpose are critical aspects when implementing new logistic solutions, as in line with Ravi and Shankar (2004). The negative attitude towards the load carrier, found during the case study at Celsa and the transport provider, would preferably be addressed through communication of the purpose and could also be reduced by adapting activities and resources into better fit with the new load carrier solution. The construction workers are more positive towards the concept, as it simplifies their operations.

Celsa is today offering services in form of color tagging and color unloading of CAB. An implementation of the load carrier would further develop this service strategy. The findings show that some important subjects need to be addressed when implementing a load carrier. The business model should be revised to fit the new value offering and contractual agreement should be designed to capture the service. Finally, the new business model should be communicated both internally and externally to Celsa's customers. With changes in Celsa's service offering, the start-up meeting may serve as an important foundation. Accurate information about the service and benefits for the customer should be provided by Celsa. It is important that the customer understands the value in terms of for example cost savings of the new solution. It is assumed that the start-up meeting for a new project may serve as an important tool to enable sharing of this information. As for now, start-up meetings are not always held or held in an insufficient way. Celsa may put more emphasis in these start-up meetings to, in some sense, market its services and show the benefits which the customer may experience. In addition, the communication and information sharing procedure may be discussed during this meeting.

In the pilot study, the load carrier was implemented in the current state of operations with no major changes to the specification process of rebar, control of the supply chain or responsibility in the supply chain. If the concept is to be developed further, a system defined as *system without return logistic*, in accordance with Kroon and Vrijens (1995), is recommended as a future ownership and responsibility structure. The system enables flexibility while reducing initial investment for Celsa, and suits well in the current operations since Celsa already has a logistic system in place. Another alternative is to outsource the whole process. This is deemed as inappropriate as Celsa already has a logistic system. If Celsa is not able to use *system without return logistic* and thus needs to perform the investment themselves, it will be important to investigate how many customers that are interested of the service. Thus, it will be of even greater importance to have a strategy how to market the benefits of the service.

To control the amount of load carriers in the supply chain, a system to track and trace should be in place in order to ensure visibility throughout the logistic system. The load carrier may be integrated in the already established bar-code system to avoid additional expenses as it would enhance tracking and visibility, in line with Hellström and Johansson (2010). This means that Celsa needs to find an efficient way to incorporate the load carrier in the existing IT-system. In addition, the load carrier may benefit from being scanned, automatically or manually, and registered in a common platform at delivery at the construction site, either by the truck operator or construction worker. This should be performed to ensure the location of all load carriers, as they may be located at many different customers. Another procedure may be to use a similar system to a two-bin-system. As a load carrier would be delivered to the construction site, an empty carrier would be picked up, similar to the *switch pool system*, described by Kroon Vrijens (1995). This means that the supply chain would at least require two load carriers, one at the construction site as well as one at the production site. This system may simplify control in the supply chain regarding tracking the carriers.

In the future state design of the supply chain, QR is suggested to be developed to serve as a common platform for information and order handling. As mentioned, track and trace system could be placed in order to handle the load carriers in the supply chain. This would enhance the transparency of the supply chain, while simplifying planning of operations for Celsa. For example, the customer could register when a load carrier is empty and ready to be picked up from the construction site. As so, Celsa may be able to observe, control and plan its operations accordingly.

9 Conclusions and recommendations

This section provides a short summary of the findings of the study as well as recommendations to involved actors.

9.1 Conclusions

The results of this thesis show that implementing a load carrier within the supply chain of CAB to construction sites is a feasible undertaking. The findings show that, in a short-term perspective, operations at construction sites benefit significantly from an implementation, while operations at the supplier become more complex and require several extra activities to be performed. Thus, the activities added at the supplier serve to fulfill a customer demand, which was the original intent of the load carrier implementation. In addition, the results show that the load carrier may enable a just-in-time concept, if developed further.

The findings of the thesis are promising in terms of an implementation of a load carrier in the supply chain context. The thesis also identifies some challenges that should be addressed in order to effectively and efficiently fit the load carrier within the operations. Existing relationships need to be revised to facilitate the investment. Through a supply chain wide platform for information sharing, an effective control system could be developed. A need for company-wide commitment towards an implementation is deemed as desirable. There are also several technical challenges that need to be overcome.

A conclusion of the thesis is that the transport vehicles should be revised in order to better comply with the load carrier. In addition, the cost structure of transportation should be revised in order to explore the benefits that were achieved due to the reduced truck occupation.

9.2 Contributions

The thesis contributes by using established empirical and theoretical knowledge within a relatively unprecedented context, which is to employ a load carrier intended for reinforcing bars within the construction sector. The construction sector is an industry that would benefit greatly from more efficient logistics processes to and within construction sites. The thesis presents findings how the logistics process at construction sites could benefit from a load carrier in terms of material handling.

The findings present how a future supply chain, including the load carrier, may be designed in order to enhance its performance. Inventory locations, activities and resource occupation were some of the parameters that the future state map was aiming to reduce. The results of the future state map shows a reduction in these parameters and should be evaluated further in order to create a future action plan.

The thesis explores how a supplier may add services to its product in order to gain a competitive advantage relative to its competitors. The fierce competition from low-cost countries in Eastern Europe cannot be addressed only on the basis on price. Instead, suppliers may focus on a competitive advantage through bundling services to its products, thus create a barrier for competitors to copy the service.

The thesis provides a methodology to evaluate and assist in the decision-making process of a load carrier implementation. A scorecard including parameters such as handleability and volume efficiency amongst others is developed to assist in the evaluation of the carrier. The findings suggest that a modularized load carrier would be beneficial in an implementation in a construction supply chain.

9.3 Recommendations

The following section provides suggestions to each actor in the supply chain regarding future actions of a load carrier implementation. The recommendations are based on the findings in the analysis. These findings are, in turn, derived from literature and collection of quantitative and qualitative data.

9.3.1 Celsa Steel Service AB

Some challenges which Celsa is facing concerning the load carrier have been identified. If implemented as so, Celsa would face significantly increased operational and administrative work. In order to successfully include the load carrier in current operations these challenges needs to be addressed. In addition, the service should be incorporated in Celsa’s business model and communicated to customers. Also, organizational learning should be addressed to capture the knowledge from earlier operations including the load carrier. A brief summary of the recommendations are:

Evaluation and decision support:

- Assess the viability of the value offering.
- Monetize activities and resource occupation.
- Evaluate and redesign the current production system to fit the load carrier.
- Assess load carrier performance in accordance with packaging scorecard.
    - Provide input regarding design of the load carrier.
- Assess the storage space’s ability to accommodate load carriers in the manufacturing process.
- Evaluate ownership and responsibility structure of the load carrier together with control and planning of the supply chain.
- Be perceptive of the transporter’s requirements and input.

Implementation recommendations:

- Establish routines of load carrier orders in regards to
    - CAB-specifications
    - Ordering process
    - Loading procedure
    - Trucks being used
- Market the service and inform the customer of its benefits.
- Implement alternative measurements in regards to performance when using the load carrier.
    - Assess through customer satisfaction, rather than shipped weight.
- Reevaluate transport contract and payment options.
- Implement the load carrier within the company’s IT-system.

    - Facilitate tracking of load carriers
    - Implement load carrier constraints in the ordering process.
- Provide continuous feedback to designer of load carrier.

9.3.2 JM AB

The findings show that the customer benefits from the load carrier implementation in the supply chain. To understand these benefits in monetary terms, a landed cost approach is suitable. In line with the strategy of JM, the load carrier may increase the ability to work just-in-time. However, these benefits need to be evaluated.

Evaluation and decision support:

- Monetize the benefits of simplified operations in construction sites.
- Assess the benefits of more accurate deliveries enabled by more precise planning.

Implementation recommendations:

- Establish long-term relationships to develop service possibilities.
- Assess the perceived effects to provide supplier feedback
- Align external actors (specification of CAB) to reduce risk of redundant work.

9.3.3 Starke Arvid AB

Starke Arvid is the provider of the load carrier used in the pilot study. The findings suggest that the supply chain would benefit from changes made to the load carrier. Thus, the recommendations to Starke Arvid are regarding the design of the load carrier. The recommendations are:

- Evaluate the possibilities to modularize the load carrier
    - Hinged arms to simplify loading procedure
    - Evaluate a fully modularized load carrier
- Develop possibilities to load voluminous and intricate CAB
- Evaluate stackability
- Address issues regarding securing
    - Securing of CAB
    - Securing of load carrier on truck
- Assess possibility of lowering center of gravity of load carrier

9.4 Further research

Derived from the conclusions and challenges of the thesis, several areas of research have been found to be of interest for further research:

- Establish a framework to quantify benefits, drawbacks and costs associated with load carrier implementations. The thesis explores the effects of the load carrier, but excludes the quantification in terms of cost. Thus, a quantification of costs would serve as a more effective decision support tool concerning load carrier implementation.
- Develop computer assisted tools to calculate efficient load schemes for geometrically complex products, such as CAB, on load carriers.
- Establish a framework regarding reverse logistics, applicable in the construction industry.

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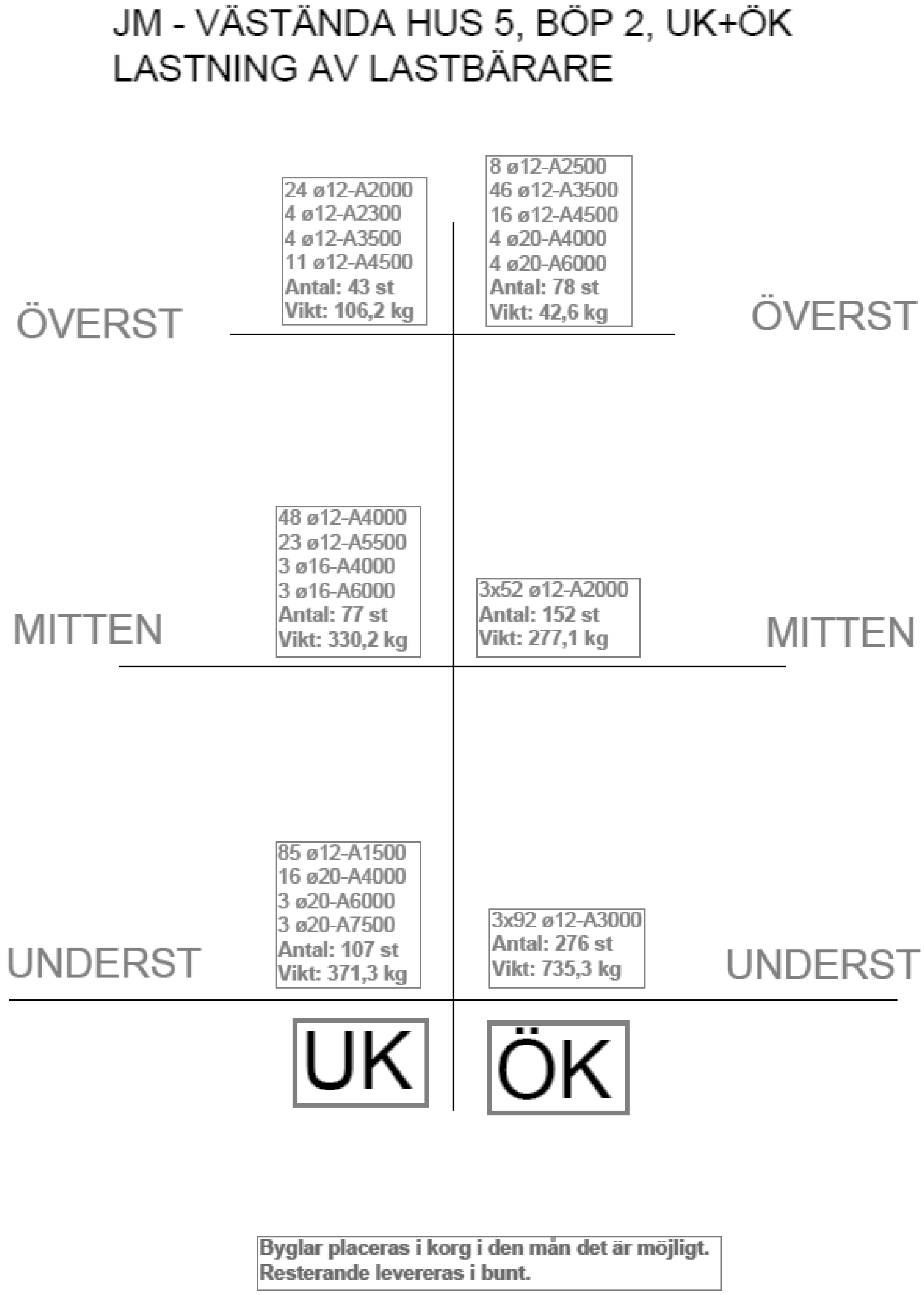
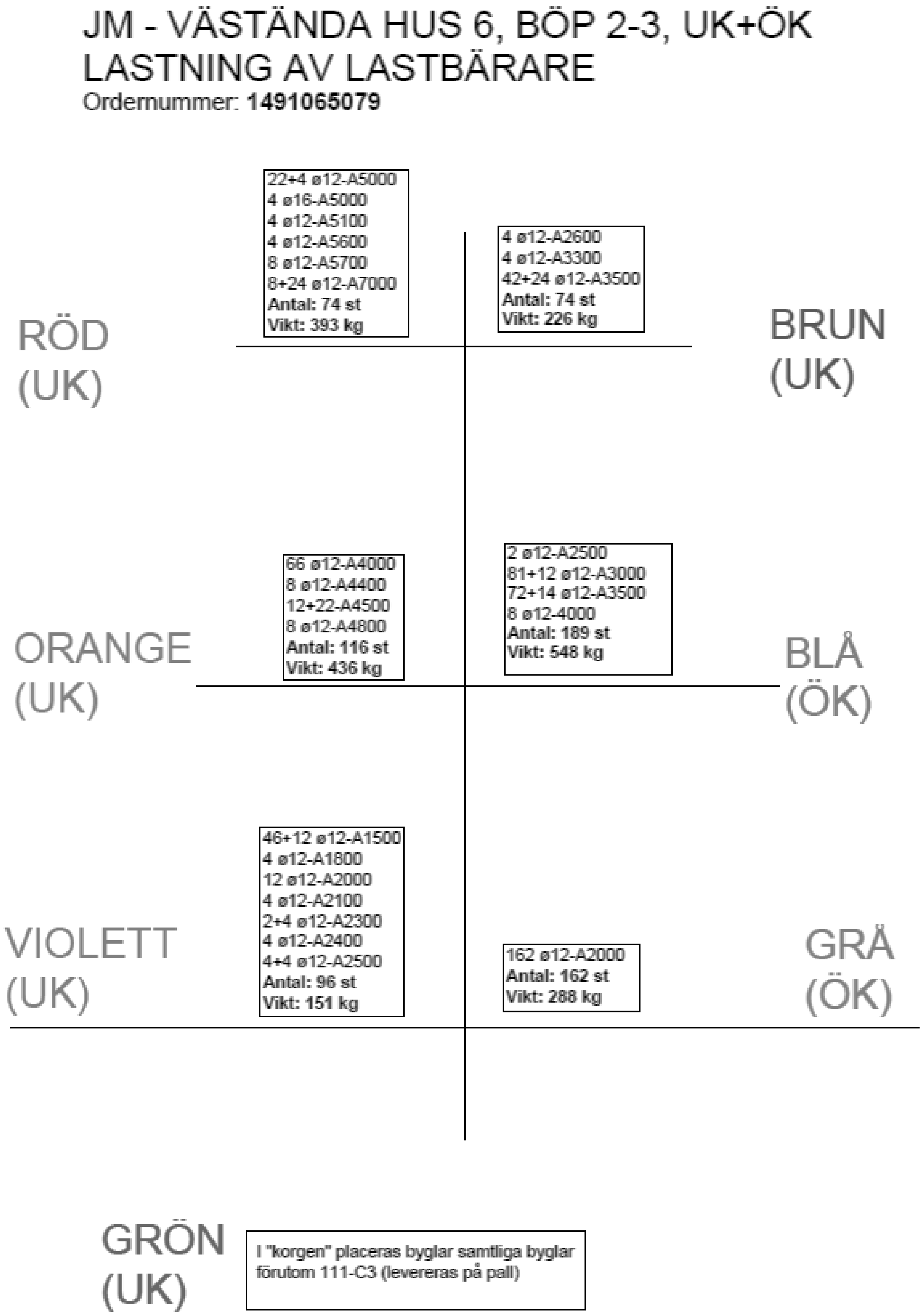
Appendix A - Developed load schemes

Load scheme for the first pilot study, arranged by shelf. UK means the lower layer and ÖK the upper layer. The order was not arranged by the common color-coding.



Load scheme for the second case study. The order was arranged in accordance with the color coding to simplify operations for both Celsa's operators and JM's construction workers.



Appendix B - Distribution of activities

Below is the measured data which serve as a basis for the figures regarding activities.

	Current			Pilot		
Activity	**Time [s]**	**Repetitions**	**Time/bundle [s]**	**Time [s]**	**Repetitions**	**Time/bundle [s]**
CAB from prod. to inv. (Celsa)	1300		76	1750		76
Planning sequence (Celsa)	0	1	0	90	1	4
Scan bundles (Celsa)	205	17	12	270	23	12
Loading carrier (Celsa)			0	2510	14	109
Securing CAB on load carrier (Celsa)			0	1800	1	78
Planning sequence (Celsa)	139		8	60	1	3
Loading truck (Celsa)	1560	5	92	230	2	10
Securing material on truck (Celsa)	240	1	14	420	1	18
Unsecuring material on truck (JM)	115	1	7	210	1	9
Unloading truck (JM)	623	7	37	180	2	8
Signing delivery documents (JM)	60	1	4	60	1	3
Sorting (JM)	45	1	45	0	0	0
Lift to level (JM)	1275	6	75	510	2	22
Total Celsa	3444	24	203	7130	43	310
Total JM	2118	16	167	960	6	42
Total	5562	40	370	8090	49	352

Appendix C - Data for resource occupation

Below is the measured data which serve as a basis for the figures regarding resource occupation.

	Current state		Pilot project		Future state
Number of bundles	17		23		n/a
Resource	**Per bundle [s]**	**Total [s]**	**Per bundle [s]**	**Total [s]**	**Per bundle [s]**
Overhead crane at Celsa	168	2860	195	4490	119
Truck at Celsa	114	1939	35	800	31
Scanner at Celsa	12	205	12	270	12
Operators at Celsa	188	3204	545	12540	407
Construction crane at JM	112	1898	33	750	11
Truck at JM	47	798	20	450	12
Construction workers at JM	235	3233	55	1260	25

Appendix D - Packaging scorecard

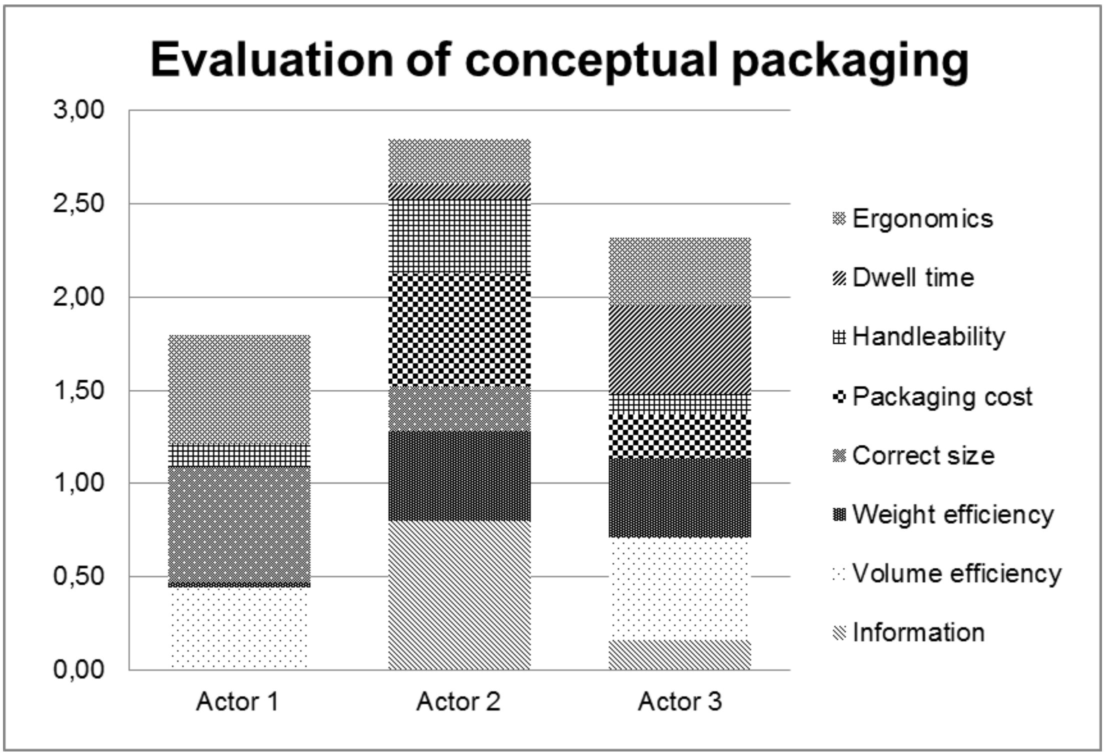
Conceptual illustration of the full usage of the packaging scorecard as intended. Note that this is solely an example. The workflow according to Olsmats and Dominic (2003):

1. List relevant factors for each actor.
2. Value the importance of relevant factors for each actor from 0-10.
3. Calculate their respective relative importance.
4. Evaluate the performance of the packaging, in regards to each factor and actor, from 0-4.
5. Multiply and summarize performance for each actor.
6. Compare to other packaging alternatives.

Note that the actors may have entirely different criteria, illustrated by zeroes in the example. The described workflow may be illustrated as following:

	Importance [0-10]			Performance [0-4]			Relative importance [%]			Relative performance		
Criteria	Actor 1	Actor 2	Actor 3	Actor 1	Actor 2	Actor 3	Actor 1	Actor 2	Actor 3	Actor 1	Actor 2	Actor 3
Information	10	5	3	0	4	2	29%	20%	8%	0.00	0.80	0.16
Volume efficiency	5	0	7	3	0	3	15%	0%	18%	0.44	0.00	0.55
Weight efficiency	1	3	8	1	4	2	3%	12%	21%	0.03	0.48	0.42
Correct size	7	3	0	3	2	0	21%	12%	0%	0.62	0.24	0.00
Packaging cost	0	5	3	0	3	3	0%	20%	8%	0.00	0.60	0.24
Handleability	1	5	1	4	2	4	3%	20%	3%	0.12	0.40	0.11
Dwell time	0	1	9	0	2	2	0%	4%	24%	0.00	0.08	0.47
Ergonomics	10	3	7	2	2	2	29%	12%	18%	0.59	0.24	0.37
Sum	34	25	38				100%	100%	100%	1.79	2.84	2.32

The data presented in the above table, may be illustrated as following:

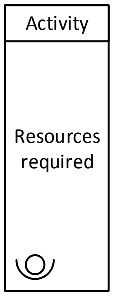


Note that the Y-axis in the above figure is arbitrary and only intended for comparison.

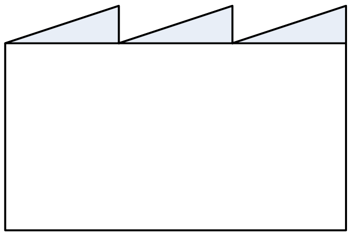
Appendix E - Value stream mapping symbols

The method of mapping the supply chain is used to visualize and facilitate the understanding of the material and information flow in C*hapter 6 – Empirical findings*, and to derive a desired future state in *Chapter 7 – Analysis.* Appendix E intends to provide a brief explanation and interpretation of the symbols used when mapping the supply chain. The symbols are gathered from Microsoft Visio and in line with Rother and Shook (2001), and Dolcemascolo (2006).

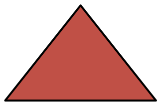
A *process* is visualized as follows. The upper box describes the activity while the lower text box describes the resource(s) involved in the activity.



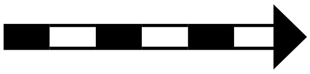
A *supplier/customer* visualized:



Inventory visualized:

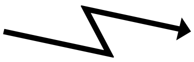


Visualization of material being *pushed* downstream:

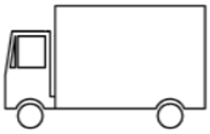


Visualization of material being *pulled* from a downstream activity*:*

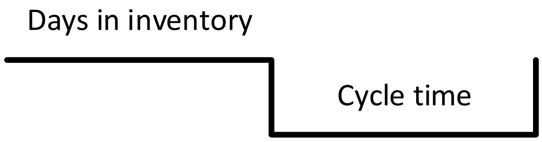
Visualization of *Electronic information*:



Visualization of *shipment truck*:



Timeline visualizes days in inventory and cycle time of each activity:



Following symbol summarizes days in inventory and cycle time: