CHALMERS

Construction logistics from a subcontractor perspective

A case study of a congested construction site

Master of Science Thesis in the Design and Construction Project Management Programme

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ABSTRACT

During the last decades a great body of research has highlighted logistics as an important area for enhancing the performance of the construction industry. An increase in urban development further indicates a need for efficient logistics since space for material, equipment and workers in these environments are restricted. The logistics concept involves integration and coordination of material flows which points to the importance of subcontractors' contributions as they are often responsible for their own supply of material.

The aim of this thesis is to examine construction logistics from a subcontractor perspective. This thesis contains a case study of a construction project with severe time and space restrictions. The interactions between the main contractor and subcontractors during the planning and production phase were examined in order to identify and evaluate the interactions that are important for logistics. Participatory observations during meetings and interviews with representatives' from both the main and subcontractors were conducted. The findings of this thesis suggest collaborative planning during preconstruction are important to create a common understanding of the projects logistics procedures since it facilitated proactive problem solving. During the production phase, project progress meetings were important since the subcontractors had the potential to coordinate their ordering procedures with the production schedule. However, poor transparency regarding schedule changes and delays resulted in urgent logistics problems at the site. These problems were mitigated through direct and frequent communication which was facilitated by operation meetings and a logistics coordinator.

The interdependencies that exist between activities performed by subcontractors at the construction site become stronger when time and space is limited. This indicates a greater need for coordination in order to achieve a match between the material and production flow. This study has shown that subcontractor involvement in planning and the use of a logistics coordinator can be beneficial to achieve this coordination. Furthermore, the study also highlights a need to create transparency of the subcontractors ordering procedures in order to achieve a more proactive, rather than reactive, logistics approach.

Keywords: collaborative planning, construction logistics, logistics coordinator, subcontractor, supply chain management

Bygglogistik från en underentreprenörs perspektiv
En fallstudie av en byggarbetesplats med begränsat utrymme

Examensarbete inom masterprogrammet Design and Construction Project Management

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SAMMANFATTNING

Under de senaste årtionden har logistik lyfts fram som ett viktigt förbättringsområde för att förhöja produktiviteten i byggbranschen. En ökning av byggande i urbana miljöer visar ytterligare på ett behov av effektiv logistik eftersom detta innebär ett begränsat utrymme för material, utrustning och arbetare. Logistik handlar om integration och koordinering av materialflöden. Underentreprenörerna utgör en viktig del i detta eftersom de oftast ansvarar för sin egen materialförsörjning.

Syftet med detta examensarbete är att undersöka bygglogistik från underentreprenörernas synvinkel. Detta arbete innehåller en fallstudie av byggnadsprojekt med begränsningar gällande tid och utrymme. Interaktionerna mellan huvudentreprenören och underentreprenörerna under planering- och produktions skedet undersöktes för att identifiera och utvärdera de interaktioner som är viktiga för logistik. Observationer under möten och intervjuer med representanter från både huvudentreprenören och underentreprenörerna har genomförts. Resultatet av detta examensarbete indikerar att ett gemensamt planeringsmöte var viktigt för att skapa en enhetlig uppfattning om projektets logistikrutiner och för att främjade proaktiv problemlösning. Under produktionsskedet så var avstämningsmötena viktiga eftersom underentreprenörerna hade möjligheten att koordinera beställningar med produktionstidsplanen. Dålig transparens gällande försening och förändring av tidsplanen ledde emellertid till akuta logistikproblem på byggarbetsplatsen. Dessa problem minskades genom direkt och frekvent kommunikation som underlättades av driftmöten och en logistikansvarig.

De ömsesidiga beroendena som existerar mellan aktiviteterna på byggarbetsplatsen blir starkare då det förekommer lite tid och utrymme. Detta indikerar att det också finns ett utökat behov för koordinering för att uppnå ett materialflöde som motsvarar produktionens behov. Denna studie har visat att underentreprenörernas medverkan i planering och användandet av en logistikansvarig kan vara fördelaktigt för att möta det utökade behovet för koordinering. Vidare så belyser studien ett behov av att skapa transparens i underentreprenörernas inköpsrutiner för att skapa en mer proaktivt, istället för reaktivt, tillvägagångssätt till logistik.

Nyckelord: bygglogistik, gemensam planering, koordinering, logistikansvarig, styrning av värdekedjan, underentreprenör

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Preface

This master thesis has been created with support from several people whom we wish to acknowledge. First of all, this thesis could not be written without our supervisor at Chalmers, Viktoria Sundqvist, who through great commitment and interest has challenged and encouraged us from start to finish. We would also like to thank Susanne Lundberg, our supervisor at Peab, for providing us access to the Gårda project. Furthermore, we would like to express our gratitude to all the interviewees that took time despite heavy workload, provided us with interesting findings and extensive knowledge. Last but not least, thanks to Lukas Isebäck, Louise Röström, and Christian Koch for reviewing our paper and contributing with sharp and developing comments.

We would also like to thank the university, our teachers, and classmates.

Gothenburg, May 2015

Marcus Hansson & Niklas Hedberg

1 Introduction

This chapter provides the background and the problem discussion with regard to construction logistics in urban environments. The chapter also contains the aim and the related research questions that have guided the research process. The chapter is concluded with the outline of the thesis.

1.1 Supply chain management and logistics in the construction industry

Especially two issues have generated much interest in the construction industry during the last two decades; the low productivity development and the fragmented supply chain. The productivity development of the construction industry is often stated to be low in comparison to the manufacturing industry (e.g. Koskela, 2000; Hellner and Modig, 2011). The inefficiency of the construction industry is further highlighted by Josephson and Saukkoriipi (2007) who demonstrate that waste in construction projects can represent 30-35% of the total construction cost. The supply chain is addressed in two renowned reports, *'Construction the Team'* and *'Rethinking Construction'*, as an important area for performance improvements in the construction industry (Latham, 1994; Egan, 1998). These reports argue that collaboration and shared objectives can yield positive result, both for the individual organisation and for the entire supply chain. The field of supply chain management (SCM) originates from the manufacturing industry but attempts to apply the concepts and ideas to construction have been scattered and partial (Vrijhoef and Koskela, 2000). A greater understanding of logistics is needed before SCM can be utilised in construction (Vidalakis et al., 2011). Agapiou et al. (1998) suggest that the main purpose of logistics in construction is to:

> "*... improve coordination and communication between project participants during the design and construction phases, particularly in the material flow process*" (p. 136)

The underlying purpose of logistics in construction is to provide an efficient flow of materials to the construction site. In other words, to match the material flow and the production flow. The cost of materials for construction projects represent between 40-45% of total construction costs (Agapiou et al., 1998) and it is estimated that poor logistics increase total construction cost with 10-30% (Strategic Forum for Construction, 2005). Thus, a better understanding of the prerequisites for efficient logistics offers a great opportunity for improving construction performance.

1.2 The need for coordination

Due to the large number of participants working simultaneously at the construction site and undertaking complementary work, there is an extensive need for communication and coordination (Olsson, 1998). It is not uncommon for a main contractor to subcontract 80-90% of the construction work from a variety of specialised contractors (Hinze and Tracey, 1994). The subcontractors are often responsible for their own material supply (Sobotka et al., 2005), which indicate their importance as a link between the construction site and material supply chain. The relationships between contractor and subcontractor are often described as adversarial due to the procurement practice of the construction industry (Khalfan and Maqsood, 2014). These adversarial relationships are seen as the main obstacle for greater collaboration and integration (Dainty et al., 2001). Despite their importance, Vidalakis et al. (2011) note that the majority of earlier research within construction SCM has focused on the contractor, located in the end of the supply chain. Hence, actors downstream, i.e. subcontractors and material suppliers, have received little attention which contradicts with the holistic view of SCM and logistics. Furthermore, Olsson (1998) argues that the contractor and subcontractor relationships are often characterised by a lack of mutual understanding of their respective needs which hampers coordination. This is problematic since coordination among subcontractors, and between the main contractor and subcontractors, is vital for achieving a match between the material and the production flow (Thunberg et al., 2014).

1.3 Construction logistics in urban environments

Urbanisation in Sweden is expected to increase during the next decades (Boverket, 2012), which in combination with urban population growth will result in denser urban environments (Ljungberg et al., 2012). A common problem for construction projects in urban areas is the general lack of space at the construction site. This implies that space for materials, equipment, and workers are limited which further complicate the already complex nature of construction. Scarcity of space limits the ability to keep buffers of materials at the construction site. This is problematic since it is the most common method used for matching the material flow with the production flow (Arbulu and Ballard, 2004). Additionally, material deliveries to construction sites in urban areas can be problematic due to other constraints such as infrastructure and traffic. Consequently, congested construction sites require an additional focus on logistics in order to achieve a match between the supply, i.e. the material flow, and the demand, i.e. the production flow. This in turn, requires well-functioning coordination among the project participants.

1.4 Introducing the Gårda project

This thesis covers a construction project in Gothenburg, Sweden. Peab Sverige AB, one of Sweden's largest construction companies, have been commissioned to design and build an office building, Gårda 3:14, and to refurbish an existing office building, Gårda 3:12. This study focuses on Gårda 3:14, the construction of a six stories high building of approximately 10,000 square meters. Construction work at the site started in March 2014 and the project is estimated to be completed in September 2015. The construction site is located in an urban environment. Consequently, the deliveries to the site are constrained by infrastructure and traffic, and there is lack of space for materials, equipment, and workers. In order to cope with these challenges, Peab focuses on enhanced coordination between project participants in order to improve logistics. The most important subcontractors have thus been involved to a greater extent during the planning phase in order to utilise the subcontractors' knowledge and expertise, while at the same time provide transparency and mutual understanding of each other's activities. In addition to collaborative planning, Peab have also uses a logistics coordinator in order to improve the supply of materials and site logistics.

1.5 Aim and research questions

The aim of this thesis is to examine construction logistics from a subcontractor perspective. The interactions between a main contractor and the subcontractors are examined in order to create a greater understanding of the coordination requirements that exist in a construction project with a lack of space at the construction site. The following research questions have been formulated in order to guide the process:

- *Which interactions between the main contractor and subcontractors are important for logistics in a construction project?*
- *How can these interactions be developed in order to improve logistics?*

1.6 Outline of the thesis

This thesis contains six chapters and is structured according to Figure 1.1.

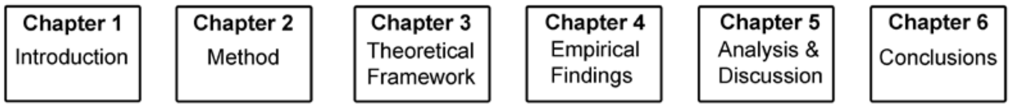

Figure 1.1 - Structure of the thesis

Chapter 1 - *Introduction* introduces the problem that is examined in this thesis. This chapter also contains the aim and the related research questions that have guided the research process.

Chapter 2 - *Method* covers the research approach used to fulfil the aim of this thesis. The research process is described and the methods used for collecting empirical data are presented and justified.

Chapter 3 - *Theoretical Framework* provides an overview of the previous research carried out in the field of construction logistics, in order to create a framework to be applied in the analysis.

Chapter 4 - *Empirical Findings* presents the case study based on the observations and interviews.

Chapter 5 - *Analysis and Discussion* contains the analysis of the empirical findings by applying the theoretical framework.

Chapter 6 - *Conclusions* contains a concluding discussion and suggestions for further research.

2 Method

This chapter provides the methodological considerations of the thesis. The research process is described and the methods used to collect empirical data are presented and justified. Finally, the quality of the research is discussed.

> "*... learning is the essence of all research. What we learn is articulated in the theoretical framework combined with the matching case. This is generally considered by far the most important outcome of the research process*"
>
> Dubois and Gadde (2002b, p. 560).

2.1 Research approach

This thesis takes an abductive approach. Abductive reasoning is particularly interesting when the researcher aim to explore new things i.e. variables and relationships (Dubois and Gadde, 2002b). In abductive research there is an interplay between theory and empirical observations. This means that the theoretical framework can be successively modified according to the empirical findings (Dubois and Gadde, 2002b).

To achieve the aim of this thesis the interactions between a main contractor and the subcontractors are to be examined. These interactions are important for logistics as the main purpose of logistics is to improve coordination and communication between project participants. By examining these interactions we aim to receive a greater understanding of the coordination requirements during a construction project with limited space. The study is of exploratory nature and a qualitative research strategy is considered to be the best way to answer the research questions. There are two major issues in logistical research; scarcity of qualitative and interpretive research, and; lack of research focusing on theory development (Spens and Kovács, 2005). Additionally, Näslund (2002) argues that qualitative research methods can be a good supplement to the quantitative methods that have dominated the field of logistics. Qualitative research strategies in contrast to quantitative strategies focus on words rather than numbers (Bryman and Bell, 2011). Since words are more explanatory than numbers, qualitative data collecting methods such as interviews and observations are often used to "*create an understanding of relationships and complex interactions*" (Ellram, 1996, p. 97). This is suggested to be appropriate in logistics since problems in logistics usually are "*ill-structured, even messy, real-world problems*" (Remenyi et al., 1998, p. 321). The qualitative approach is also suggested to be favourable when conducting a case study since it permits detailed and in depth analysis (Bryman and Bell, 2011).

> "*In exploratory research, the issue could be how or why something being done? A case study methodology would be desirable in those circumstances because it provides depth and insight into a little known phenomenon*"
>
> Ellram (1996, p. 97)

In order to achieve the aim of this thesis, a single case study was conducted at a Swedish construction company and empirical data was collected through interviews and participatory observations.

2.2 Research process

This thesis has been conducted as the final part of the Design and Construction Project Management master programme at Chalmers University of Technology. The work was carried out between December 2014 and June 2015. The research process is illustrated in Figure 2.1.

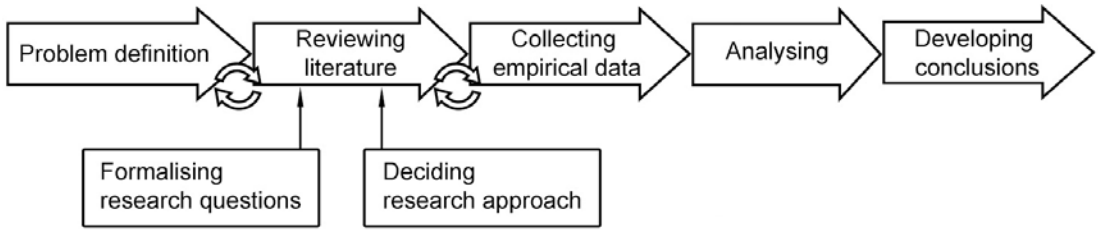

Figure 2.1 - The research process

We received information about the Gårda project in December 2014 during a meeting with a manager at Peab. Since the project had severe time and space constraints, Peab had employed extra resources to ensure the success of the project. The basic idea was that inadequate logistics would lead to problems during the production. In order to ease the project execution, a project planner was used and a site supervisor was assigned the role as logistics coordinator. Peab wanted to evaluate the overall performance of the project in order to identify areas of improvements. Peab was particularly interested in the subcontractors' opinions of the project. In consultation with the manager at Peab and our supervisor at Chalmers, it was decided that we were going to examine the projects logistics from a subcontractor perspective.

A preliminary suggestion for the thesis topic was developed in late December 2014. In January 2015, after an initial literature search, a more precise problem formulation started to emerge. During this time we also began an extensive literature review to explore the existing research within the field of logistics; this process is in depth described in section 2.3. An explorative interview with the project planner was conducted during the same period as the initial literature search. This interview gave us an insight into the project procedures that enabled us to delimit the literature review in order to find relevant theories for the scope of the thesis. We also received a better understanding of the collaborative planning approach used in the project and the interactions that Peab had with the subcontractors.

After we gained a better understanding of the Gårda project and the existing literature, we started to reformulate the research questions that were submitted as a part of the preliminary suggestion for topic back in January. This was done in consultation with our supervisor at Chalmers. The literature search continued throughout February while at the same time a theoretical framework for the thesis started to emerge. During this time, we started to consider approaches for data collection. After examining some methodology theory and the methods often used in logistics research we chose to use interviews and participatory observations. This approach seemed to be an appropriate since examining interactions concerns an investigation of a social phenomenon. We argued that the data obtained from interviews and observations would provide the contextual understanding required for answering the research questions. Both project managers and foremen were interviewed to get a comprehensive picture of the projects logistics procedures. We believed that the project managers would have an insight in the supply logistics procedures while the foremen should have a better insight in the site logistics procedures.

In late February, we participated in a subcontractor coordination meeting. During this meeting we introduced ourselves to the subcontractors and explained the aim of the thesis. Participatory observations were performed during 7 occasions between February and May 2015. This is further described in section 2.4.2. These observations gave us a better understanding of the project procedures which further helped us to develop the theoretical framework.

Three interviews were conducted in March 2015 with representatives from Peab: the logistics coordinator, project planner, and the site production manager. The purpose was to obtain detailed information regarding project procedures and to identify the interactions between Peab and the subcontractors during the planning and production phase of the project. Together with information from the literature review and the observations, this served as a basis for the development of an interview guide for the interviews with the subcontractors.

In early March 2015, we sent emails to four of the subcontractors' project managers. The email contained a request for a meeting and a general description of the purpose of the interview. During the participatory observations, we met all of the project managers and thought that meeting them in person before we sent out the email would result in a willingness to participate in an interview. Despite this some of the project managers were reluctant to take participate or even respond. After a number of telephone calls and additional e-mails, we managed to book interviews with two of the project managers.

In the beginning of April 2015 the first interview with a project manager was conducted. At the end of the interview we asked for contact information to the foreman responsible for the subcontractors activities at the construction site. The foreman was contacted by phone immediately after the interview with project manager. This approach was repeated and we managed to finalise all the six interviews with the subcontractors by the end of April. The interview procedures are in depth described in section 2.4.1. The interviews were transcribed shortly after they were held in order to create an as accurate as possible recollection of the situation.

The findings from the observations and interviews were analysed during May 2015. During this period we actively discussed the findings from a theoretical perspective in order to connect theory and reality. The research was concluded by developing conclusions and suggestions for further research.

2.3 Literature review

A literature review was conducted in order to create a relevant theoretical frame of reference for the thesis. The literature review is an essential part of the research process as it aims to give the researcher a general overview of the subject area, i.e. knowledge of previous research carried out within the field, and possible gaps in the literature that can be examined as well as a better understanding of suitable methods that can be used (Remenyi et al., 1998). The literature search was performed by using the following key words; *construction, coordination, collaboration, logistics, material delivery, material management, planning and supply chain management* in academic search engines such as SCOPUS, ScienceDirect and Google Scholar. The abstracts, keywords and conclusions of the articles found in the search were examined in order to sort out relevant information. Articles related to the aim of the thesis were primarily selected. The place of publication, number of citations and extent of bibliography were examined and taken in consideration when selecting sources. In addition to the literature found during the database search, books related to the research field and qualitative research methods were found at the main library at Chalmers University of Technology. It is also important to note that the case study is conducted within a Swedish context but that the literature review is not limited in this respect. The literature search was conducted between January and April 2015 and included approximately 130 articles and five books.

2.4 Data collection

Two main data collection methods have been used during the research process; interviews and participatory observations. The combination of these two methods is common in qualitative research (Bryman and Bell, 2011).

2.4.1 Interviews

Interviews are probably the most widely employed method in qualitative research. Both open ended and semi structured interviews were used during the research process. In a semi structured interview, some questions have been prepared before the interview to guide the process. However, there is still much flexibility for both the interviewee and the interviewer; the former can answer questions freely while the latter can change questions as the interview progress (Bryman and Bell, 2011).

Three open ended interviews were conducted with representatives from Peab in order to get a better understanding of the project and the interactions that Peab had with the subcontractors during the project. Four subcontractors with different area of expertise and responsibilities at the construction site were selected for additional interviews. In total, six semi structured interviews were conducted with the subcontractors: three with project managers and three with foremen, illustrated in Table 2.1. A more detailed list of interviewees can be seen in Appendix A.

Table 2.1 - Interviews

Subcontractor	Project manager	Foreman
Electrician	X	X
HVAC	X	X
Sprinkler	X	
Plumber		X

The interview process in this thesis followed four steps:

1. *Developing an interview guide:* Interview questions were developed to guide the interview process. The findings from the open ended interviews with the representatives from Peab served as basis for the development of the interview guide with regard to subcontractors.

2. *Selecting interviewees:* The subcontractors who participated in the collaborative planning session were selected for interviews since Peab were especially interested in their opinion.

3. *Performing the interviews:* The interviews lasted for 1 - 2 hours and were held at the offices of the respective interviewees or at the project office. The interviews with the subcontractors were structured according to the interview guide and all interviews were reordered. The interview guides for the project managers and foremen can be found in Appendix B and C.

4. *Summarising the interviews:* The notes produced during the interviews were transcribed and supplemented with additional information from the recordings.

2.4.2 Observations by participation

In order to get a sufficient understanding of the case and its context, participatory observations during meetings were also performed. The degree of involvement has been limited to what Bryman and Bell (2011) refers to as observer-as-participant. Despite limited involvement as such, participation can be advantageous to get a comprehensible understanding of the social context (Remenyi et al., 1998). Observations were made during the following four occasions:

Collaborative planning session: Initial meeting where the subcontractors' project managers and foremen together with representatives from Peab developed the structure for the production schedule. This session was held for an entire day. We participated in the collaborative planning session for Gårda 3:12, the refurbishment, since the session for the new construction was held before our involvement in the project.

Subcontractor coordination meeting: Coordination meeting participated by the subcontractors' project managers, the production and administrative site managers, and the logistics coordinator. Held biweekly and lasts for approximately two hours.

Operation meeting: Coordination meeting participated by the subcontractors' foremen, site supervisors and the logistics coordinator. Focus on production related issues. Held weekly and lasts for approximately one hour.

Project progress meeting: Actual production progress is compared with the planned progress. Participated by the subcontractors' project managers and foreman, project planner and production site manager. Held once a month and lasts for approximately two and a half hour.

Each meeting has its specific purpose and goal, but they are all an important for coordination between the project participants. By participating in these meetings we gained a comprehensive knowledge of the meeting procedures and the social- and cultural context.

2.5 Data analysis

Analysing qualitative data is challanging since the results from interviews and observations consist of transcripts and field notes (Bryman and Bell, 2011). Bryman and Bell (2011) noted that *'thematic analysis'*, when the researcher tries to find themes or patterns in the data, is the most frequently used analysis. This was the analytic approach used in this thesis. The field notes and recordings are summarised and structured and then reviewed in order to discover themes between the data obtained from the interviews and observations.

2.6 Quality of the study

The quality of research essentially concerns validity and reliability (Bryman and Bell, 2011). Bryman and Bell (2011) mention four criterions for evaluating the validity and reliability of qualitative research:

- Credibility - How trustworthy are the results?
- Transferability - Are the results applicable in different environments?
- Dependability - Is it probable that the results are applicable at other times?
- Confirmability - Has the researcher acted objectively?

Bryman and Bell (2011, p. 43)

The credibility of the findings in this thesis is supported by two techniques discussed by Lincoln and Guba (1985): prolonged engagement and persistent observation. In order to understand a phenomenon and prevent disturbances in the collected data the researcher must understand the context in which the findings are extracted from (Lincoln and Guba, 1985). Prolonged engagement basically means that the research spends time within the specific context in order to: "*be certain that the context is thoroughly understood*" (Lincoln and Guba, p. 302). This study was carried out during six months and during this time both formal and informal interviews and observations has been performed. Before collecting data concerning the subcontractors' perspectives, informal interviews were conducted with representatives from Peab in order to get information about the project context: why certain subcontractors had been involved more than others; to get a holistic understanding on how the project was progressing, and; to get an indication how their relationship has been developing along the way. Lincoln and Guba (1985) also discussed the necessity of prolonged engagement in order to build trust between the researcher and the respondents. We established trust by introducing ourselves and participating in meetings before the actual interviews with the subcontractors were performed. Additionally, since Peab and the subcontractors had a business relationship, we emphasised that the paper was not written for Peab specifically and that their responses could be made anonymous. As a complement to the wide scope provided by prolonged engagement, persistent observation facilitates depth, or as Lincoln and Guba (1985) put it: "*... to identify those characteristics and elements in the situation that are most relevant to the problem or issue being pursued and focusing on them in detail*" (Lincoln and Guba, 1985, p. 304). Using both interviews and observations was beneficial in this respect. The findings during observations could be brought up and discussed during interviews, allowing multiple views and extending our understanding.

Since this thesis investigate a specific case the transferability of the findings can arguably be questioned, as expressed by Godfrey-Smith (2003): "*if we see a multitude of cases of white swans, and no other colors, why does that give us reason to believe that all swans are white?*" (p. 40). The findings of this thesis are intended to provide Peab with information regarding their logistics procedures. Whether this can be transferred to other contexts, we refer to Lincoln and Guba (1985) who argued that it is not the task of the qualitative researcher to specify the transferability; "… *he or she can only provide a thick description necessary to enable someone interested in making a transfer to reach a conclusion about whether transfer can be contemplated as a possibility*" (p. 316). In regard to this, we have tried to create a rich recollection of the findings.

The research process described in this chapter, together with the information regarding the data collection aims at facilitating transparency and thus increasing the dependability of the result. Finally, the abductive research approach should strengthen the conformability of this thesis since the both data and theory has evolved progressively, i.e. the choice of theory has been made with consideration to the findings, and theory has supported us to find relevant data. The research is always to some extent influenced by the researcher, especially in qualitative research. In order to prevent subjectivity during the research process, we have had open discussions and tried to structure the process so that our values will not affect the result.

3 Theoretical Framework

This chapter provides an overview of the underlying theories related to the scope of the thesis. The theoretical framework is divided into seven sections. In the first section, the concept of supply chain management and logistics is introduced. The following section contains a description of the complex and uncertain nature of the construction industry. The third section covers the interdependencies that exist in construction and how they have created a pattern of loose and tight couplings. The fourth section contains a brief description of how the construction and supply process relate to each other. The following section conceptualise construction logistics and its current application in the industry. Problems related to congested construction sites are presented in the sixth section. The seventh section covers what the existing literature suggest as measures for how the material flow can be matched with the production flow when space at the construction site is limited. Finally, the chapter is concluded with a summary and a conceptual model.

3.1 Introducing supply chain management and logistics

Logistics can be understood as "*the art of efficient material flows*" (Persson and Virum, 1996). The term originates from the military but has been used in other contexts since after the industrial revolution (Agapiou, 1998). In recent years the logistics concept has changed and is now viewed as a strategic approach to create competitive advantage through inter-organisational relationships, rather than only being perceived as an operational approach to achieve efficient flow of materials for an individual organisation (Jonsson, 2008). In other words, an increased focus on the entire supply chain which often is referred to as supply chain management, a holistic perspective of logistics that extends across organisational boundaries (Vidalakis et al., 2011). Christopher (2011, p. 9) argue that:

> *"The underlying philosophy of the logistics and supply chain concept is that of planning and coordinating the materials flow from source to use as an integrated system rather than, as was often the case in the past, managing the goods flow as a series of independent activities"*

In this paper, SCM is understood as a logistics philosophy that proposes coordination and collaboration across organisational boundaries in order to achieve an efficient flow of information and resources. It is important to recognise that SCM originated from the manufacturing industry and attempts to transfer the concept to construction have been scattered and partial (Vrijhoef and Koskela, 2000). This is supported by Fernie and Thorpe (2007) who argue that much of the research that advocates SCM in construction lack sufficient consideration of the nature of the construction industry.

3.2 The nature of the construction industry

The construction industry is complex and faced with many challenges due to its specific nature. The industry suffers from fluctuating demand cycles, project specific product demands and uncertain productions conditions (Dainty et al., 2001). Production in construction is more uncertain and complex than in manufacturing (Ballard and Howell, 1998b) and Koskela (1992) identifies three characteristics that contribute to this complexity; unique products, on site production, and temporary multi organisations.

3.2.1 Unique products

The deliverables of construction projects tend to be unique products that are tailored to the requirements of the client (Dainty et al., 2006). Although the output from different construction projects share several similarities they can be understood as unique. Warszawski (1990) argues that the output uniqueness is caused by different client preferences, different local prerequisites, and different design solutions from the architect. The uniqueness of outputs means that construction methods and inputs differs from project to project (Koskela, 1992). In other words, how to deliver the project, what construction method to use, and what materials and labour to use, needs to be considered in each individual project.

3.2.2 Site based production

Koskela and Ballard (1998) suggest that construction production can be uniquely defined by a combination of two characteristics; fixed positions manufacturing; and rootedness-in-place. The first characteristic implies that labour resources moves around the products, which is in clear contrast to manufacturing where it is the products that move through labour resources (Eccles, 1981). Furthermore, the fixed position manufacturing can result in congestion at the construction site since several interdependent activities needs to be performed simultaneously and in close proximity (Koskela, 1999). Rootedness-in-place implies that construction projects are constrained by the prerequisites of the local environment. For instance, legal restrictions i.e. building codes and zoning regulations, and physical constraints i.e. geological conditions, space limitations, seismic activity, and weather will affect both the project organisation and the production process (Ballard and Howell, 1998b).

3.2.3 Temporary multi organisations

The construction industry is fragmented and construction projects require expertise from multiple organisations (Dainty et al., 2006). Generally, a temporary organisation with diverse range of participants from different organisations is created in order to achieve the purpose of the project (Koskela, 1992). A project organisation usually consists of several participants such as; architects, engineers, a main contractor, subcontractors, and suppliers (Wegelius-Lehtonen and Pahkala, 1998). It is not uncommon for a main contractor to subcontract a large proportion of the construction work to a variety of specialised contractors (Hinze and Tracey, 1994). For instance, subcontractors can be divided in different areas of labour expertise; carpenters, bricklayers, plumbers, pipefitters, electricians, painters etc. (Eccles, 1981). The extensive use of subcontracting entails problems since it requires a great deal of information processing and coordination between project participants that may or may not worked with each other before (Olsson, 1998).

3.3 Interdependencies and couplings in the construction industry

Dubois and Gadde (2002a) examine how organisations behave and operate in order to manage the complexity of the construction industry. By using a network strategy and the concept of ‘couplings’ (Weick, 1976), they identify the strength of relationships within individual projects, among organisations involved in supply chains, between project and between organisations. This is illustrated in Figure 3.1. They also distinguished two levels of networks; the temporary i.e. the project and the site, and; the permanent, i.e. where components and materials are exchanged.

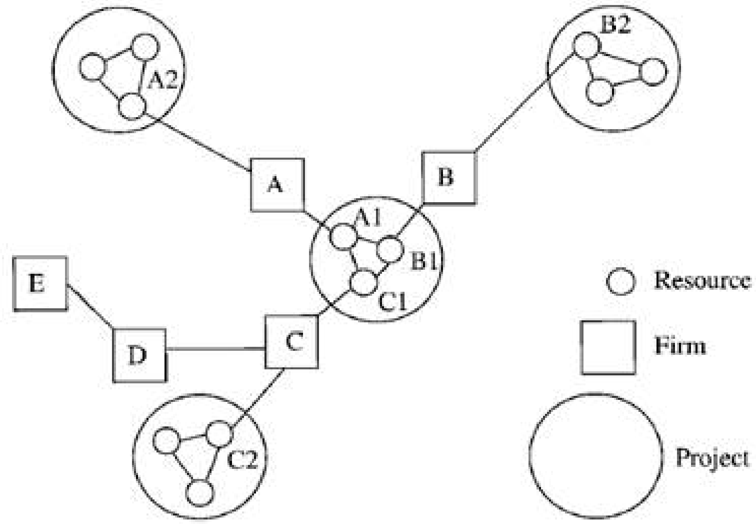

Figure 3.1 - A loosely coupled system (Dubois and Gadde, 2002a, p. 625)

In construction, the couplings between buyers and suppliers are loose since this prevents dependence (Dubois and Gadde, 2002a). There are especially three benefits that follow with loose couplings: the uncertainty in a single transaction is reduced since alternative suppliers are available; it avoids becoming locked to a single technical solution that is provided by a single supplier, and it stimulates competition between suppliers (Gadde and Dubois, 2010). However, the consequence of keeping the supplier at an arm's-length is the lack of motivation for collaboration and adaption. For instance, the supplier is unlikely to develop joint efforts such as improving logistics operations or product development since there is no guarantee for future business. Hence, there are loose couplings between the buying and supplying firm and standardised products become the main business exchange with little consideration of each other's operations (Gadde and Dubois, 2010).

Since labour resource in construction moves around the product, adjustments of standardised products need to be conducted at the construction site. This in combination with project time restrictions creates strong interdependencies on the construction site (Dubois and Gadde, 2002a). Thompson (1967) identifies three types of interdependencies in construction; pooled, sequential, and reciprocal interdependencies. In pooled interdependencies there is no direct dependence between activities but the failure of one will affect another. This could for example be two activities that both needs a specific resource such as labour, equipment or space; if one of the activities fails or take longer time than expected, the other activity will suffer as well. Sequential interdependencies exist where the output of one activity serves as the input for the next. For instance, the foundation of a building need to be completed before work on the walls can begin. Reciprocal interdependencies exist due to the need for mutual adjustment between activities or units. For instance, ventilation, electricity, and heating need to be adjusted to each other and thus dependency between them exists. (Bankvall et al., 2010)

In contrast to manufacturing where sequential interdependencies are common, reciprocal interdependencies prevails in construction (Bankvall et al., 2010). This has resulted in a highly complex production which requires frequent and direct interactions between the actors at the construction site. Thus, the couplings in the temporary network i.e. the project and the site, is strong (Bankvall et al., 2010).

This pattern of loose and tight coupling is argued to be favourable for the productivity for the individual project but hampers collaboration and coordination on an industry level (Dubois and Gadde, 2002a). This is especially problematic since coordination between the permanent network (the supply chain) and the temporary network (the project) is required to achieve the benefits of SCM (Olsson, 2000).

3.4 The construction and supply process

In order to achieve efficient construction logistics, both the material supply process and construction process needs to be considered (Olsson, 2000). Olsson (2000) argues that these two processes are uncoordinated due to a lack of communication between various actors. Decisions regarding design and construction method that are made early in the construction process influence the requirements of the supply chain and ultimately the logistics during production. Improved coordination between the supply chain and the construction process is suggested to be a solution for many of the problems that occur at the construction site (Thunberg et al., 2014).

Olsson (2000) developed a model that describes the interaction between the *construction process* and the *supply chain process*, illustrated in Figure 3.2. The figure illustrates the supply chain process, the horizontal arrow, converging with the construction process, the vertical arrow, at the construction site. Olsson (2000) argues there needs to be information flows between all the phases of the two processes in order to achieve coordination.

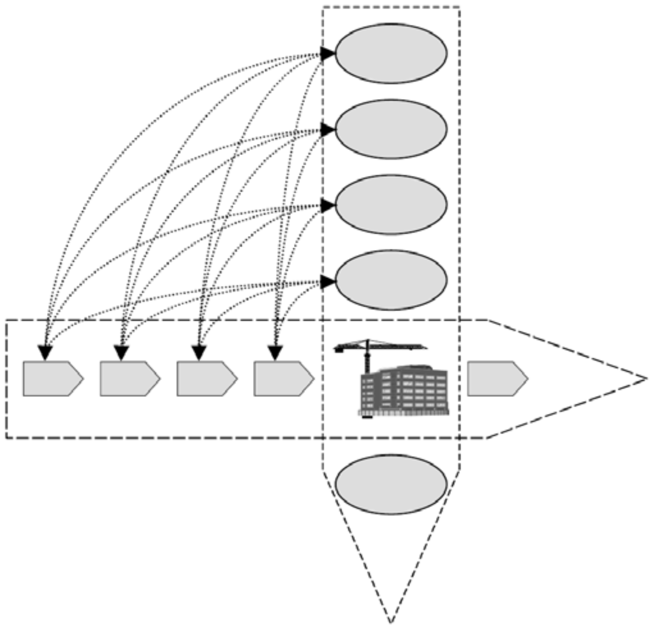

Figure 3.2 - Interactions between the construction process and the supply chain process (Olsson, 2000, p. 138)

Vrijhoef and Koskela (2000) identify four roles of SCM in construction. The main purpose of the first role, the interface between the supply chain and the construction site, is to match the material and labour flows with the requirements at the construction site. Vrijhoef and Koskela, (2000) argue that this can be achieved by "*focusing on the relationship between the site and direct suppliers*" (p. 171). In general, a large proportion of the work related to construction projects are performed by subcontractors. It is not uncommon for a main contractor to subcontract 80-90% of the work to a variety of specialised contractors, i.e. subcontractors (Hinze and Tracey, 1994). The subcontractors are often responsible for their own material supply (Sobotka et al., 2005) which indicates their importance as the link between the construction and material supply process. Consequently, subcontractor performance greatly affects the successful execution of construction projects (Proctor, 1996). Hinze and Tracey (1994) argue that the relationship between main contractors and subcontractors needs more attention.

> "*Although subcontractors plays a vital role in the construction process, little is known about the actual terms of working relationship that exist between subcontractors and general contractors.*"
>
> Hinze and Tracey (1994, p. 274)

It is generally acknowledged that adversarial relationships between subcontractors and main contractors are common in the construction industry (Latham, 1994). It is argued that this adversarial situation originates from the procurement practices used in the industry (Khalfan and Maqsood, 2014). These adversarial relationships are seen as the main obstacle for greater collaboration and integration (Dainty et al., 2001). This can be problematic from a main contractor's perspective since it is their responsibility to coordinate the subcontractors so that the project can be executed successfully (Tommelein and Ballard, 1997). Achieving coordination is a challenging task since the subcontractors perform their tasks simultaneously in close proximity to each other while competing for site resources such as space and equipments (Tommelein and Ballard, 1997). It is further complicated due to the strong interdependencies that exist between the activities that are performed at the construction site.

SCM initiatives in construction should focus on coordinating both the supply of materials to the site and materials at the site (Ekeskär et al., 2014). The first step should concern the improvement of coordination and communication between project participants (Ekskär et al., 2014). There is also a need for better understanding of the logistics concept since logistics is a prerequisite for supply chain integration (Vidalakis et al., 2011).

3.5 Logistics in construction

Logistics is an important element of construction since the cost of materials represents a large part of the total cost of construction. Studies have shown that logistics cost in construction constitutes 10-30% of total construction cost and in contrast to other industries the majority of costs are incurred at the construction site (Elfving et al., 2010). In addition to its influence on cost, logistics also affect the time it takes to execute the project as well as the quality of the end product (Sobotka et al., 2005). However, several researchers note that the logistics practices in construction is a considerable source of waste due to poor material handling and redundant inventory levels (Olsson, 2000; Vrijhoef and Koskela, 2000; Josephson and Saukkoriipi, 2007). Sobotka et al. (2005) argue that there are five reasons why logistics is more difficult in construction than in manufacturing; project diversification, project complexity, number of participants, tendering procedures and poor alignment of logistical routines between the project participants. For instance, construction projects with several subcontractors that are responsible for their own supply of materials, in combination with a lack of coordination and misalignment of logistics procedures will result in an unsynchronised flow of materials to the construction site (Sobotka et al., 2005).

Sobotka and Czarnigowska (2005) compiled a list of important logistics activities during the construction process. The activities related to the planning and production phase are partly summarised in table 3.1. An interaction between the main contractor and subcontractors can be perceived as important for logistics when it supports coordination and communication regarding these activities.

Table 3.1 - Logistics activities during the planning and production phase (Sobotka and Czarnigowska, 2005, p. 79 - 80)

Planning	Production
• Preparing schedules and charts of labour and equipment utilisation, subcontractor's work and material consumption • Preparing logistics concept of the building site • Planning and placing orders, scheduling deliveries • Waste management planning • Planning information flows management and methods	• Work progress monitoring • Schedules and plans update • Adjusting orders to current demand for resources • Planning and coordinating horizontal and vertical transport to site • Planning and coordinating deliveries, loading, unloading and warehousing, distributing deliveries to contractors • Managing waste

Construction logistics can be divided in supply and site logistics (Jang et al., 2003), as illustrated in Figure 3.3. Supply logistics relates to the procurement, transport and delivery of materials to the construction site (Jang et al, 2003). Site logistics concerns activities that are related to planning and controlling the material and labour resources at the construction site (Jang et al, 2003). For instance, preparation of site layout and scheduling can be understood as site logistics activities.

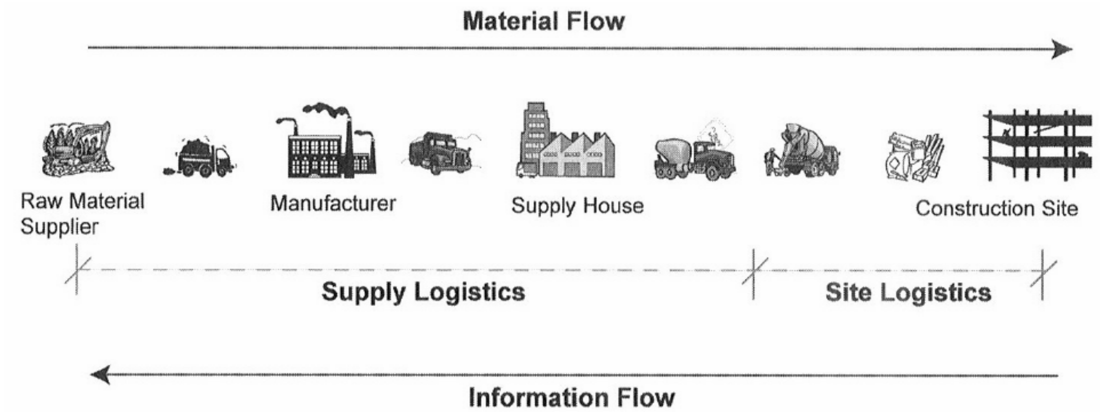

Figure 3.3 - Logistics in construction (Jang et al., 2003, p. 1134)

Coordinating the material flow with the production flow is a problematic endeavour in construction. Materials are in some cases ordered weeks or months before they are needed (Akintoye, 1995). The delivery to the construction site is usually included as a part of the purchase and it is often, in terms of price, advantageous to order in truckloads (Bertelsen and Nielsen, 1997). This approach to purchasing can result in redundant inventory, i.e. buffers of materials, at the construction site (Akintoye, 1995). Even if materials are delivered according to the production schedule, it is not uncommon that poor production reliability results in redundant inventory and unnecessary material handling at the construction site. How materials are ordered and delivered is influenced by the characteristics of the supply chain.

3.5.1 Construction supply chains

Sobotka and Czarnigowska (2005) note that there is much research regarding logistics and the supply chains in construction. However, they argue that much of this research takes a simplistic perspective and assumes that the supply chain is similar to other industries. Since construction is project based the supply chain of materials will be unique for every project (Winch, 2010). Additionally, geographical constraints and a varying input of material and components require specific storage and transportation solutions for each construction site (Ekeskär et al., 2014). Wegelius-Lehtonen and Pahkala (1998) identify three types of logistics chains, i.e. supply chains, with different supply characteristics; customised, standardised and small purchases. The three types of chains are illustrated in Figure 3.4. Depending on the type of materials, certain supply chain characteristics can be identified.

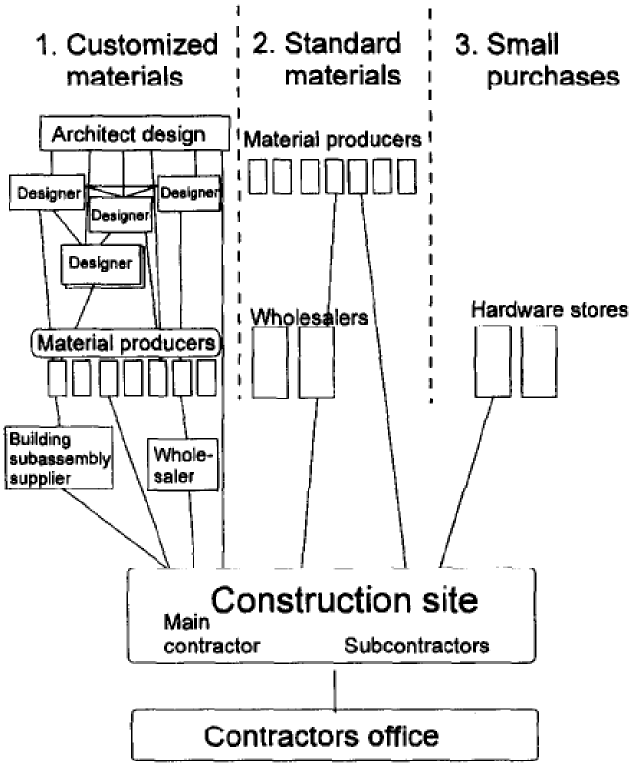

Figure 3.4 - Different types of logistics chains in construction (Wegelius-Lehtonen and Pahkala, 1998, p. 691)

Customised materials are typically design-to-order materials such as windows, concrete elements and kitchens while standardised materials like plasterboards and mortar, and small purchases are make-to-order or make-to-stock (Wegelius-Lehtonen and Pahkala, 1998). Materials that are customised generally have longer lead times from the time of order to the time of delivery than standardised and small purchases. This implies that customised materials require long term planning (Christopher, 2011). Standardised materials require extensive planning for unloading and transportation since they are often bulky and heavy and thus difficult to store and manage at the construction site (Wegelius-Lehtonen and Pahkala, 1998). For customised materials however, the majority of problems seem to originate due to poor communication. Wegelius-Lehtonen and Pahkala (1998) describe a situation where an electrical contractor had received information regarding the dimension of the room where the main fuse panels were going to be installed but not the size of the corridors leading to the room. Consequently, the fuse panels, due to their size, could not be moved through the corridors which resulted in additional adjustments at the construction site. To achieve efficient logistics, the various supply chains need to be matched with a demand at the construction site. However, this is argued to be problematic due to a high degree of supply and demand variability.

3.5.2 Supply and demand variability

Koskela (1999) suggests that the production in construction can be perceived as an assembly based operation where task execution is dependent on resource flows. In other word, tasks on the construction site require certain preconditions before they can be executed. Koskela (1999) identify seven resource flows;

- Construction design
- Components and materials
- Workers
- Equipment
- Space
- Connecting works
- External conditions

Due to the variability of these resource flows, it is not uncommon that only 60% of the daily planned activities are completed (Ballard and Howell, 1998a). A reduction of variability means that it becomes easier to coordinate the production flow with the flow of materials (Koskela, 1992). Indeed, it is essential to maintain a reliable production flow so that it becomes easier to predict when materials are required on site (Akintoye, 1995). Project performance is directly related to the variability of the material and production flow and Arbulu and Ballard (2004) illustrate this with three theoretical scenarios; *utopia*, *reliable supply and variable demand*, and *variable demand and supply*. The three scenarios are illustrated in Figure 3.5.

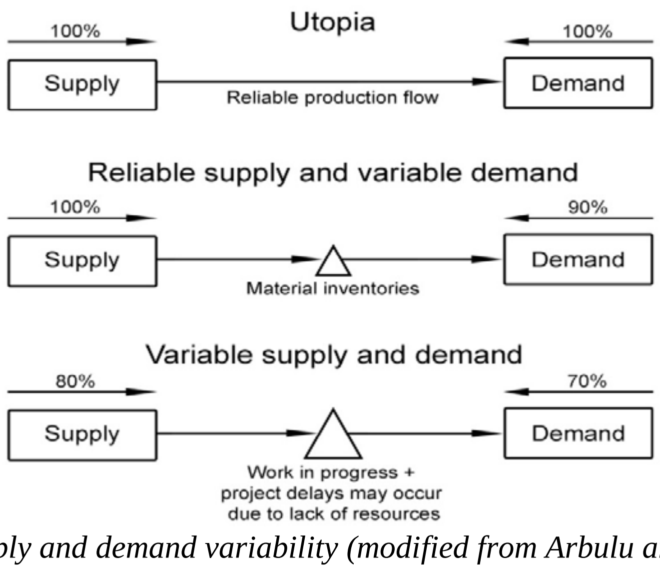

Figure 3.5 - Supply and demand variability (modified from Arbulu and Ballard, 2004, p. 5-6)

In a perfect world, there would be a reliable production flow that matches a reliable flow of materials, an utopia. However, an activity that is not completed according to the schedule would mean that the demand of the production flow does not match the supply of the material flow which would result in inventory at the construction site. This is the second scenario, reliable supply with a variable demand. The third scenario, where both the demand and supply is variable is suggested by Arbulu and Ballard (2004) to be the closest one to reality. However, they also stated that it is a simplification since it does not consider the entire complexity of the supply chain.

The most common method used to solve the matching problems is by keeping buffers of materials to absorb the variability of supply, i.e. the material flow, and demand, i.e. the production flow (Arbulu and Ballard, 2004). Having on site buffers of material entails both advantages; absorbing the uncertain conditions of construction (Horman and Thomas, 2005) and the variability of material supply (Arbulu and Ballard, 2004), and disadvantages; cost of storage and slowing detection of problems (Horman and Thomas, 2005).

Reducing buffers of materials at the construction site is according to Akintoye (1995) one of the principles of just-in-time (JIT). In a JIT production system, replenishment of material starts when that material is used, unlike a traditional production system, where material is pushed from one process to another even if the next process does not need the material. Material delivery according to the JIT principles requires good communication and planning by both the ones supplying materials and the ones receiving materials (Akintoye, 1995). However, Horman and Thomas (2005) argue that even though some variability might be reduced through improved planning, it is unlikely that all variability of can be removed. They examined the correlation between inventory buffers and construction labour performance. By investigating the manufacturing and assembly of steel reinforcement in three similar projects, they noted that "*it seems that zero inventory is related to poor labor performance, while an excess inventory does not improve labor performance*" (Horman and Thomas, 2005, p. 841). For this reason, they argue that buffers are needed to absorb some of the variability of construction. However, congested construction sites lack space for buffers which indicates that variability must be counteracted in another way.

3.6 Congested construction sites

A common problem when constructing in urban areas is the general lack of space at the construction site. This implies that space for materials, equipment, and workers are limited which further complicate the already complex nature of construction. This is an emerging area of research since Boverket (2012) expect urbanisation in Sweden to increase over the next few decades. Urbanisation, in combination with urban population growth will result in denser urban environments (Ljungberg et al., 2012). Spillane et al. (2011) however note that there is gap in the current research concerning the issues related to material management at confined construction sites. Spillane et al. (2011) identify five issues related to material management on confined construction sites:

1. *Contractor's material spatial requirements exceed the available space*
2. *Difficult to coordinate the storage of materials in line with the programme*
3. *Location of the site entrance makes delivery of materials particularly difficult*

4. *Difficult to store materials on site due to the lack of space*
5. *Difficult to coordinate the storage requirements of the various sub-contractors*

Spillane et al. (2011, p. 31)

Scarcity of space means that spatial planning becomes essential in order to reduce the risk of collision between workers, stored materials and equipment (Riley and Sanvido, 1997). In construction, the use of interior space is challenging due its dynamic nature and previous research does not provide a sufficient foundation for logistical planning when space is limited (Said and El-Rayes, 2012). Spillane et al. (2011) argue that: "*Due to spatial restriction, effective logistics management should result in more proactive and productive utilisation of materials on confined construction sites*" (p. 27). Indeed, material and labour requirements as well as construction method should be carefully considered during an early stage to reduce the risk of problems and delays at a later stage (Burch, 1985). Furthermore, "*When working on confined sites and during the early planning stages of the contract, sub-contractors and suppliers must be made fully aware of all restrictions and difficulties imposed upon them by the nature of the site*" (Burch, 1985, p. 78). It seems that congested construction sites require an additional focus on logistics in order to match the material flow with production flow.

3.7 Matching material flow with production flow

Previous discussions have shown that there are significant challenges when it comes to matching the material with production flow, especially when space for storage at the construction site is limited. It seems that there are two principal elements for achieving a match between the two flows; *increasing coordination between supply and demand* and *increasing production reliability*.

3.7.1 Increasing coordination between supply and demand

Coordination between supply and demand essentially concerns communication between the ones who perform activities at the construction site and the ones providing the site with materials. In many cases, activities at the construction site are performed by subcontractors who also are responsible for acquiring the materials required for those activities. The activities suffer from strong interdependencies which results in a need for extensive coordination among subcontractors. Consequently, this '*activity or subcontractor coordination*' is a prerequisite for the coordination of the supply of materials. This calls for a *"holistic view of procurement and the planning and control of material deliveries"* Agapiou et al. (1998, p. 136).

3.7.1.1 Logistics coordinator

The large number of participant at the construction site makes it hard to acknowledge and support all their individual needs. It is not unusual that protection of individual needs result in sub optimisation (Olsson, 1998). Olsson (1998) argues that mutual understanding is a prerequisite for better coordination among participants and found that there has been an increasing interest among construction clients in Sweden to demand that contractors employ a subcontractor coordinator in their projects. The coordinator can be seen as an intermediary between different actors that ensures mutual adjustment between them. The purpose is to secure that the client objectives are met through a production that runs smooth and efficient (Olsson, 1998). Traditionally, this is not the case, since the various actors are preoccupied with their own work and offer limited interest in the needs of others. Agapiou et al. (1998)

highlight the problems associated with subcontractors acquiring their own material, where the objective is to get the lowest possible purchasing price without considering the costs for material handling. They found that a material coordinator offered several advantageous in that material deliveries were coordinated to and within the site. However, they also found there was some scepticism among subcontractors towards this extra link in the supply chain. This meant that subcontractors lost their direct contact to the supply process which required them to work proactive through planning their material purchasing, which traditionally was conducted on ad hoc basis (Agapiou et al. 1998).

3.7.1.2 Collaboration

Wegelius-Lehtonen and Pahkala (1998) found in their case study that the majority of problems related to material flows originate in the boundaries between organisation and different departments. They suggest that material and information flows can only be coordinated if there are collaboration between the links in the supply chains. This requires both the contractor and material suppliers to produce delivery practices together so that both parties can benefit from cutting logistics cost and facilitating efficient information flows (Wegelius-Lehtonen and Pahkala, 1998). Similarly, Thunberg et al., (2014) argued that poor coordination between actors stems from either the design process or the supply process. The choice of material in the design process will have impact on the configuration of the supply process since this will determine the choice of supplier. In turn, this will have consequences on cost and lead times for the specific material or components. Furthermore, Thunberg et al., (2014) also found that the majority of problems detected are not solved during preconstruction. In contrast, they are solved ad hoc on the site according to a *"fire-fighter mentality"* (Thunberg et al., 2014, p. 1077). They suggest that planning should be made co-jointly in order to exploit the knowledge and information from all the concerned actors. This is in clear contrast to how traditional planning is conducted in construction, where the main contractor's push their plan to the subcontractors letting them produce their own plans (Thunberg et al., 2014).

Problems concerning poor coordination are evident in the internal organisation as well. Due to the project nature of construction it is common that contractors purchase materials and components both through centralised and decentralised departments (Dubois and Gadde, 2002a). Thunberg et al., (2014) found that the internal departments can be uncoordinated which cause problems on site. For example, faulty plans, lack of information, faulty materials etc. is a consequence of poor coordination internally and between external actors during preconstruction (Thunberg et al., 2014).

3.7.2 Increasing production reliability

Production reliability is a prerequisite for efficient logistics since poor production reliability makes it harder to match the flow of materials with the actual requirements at site (Elfving et al., 2010). For instance, a redundant inventory of materials at the site would accumulate if only 50% of the planned activities are completed since materials often are ordered and delivered according to the production schedule. Indeed, "*Logistics can only be as good as the production management*" (Elfving et al., 2010, p. 229). According to Koskela (1999), contemporary production management in construction follows the following pattern; a master schedule is prepared which is later used as a foundation for more detailed production plans. During the production, the variability of the resource flows causes the master schedule to become out dated which ultimately results in task management being done on ad hoc basis at the construction site (Koskela, 1999).

Ballard (1994) conducted a survey in order to identify the most frequent reasons why planned work was not completed. The three main obstacles identified were; lack of materials, prerequisite work not completed and a lack of information. This indicates that there is poor match between the material and production flow, and also the importance of coordination between subcontractors at the construction site. Consequently, a lot can be gained by improving the quality of planning (Ballard, 1994). Improved planning can result in: a reduction of delays; make it easier to choose the correct sequence of activities, and; promote better coordination between interdependent activities at the construction site (Ballard, 1994).

Traditional project planning in the construction industry focus on producing plans and schedules that dictates what *should* be done (Ballard and Howell, 1997). The dynamic nature of the construction industry, with variable resource flows in combination with uncertain completion of prerequisite work limits what work that *can* be done (Ballard, 1994). Consequently, if an activity cannot be done, there will be a mismatch between the work that *should* be done, and the work that *will* be done (Ballard, 1994). The Last Planner System was developed by Glenn Ballard and it focuses on what activities that *can* be done, in contrast to traditional planning that focus on what activities that *should* be done, illustrated in Figure 3.6. The LPS is a collaborative way of planning construction activities at the last responsible moment. The purpose of the last planner is to create a reliable production flow by performing the detailed planning, together with the ones doing the work, when you get closer to the actual work. (Ballard, 2000)

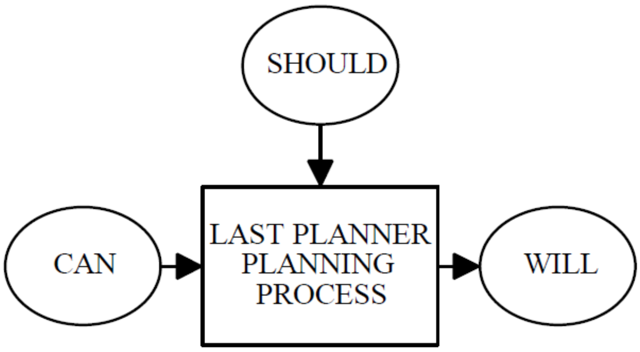

Figure 3.6 - The last planner process (Ballard, 1994, p. 4)

The last planner is the individual who plan the assignments that are supposed to be done in the near future. A constraint analysis is performed in order to determine if the assignments that *should* be done *can* be done, i.e. are all the prerequisite work completed and are all the resources required available. Only assignments that can be done are committed to and distributed to production. The numbers of executed activities are compared with the number of planned activities in order to facilitate continuous improvements and to evaluate the causes of failures. (Ballard, 1994)

Ballard (2000) demonstrates that production plan reliability could be increased by implementing the 'Last Planner system'. Ballard (2000) noted that "*constraint analysis and subcontractor participation in planning and control*" (p. 9-7) was important in order to achieve this high plan reliability.

3.8 Summary

The strong interdependencies at the construction site in combination with the variable resource flows create a need for extensive coordination between the project participants. This coordination requirement increases when there is a limited amount of space at the construction site and buffers cannot be utilised to the same extent. This is problematic from a logistics perspective since buffers traditionally are used to absorb the variability of production. Consequently, congested construction sites require additional focus on receiving the right amount of materials at the right time which suggest a need for increased coordination between the supply and demand. This further indicates the need for coordination between the actors at the construction site since the subcontractors are responsible for their own material supply. Receiving the right amount of materials at the right time also indicates a need for a reliable production flow in order to facilitate match between supply and demand.

In this thesis, the interactions between a main contractor and subcontractors during the planning and production phase have been examined in order to evaluate their importance for logistics. An interaction can be perceived as important for logistics when it supports coordination of material flow processes, i.e. logistics activities, and ultimately the match between the material and production flow. Figure 3.7, influenced by Olsson (2000), illustrates the scope of this thesis.

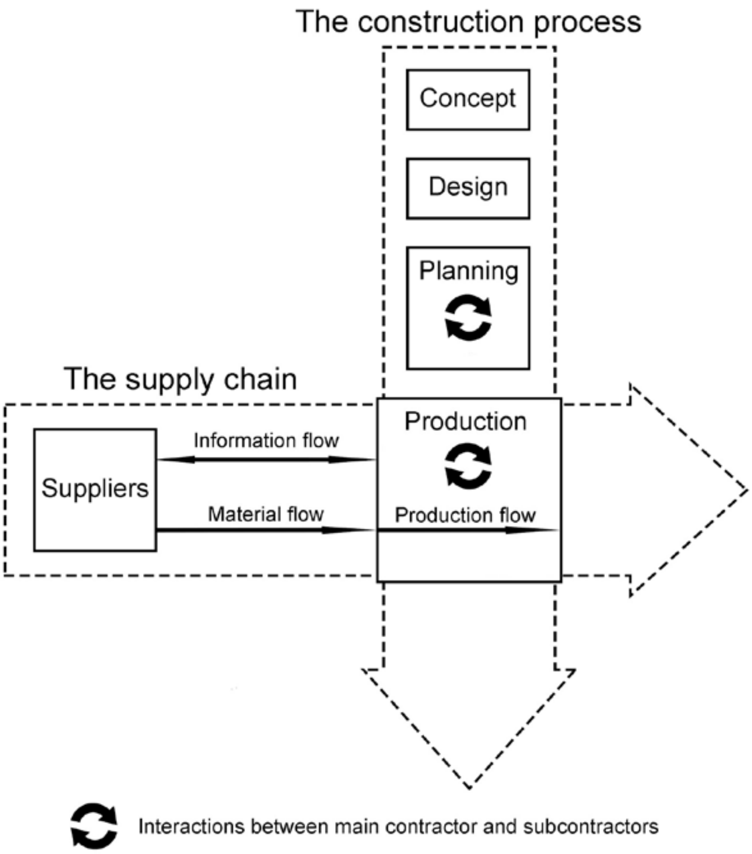

Figure 3.7 – A conceptual model illustrating the scope of this thesis (modified from Olsson, 2000)

4 Empirical Findings

This chapter introduces a case study of a construction project that suffers from severe time and space restrictions. The first section contains a description of the construction project. The second section presents an account of the interactions between the main contractor and subcontractors that occurred during the planning and production phase of the project. In the third, the focuses of the meetings are discussed in regards to material flow processes. Finally, the fourth section presents the subcontractors' perspectives of the logistics.

4.1 The Gårda project

Peab Sverige AB have been commissioned to design and build an office building, Gårda 3:14, and to refurbish an existing office building, Gårda 3:12. The construction site is located in Gothenburg, Sweden, and the whole project has a contract sum of 170 million SEK. Gårda 3:14 is built from scratch and will eventually form a six stories high office building of approximately 10,000 square meters. Construction work started in March 2014 and the project is estimated to be completed in September 2015. The adjacent Gårda 3:12 include a refurbishment of an existing building that enclose approximately 8,000 square meters. This study focuses on the new construction but observations have also been made of the refurbishment.

Figure 4.1 - Gårda 3:14 from Anders Personsgatan and Norra Kustbanegatan, Gothenburg, Sweden.

The construction site is surrounded by roads and existing buildings, as can be seen in Figure 4.1. The conditions of the surrounding environment created a lack of space for materials, equipment, and workers at the construction site. The narrow road next to the construction site offers limited space for trucks to deliver materials. In addition, the roads carry on going traffic, which further complicated the logistical situation. The spatial restrictions of the site, in combination with a tight time schedule, have resulted in an increased focus on coordination between project participants in order to improve the logistics. Logistics procedures have been developed by Peab in order to create a shared understanding of the project logistics prerequisites. There are approximately 25 subcontractors involved in the project. Four of these subcontractors responsible for respective work related to; electrical- HVAC- plumbing- and sprinkler installations had a higher level of involvement during the planning phase. These four subcontractors were chosen since they have significant roles during the production. The purpose of this approach was to utilise the subcontractors' knowledge and expertise, while at the same time provide transparency and mutual understanding for each other's activities. In addition to collaborative planning, Peab also used a logistics coordinator in order to improve the supply and site logistics. The next section contains an account of the interactions between Peab and the subcontractors that occurred during the planning and production phase in the Gårda project.

4.2 Interactions between Peab and the subcontractors

The first interaction between Peab and the subcontractors occurred during the tendering process. The tendering documents that the subcontractors received contained an attachment that described the project's logistical situation and the procedures that had to be followed by all the project participants in order to achieve the projects logistical goals:

- Support the work process by using visual aids
- Increase delivery precision and secure resources for unloading
- Use materials that are easy to transport and assemble
- Reduce material inventory and unnecessary material handling
- Keep the construction site organised and clean
- Reduce material waste and achieve a high degree of waste sorting

The logistics attachment also contained information about: how to book deliveries to the construction site; how the material should be packed and labelled; alternatives for unloading; how materials are supposed to be stored at the construction site; demands for cleaning, and; information about waste management at the construction site. The attachment also described the limitations of the equipments used for unloading, i.e. capacity of the building elevators and the crane.

In order to further clarify the construction site logistics prerequisite the subcontractors were provided with a site disposition plan that, for instance, illustrated the transportation routes, delivery areas and how the building elevators are positioned, see Figure 4.2. The disposition plan was adjusted during the production phase to correspond to the current situation at the site.

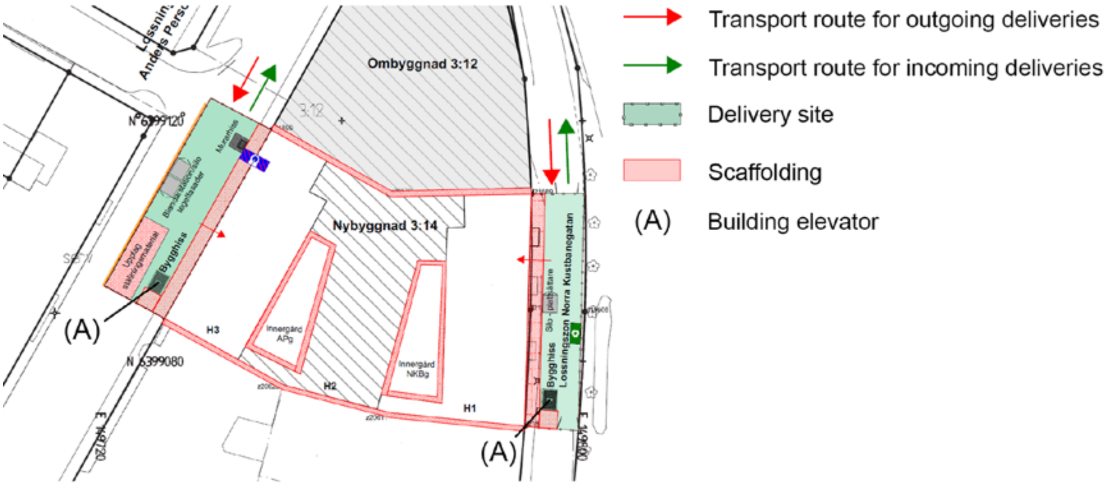

Figure 4.2 – Part of the site disposition plan

During the planning phase of the project, four project managers from the selected subcontractors participated in individual meetings with a project planner. The main purpose of these meetings was to clarify the work of the subcontractors during the production. The time it takes to perform the activities and the subcontractors expected labour requirements for the different activities were discussed during the meeting. The project planner (2015) pointed out the importance of these individual meetings as the subcontractors have an opportunity to express their requirements and preferences for the work that they will perform. A preliminary production sequence was presented and the subcontractors had the possibility to express how it affected their activities.

The subcontractors' site foremen and project managers along with representatives from Peab participated in a collaborative planning session during the planning phase of the project. The meeting was facilitated by the project planner and the main purpose of this session was to: create a team spirit and a common understanding of each other's activities and obligations; to discuss the sequence of the production, and; to produce a foundation for the production schedule in a collaborative way (Project planner, 2015). During the session, the discussion of the different activities also aimed to highlight potential critical problems that could affect the production.

The subcontractors were asked to prepare post-it notes for all the activities they were supposed to undertake in the production phase. The subcontractors also wrote down information about the time and labour requirements of each activity. A structure was developed by discussing the sequence of the activities. The project planner asked for the first activity in the production sequence. After a group discussion, the post-it note corresponding to the first activity was put up on a whiteboard. Then the project planner asked for the subsequent activity to be carried out. Once this process was completed, a structure existed that served as a foundation for the production schedule. This approach provided the project participants with a common understanding of each other's activities and it highlighted relationships' between the different activities.

When the production schedule was established and the production had started, project progress meetings were held approximately once a month. The purpose of these meetings was to check if the production was on schedule and to make adjustments to the schedule if necessary. All the subcontractors that had on going activities on the construction site and representatives from Peab participated in these meetings. The production site manager, the project planner and the subcontractors' project managers and foremen usually attend. During the progress meetings, the progress on the construction site was compared with the production schedule. 20% of the meeting time concerns the past, i.e. what have been done, and 80% concerns the future, i.e. how to proceed (Project planner, 2015). There was no percentage measurement of the accuracy of the plans but the causes for discrepancies were discussed. The production site manager (2015) argued that it was beneficial to perform these meetings in one big group instead of individual meetings with each subcontractor to increase transparency and to prevent concealment of the actual progress.

One of Peab's site supervisors has been assigned the role as a logistics coordinator for the project. The logistics coordinator was responsible for: coordinating material deliveries to the construction site, both for Peab and the subcontractors, and; ensuring that there was equipment available for the material movements from the delivery area to the workspaces on the different floors. The logistics coordinator compiled all the incoming deliveries on a 'delivery board' that was visible for all the project participants (see Figure 4.3). The subcontractors' and Peab's own personnel contacted the logistics coordinator to request time for delivery. Several aspects were considered when evaluating an incoming delivery: when is the material needed; the type of vehicle used to deliver the material; equipment needed to get the materials to the workspace and, the type of material included in the delivery with regards to size, weight and quantity.

Figure 4.3 - The delivery board

The delivery board and future deliveries were also discussed during the operation meetings that were held once a week on Mondays. The operation meetings usually involved the site supervisors from Peab, the logistics coordinator and the subcontractors' foremen. The meetings were facilitated by a site supervisor from Peab and the discussions mainly focused on production issues that the foremen and supervisors had encountered during the previous week. The meeting followed an agenda that included health and safety, upcoming deliveries, the progress made, and what needed to be done during the week. During these meetings, the subcontractors were asked if they need any material delivered to the construction site in the upcoming week. The subcontractors that required delivery of bulk materials or materials with long lead times were supposed to provide the logistics coordinator with a delivery plan. The delivery plan should, in addition to time and date of the delivery, contain information about what type of materials the delivery concerns, what quantity and what equipments that are required for the unloading. For occasional deliveries it was enough to send an email or to call the logistics coordinator. Small materials and minor equipment that did not require extensive time and space for unloading were often brought to the site by the subcontractors without any contact with Peab. In order to minimise worker collisions at the construction site, post-it notes were used on drawings to illustrate where the workers were going to be performing activities during the upcoming week (see Figure 4.4). At the end of the meeting, all the participants took turns expressing issues that they wanted to discuss. The operation meetings were primarily important for site logistics while the subcontractor coordination meetings were especially important for the supply logistics (Site production manager, 2015).

Figure 4.4 - Workspace coordination

Every second week, there was a subcontractor coordination meeting that were participated by the project managers, the logistics coordinator and the production and administrative site managers. During these meetings a large variety of production related topics were discussed: production progress; number of workers currently working at the site; health and safety, and; other issues that have emerged. In addition, subcontractors could notify if there were upcoming deliveries that required consideration.

Another effort to increase coordination at the construction site was the introduction of pulse meetings every Thursday. At these meetings, the subcontractors' foremen and site supervisors from Peab discussed production related issues for 15 minutes. What has been completed and what should be done next? These meetings were held to improve coordination and to solve problems in a collaborative manner when they occurred. The interactions between Peab and the subcontractors are summarised in Figure 4.5.

Construction phase	Interactions
Planning	Interactions during the tendering process Initial meeting with the project planner Collaborative planning session
Production	Project progress meetings Subcontractor coordination meetings Operation meetings Interactions with the logistics coordinator Pulse meetings

Figure 4.5 – Interactions during the planning and production phase

Participatory observations were made during four of the meetings: the project progress meetings, the subcontractor coordination meetings, the operation meetings and the collaborative planning session. The logistics focuses of these are presented in the next section.

4.3 Focus of the meetings

Most of the interactions with the subcontractors focused on production related issues. Figure 4.6 illustrates the scope of the discussions in relation to material flow processes. The interactions during the production phase did not involve any discussions regarding the subcontractor's ordering procedures. Ordering was briefly considered during the collaborative planning session, but this consideration was limited to issue of volume and labelling. Subcontractors' deliveries were occasionally addressed during both the project coordination meeting and the operation meeting. However, in general the material flow processes received little attention during any of the interactions.

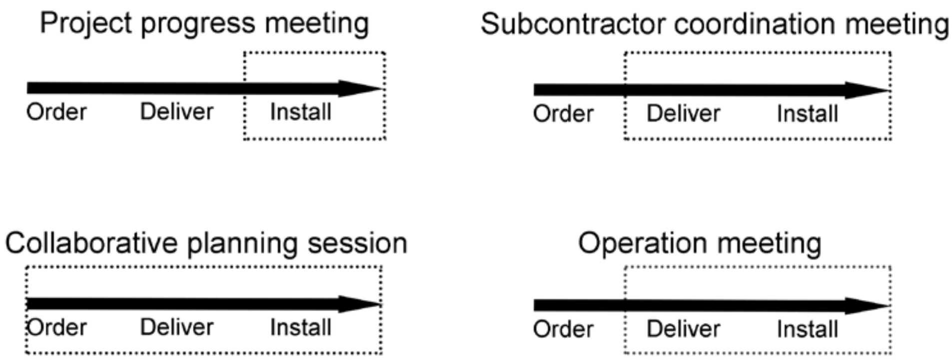

Figure 4.6 - Discussions regarding material flow processes identified during the observations

The next section presents the subcontractors' perspectives of the logistics in the Gårda project.

4.4 Subcontractors’ perspectives

In general, the subcontractors perceive that the logistics of the project have functioned well. “*It has worked far better than we had imagined, I thought it would be complete chaos, but so far it has progressed smoothly”* (Foreman, 2015b). A majority of the subcontractors believe that the collaboration between the project participants has functioned well despite that many subcontractors had never worked together before (Project manager 2015a; 2015b; 2015c).

4.4.1 Logistics prerequisites

The logistics attachment included in the tendering documents has received modest attention from the subcontractors. This document should primarily be of interest for the project managers who are involved during the tendering process. However, the project managers barely recall this document, as one project manager (2015a) stated; *“I do not remember any logistics attachment but logistical issues have been communicated frequently both before and during production. This has made me think differently, nagging on my guys to clean up after themselves and only order material in a just-in-time manner”*. Another project manager stated that he might have read through the document quickly, but thought that information regarding the logistics prerequisites was only important if the construction site would be located in urban areas where public transport is present (Project manager, 2015b). The project manager further stated that this project was not as problematic since there were two delivery areas. Despite that the logistics attachment has received little attention from the project managers there was a consensus that the logistics issues have been discussed in an early stage during the collaborative planning session, which created a more proactive way of working with logistics. One foreman (2015b) stated that: “*I did not see any logistics attachment, but the construction sites space limitations were presented together with the site disposition plan. The logistics coordinator also emphasised that every delivery should go through him*”. All of the project managers remembered the collaborative planning session as the first interaction with Peab.

4.4.2 Collaborative planning

Logistical issues were not the main focus of the collaborative planning session. However, the subcontractors were introduced to the site disposition plan and got information regarding the projects logistics procedures and the site constraints. This has affected the subcontractors’ logistics practices during the production. As one foreman (2015b) stated that: “*we probably understood quite early that we were unable to do as usual, we cannot order everything at once and hope for the best*”. The main purpose of the collaborative planning session was to establish the sequence of the production schedule, which was important from a logistics perspective since: “*a good production schedule leads to better logistics*” (Project manager, 2015b). The majority of the interviewees regarded the collaborative planning session as beneficial for the overall project performance. One project manager stated that: *“I think it was great and we received much critical information. We got the opportunity to really highlight critical issues and bringing them up for discussions. Discussions regarding the planning structure are important and we got plenty of information regarding time requirements for different activities”* (Project manager, 2015b). During the collaborative planning session several problems could be solved by group discussions. For instance, one of the project managers could not estimate the amount of time one activity would take since he lacked sufficient drawings and specifications. However, by combining the information from the different participants the group could estimate how the activity would be conducted and thus the amount of hours it would require. According to two of the project managers (2015a; 2015b), the collaborative planning session could be improved by allocating more time to early problem solving and by dividing the session into two days. If the session was divided into two days, one could go deeper into the critical issues instead of getting stuck in discussions about the production sequence. They also argued that this type of planning was new for them, and that there should be a pre-planning meeting so that every participant could get sufficient information on how the session would be conducted. There was also a proposal that additional time should be allocated to examine the boundaries of the subcontractors' obligations. In other words, to sort out the responsibilities of the various parties. This could be beneficial since the contract documents often are unclear and sometimes contain contradictory information (Project manager, 2015b). Uncertainties regarding responsibilities could be discussed and solved at an early stage if everyone would be prepared better for the meeting, rather than creating confusion and irritation during the production (Project manager, 2015b).

Several of the subcontractors expressed severe dissatisfaction with the project drawings and specifications. One of the project managers stated that the quality of the design is crucial for design-and-build contracts since drawings and specifications are not completed before tendering and partly develops in parallel with the production (Project manager, 2015a). Problems related to insufficient drawings and specifications could partly be solved during the collaborative planning session. For example, one of the subcontractors did not know how to make certain connections owing to lack of information regarding the height of the ceiling. For this reason, the project planner brought up a digital 3D model of the office building. The group could together orientate themselves within the building and could visualise how each of their installations was positioned in relation to each other. This added to a common understanding, even though several participants noted that there was a lack of information about the installations fixings. Some of the subcontractors expressed that additional resources should be allocated in order to solve problems related to drawings and specifications during the collaborative planning session. For instance, one project manager (2015a) and one foreman (2015b) expressed that peoples responsible for creating the design documents should be present at the collaborative planning sessions so that their expertise could be taken into account, since: *"they are the ones with the greatest knowledge during this stage of the project"* (Foreman, 2015b). Additionally, several of the subcontractors expressed the idea of involving more subcontractors in the planning session. One project manager (2015b) stated that: "*it is a pity that not all the trades participated … it might have been better*". This is supported by the production site manager (2015) who argued that the success of a construction project is dependent on all the participants. This was also highlighted by one of the foreman (2015a), who argued that: *"... but greater subcontractors, such as the painter and bricklayer, should not be excluded from this meeting. For example, it is very important for us to know where the bricklayer puts their material. All those subcontractors with great material volumes should be involved"*. Peab represented those subcontractors as they were not invited for the collaborative planning session. However, Peab did not have complete knowledge of all their activities and could not always answer questions regarding their work.

Some of the subcontractors argued that the collaborative planning sessions facilitated a better understanding of each other's activities, and that their time and space requirements were taken into account (Project manager, 2015a; 2015b). However, the project manager (2015a) also stated that this type of planning opens for "*unjustified time requirements*", implying that some actors might exaggerate the amount of hours one activity takes in order to cope with risks and other contingencies. Tendencies to such behaviour were seen during the participatory observation. During the planning session, the project planner reacted to one of the time requirement estimations. The project planner asked the subcontractor again if he really needed that many hours to perform the activity. The subcontractor responded that the estimation corresponded to the needs which resulted in strong reactions among several of the other participants that also seemed to question the estimated amount of hours. One project manager (2015c) argued that there needs to be a greater understanding of the work that subcontractors are supposed to perform, "*If I say I need 6 weeks then I need 6 weeks ... it is not the same as 3 weeks with double labour capacity*". The collaborative planning session can to some degree contribute to a better understanding but it would be better if Peab would consider the subcontractors' perspectives to a greater extent (Project manager, 2015c)

Subcontractors' opinion on whether planning in collaborative manner leads to better production schedule reliability varied significantly. One foreman (2015b) argued that the planning session was worthless since 98% the production sequence is the same for every project. He further stated that: "*Well, we can see that now. We revised the schedule one month ago and we are already two weeks behind. Collaborative planning does not lead to better plan reliability and the worst part is that it is the subcontractors that will be punished and forced to catch up towards the end*" (Foreman, 2015b). However, the foreman thought that the session was a good way to get to know the people executing the project. Communication during production was improved since you knew "*who is who*" (Foreman, 2015b). This was supported by the project managers (2015a; 2015b) who argued that the collaborative planning session resulted in a better understanding of each other's space and time needs and it also offered the possibility to get to know each other before the production started: "*You are more inclined to contact someone if you have met them before and thus it becomes easier to collaborate*" (Project manager, 2015a). It seems that the majority of the subcontractors thought that issues such as communication and collaboration during production were enhanced by the collaborative planning session. One project manager (2015a) stated that the production schedule gets more credible if you can take part in the planning and that the relationships between actors get better. He further stated that collaborative planning at an early stage was a good opportunity to take advantage of each other's expertise and to solve problem together. This was also was supported by another project manager (2015b).

4.4.3 Supply logistics

The interplay between purchasing and production is important for the logistics of a project. This was highlighted by the logistics coordinator who described an example related to the ordering of windows. The labelling was forgotten when the windows were ordered which resulted in deliveries with unclear marking of which floor the various windows were going to. Consequently, this resulted in extra work of sorting and repackaging the windows correctly. He argued that: "*there should be better communication between purchasing and production*" (Logistics coordinator, 2015).

This is supported by the project planner (2015) who argued that purchasing is an important part to consider when planning the production. The project planner (2015) stated that: "*There are three main points in time that needs consideration: when should the materials be purchase; when should the materials be delivered, and; when should the materials be installed*". The time for installation is illustrated in the production schedule and the materials have to be delivered accordingly. The time for purchase, i.e. when to order the materials, will in turn depend on the lead time of the materials. The project planner (2015) thought that during this project there had been an absence of a structure that clarifies the connection between 'when to purchase' and 'when to install'. He referred to the internal procedures of Peab but there also seems to be a lack of transparency between the subcontractors' purchasing procedures and the production: "*Peab have a limited insight in the subcontractors purchasing procedures and the lead times for their materials*" (Production site manager, 2015).

The subcontractors' materials and components with long lead times, such as ventilation ducts or armatures, were in general ordered by the project managers while materials with shorter lead times were ordered by the foremen. Materials with short lead time usually required little adjustment and orders are placed throughout the project by keeping track of what is needed at the construction site. The majority of the subcontractors used the production schedule in order to determine when the materials with longer lead times were required at the construction site. One project manager (2015a) ordered the material as soon as he knew what needed to be ordered, i.e. when the design is finalised, while another project manager (2015b) waited as long as possible since he expected the production schedule to change. All of the subcontractors have tried to order smaller quantities of materials to avoid material stockpiles at the construction site. This is a trade-off since a greater number of deliveries to the construction site imply an increased use of the delivery areas and surrounding roads (Logistics coordinator, 2015). The quantity of materials and numbers of deliveries were also explained by one of project manager (2015c) as a matter of economics. Few deliveries with larger quantities meant that the subcontractor had to pay a large amount of money long before installation of the materials. This was problematic since: "*we have to pay for all the materials directly and we only get paid after it is installed … in a perfect world the material would be installed immediately after delivery*" (Project manager, 2015c). However, from an administrative perspective fewer orders were better since every order entailed a placement call, an order confirmation and a delivery: "*when you order materials then you have a logistics problem, it's always a problem*" (Project manager, 2015c).

Two of the project managers (2015b; 2015c) pointed out the importance of a reliable production schedule. One project manager (2015b) explained that some deliveries had to return with materials to the suppliers due to delays at the construction site. In these situations, the project managers usually tried to stop deliveries before they were sent, but they did not always receive information about delays. In some cases, materials were brought into the site even though they could not be assembled. One foreman (2015c) described his ordering process: "*I use the drawings and production schedule to determine what is needed ... I might order materials week 3 if I want them to arrive at the construction site week 8. I do this to ensure that the manufacturer have time to produce the parts*". The materials were unique and designated for a specific part of the building. This meant that delays and change of production sequence would result in the accumulation of materials on the construction site (Foreman, 2015c). In regard to this, one project manager (2015b) stated that: *"It is important to have an accurate production schedule in order to avoid large material stockpiles at the construction site*". The status of the production schedule and the need for updates were evaluated at the project progress meetings. The majority of the subcontractors argued that it was beneficial that all participants were involved in this meeting since everyone got a holistic understanding of how the project was progressing. It was also argued that this facilitates a more honest update since: *"one cannot lie on how they are progressing since everyone is present and know how the reality on the site looks like"* (Project Manager, 2015a). However, one foreman (2015b) argued that Peab made changes without considering the consequences for other actors, and stated that: *"we need more time for reflection"*. He specifically referred to one example where Peab changed the production sequence for the upper ceiling without considering the subcontractors that had related activities. Several of the subcontractors also stated that there should be more emphasise on the future planning during these meetings. The project manager (2015a) argued that the there was too much focus on the past and that the activities in the schedule was just pushed without further consideration. Instead, a more realistic and detailed future planning would be useful, including the consequences from schedule changes to be discussed and considered from everyone's perspectives: *"I need to have detailed information regarding those subcontractors that perform activities that are related to ours"* (Project Manager, 2015a).

There might sill be problems even if the subcontractors were well aware of the actual progress and the need for order changes. One project manager (2015a) stated that: *"changes often results in a catastrophe since the suppliers do not think like us"*. He referred to one example when he changed the armatures order to a later delivery date. Despite this, the armatures arrived to the site on the previously stated delivery date. Consequently, 10 pallets with armatures had to be stored and moved around on the site. The project manager (2015a) noted that suppliers are very diffuse when expressing the delivery date. For instance, suppliers can provide a date but it is unclear whether this date refers to shipping date or actual delivery date. In addition to the suppliers' delivery flexibility, the suppliers' delivery precision also seemed to be a problem for several of the subcontractors. One foreman (2015c) said that it was difficult for the suppliers to deliver at a specific time: "*If we notify the logistics coordinator that we have a delivery at 9 o'clock, the supplier might arrive at the site between 7 to 12*". One project manager (2015b) thought that the deliveries have worked well in this project and that it was good with not too demanding requirements for deliveries. He referred to another project where the suppliers had been denied to deliver to the site due to late arrival. This had not been the case during this project.

Several of the subcontractors had little knowledge about when certain deliveries would take place and what they contained. For example, at least two times, deliveries for subcontractors arrived to the site, but none of the subcontractors knew what the deliveries contained and they were both surprised by this. Similar observations were made during a subcontractor coordination meeting. Deliveries seemed to be even more problematic if there was a third party involved in the transportation from manufacturer to the construction site. One of the project managers (2015a) stated that: *"When the manufacturer delivers the goods in their trucks the arrival are more precise. It is harder to match the deliveries with production when forwarders are involved"*. This was supported by another project manager (2015b) who stated that: "*it is difficult to get the forwarders to adjust to us*". There was a clear consensus among the subcontractors that the operation meetings were the most important for coordinating deliveries to the site. During these meeting the upcoming activities for that week were discussed and major deliveries, together with an update on the delivery board, were brought up. However, due to poor delivery precision, subcontractors could only specify the day for deliveries to arrive. Instead, the majority of subcontractors stated that a more precise delivery time was communicated to them the day before delivery would take place, or as one of the project manager (2015a) stated: "*Sometimes the suppliers notify us before they come but that varies. Sometimes it works, sometimes it does not*". It was also highlighted that some subcontractors were not always present at the operation meetings, and one foreman (2015a) argued that these actors were more difficult to communicate and coordinate with: "*It is not unusual that some actors run their own race. For example, in this project it is the bricklayer that is not present at the meetings*".

Supplier relationships were often discussed. One project manager (2015a) expressed that foreign suppliers had poor logistics services compared to Swedish suppliers. He stated that: "*Swedish manufacturers know that they must deliver high service quality since they are dependent on us in the future. Foreign suppliers are not as dependent which imply that they often neglect labelling and other service quality aspects*". Problems related to foreign suppliers were also something that the logistics coordinator (2015) and production site manager (2015) addressed. Glass facades were in this project ordered from Latvia. When they arrived at the construction site it was apparent that they were too big to be transported with the building elevator. This happened even though the dimensions of the elevators were described in the logistics attachment and the supplier had visited the site to perform control measurements.

All subcontractors were positive towards the use of a logistics coordinator and one project manager (2015b) stated that: "*it is usually a site supervisor that gets the responsibility for coordinating the logistics but it is not always expressed explicitly. Having one formally appointed coordinator makes everything easier*". This way of thinking seems to be supported by all subcontractors. Logistics often entail urgent problems that require direct attention and a logistics coordinator might be a good solution (Foreman, 2015c). Another foreman (2015c) described a typical interaction with the logistics coordinator: "*I notify the logistics coordinator when I have a major delivery and then he checks that there are no clashes ... by doing this we prevent that 20 trucks arrive to the site simultaneously*". Another foreman (2015b) also stated that: "*... you know who to talk to. If I need a forklift in two days for unloading my materials on the site, then the coordinator solves this. He coordinates and checks whether there are other operations at the site that need a forklift that day*". The delivery board was also perceived as positive for coordinating deliveries. Some of the subcontractors wrote their own deliveries on the board while others contacted the logistics coordinator who did it for them. The board has also been used by the subcontractors to check when other deliveries were scheduled for arrival to the site so they knew when it would be possible to arrange for a delivery.

4.4.4 Site logistics

The majority of the foremen thought that the most important elements of site logistics were to keep small material buffers on site and to clean the workspace after an activity has been completed. The available space was considered to have great effects on the estimated time requirements, as one project manager (2014a) stated: "... *one* *activity can take three days if my workers are alone. However, if my workers need to share space with another contractor or if there are things in their way, the activity can take up to three weeks”.* Some subcontractors have worked proactive in order to keep small material buffers on site, while at the same time influencing their employees to leave the work space clean when activities are finished (Project manager 2015a; 2015b; Foreman, 2015a). In order to keep the space clean and free from materials, one foreman (2015a) explained that it was important that people who order materials knew how much materials that will be used in the near future. Having the site clean was especially important for them since: *“Our cables stretch over whole floors. We cannot move around and conduct work elsewhere. The entire cable route must be clear”* (Foreman, 2015b). However, they also argued that not everyone was working according to this practice and several of the subcontractors argued that many actors mismanaged their logistics at the site: “… *there are many actors that do not clean up after themselves. This is a problem frequently mentioned at the operation meeting but all actors are not there”* (Foreman, 2015a). Another foreman (2015c) stated that: *“It is on Peab terms. We are supposed to move around our materials while they think that their material can be stored on the site. If one of our pallets is in the way we move it, they do not”.* This type of behaviour was also expressed by the project manager (2015a) who found tendencies to group formations on the site between different trades. However, there was also more positive statements: *“the collaboration has worked very well. It seems that everyone has accepted the limited amount of space and order material in smaller batches. No one has pursued their own interest, everyone has embraced the prerequisites”* (Foreman, 2015). All the subcontractors expressed that the collaboration on the site has worked well. For example, problems with the design specification and the prevailing schedule delays have been managed with tight collaboration and communication between actors on the site. One foreman (2015b) stated that: *“in order to keep track of each other there is much communication on the site which has worked well. By asking the other subcontractors frequently on how they are progressing, I know when my work can start and I can give a heads up to the supplier when I need my things”.* Some of the subcontractors (Project manager, 2015c; Foreman, 2015b) also stated that the problems related to the design drawings i.e. installation clashes, have been solved on the site: *“We have helped each other to find the best possible position of our respective installations”* (Project manager, 2015c). In general, there have been a lot of ad hoc solutions generated at the construction site due to a lack of sufficient drawings (Foreman, 2015b).

Having the transportation routes, i.e. the elevators and the surrounding space, free was also highlighted as important for the site logistics. While referring to another project, one foreman (2015a) stated that: *“It is very important that transportation routes are clear. Sometimes it happens that people use the elevators for transporting themselves between floors. This is especially problematic for high rise building where it is not uncommon that the transportation of a pallet can take up to 30-60 minutes due to occupied elevators. Here it is good with the logistics coordinator that coordinates the transportation routes, as it goes fast and it can suddenly be materials in the way”.* The foreman also argued that the constrained transportation routes inevitably result in stocks of materials on the site: *“We are supposed to assemble our material and components as soon as it arrives to the site. But we know that the elevators sometimes are unavailable so we create buffers on the site to mitigate the consequences”* (Forman, 2015a).

In this study there have been no pulse meetings, although these were planned for in the beginning. Different explanations for this were, *"it has not been necessary"* (Foreman, 2015a), while Peab argued that there were no subcontractors participating in these meetings (Production site manager, 2015). However, one of the foremen argued that they were going to use these meetings: *"We are going to have these meetings with Peab now since we are in a time where full control is crucial. In the beginning of the project there is a certain indulgence for delays, while we now must count hours and minutes in order to complete in time. It is especially important for us since we have the final activities"* (Foreman, 2015a).

There were several reasons for the many material stockpiles and movements of material at the construction site. One project manager (2015c) explained that the workers had to move piping from the first floor to all the other floors since the crane did not move their pipe to the respective floor. The idea was initially to order the pipes for all the floors at one point in time so that the crane could be used for lifting (Project manager, 2015c). However, all pipes were left on the first floor since it was not possible to lift the pipes to the other floors. Consequently, "*a lot of production time is spent moving materials*" (Project manager, 2015c). Considerable material movement was also a result from the change of the production sequence. One project manager (2015a) experienced logistics problems since the production sequence communicated during the collaborative planning sessions changed during construction. The time requirements of the floor float finishing could not be specified during the session which resulted in a rearrangement in the production sequence. Consequently: *"all our deliveries had to be changed which caused several problems for us"* (Project manager, 2015a). The majority of deliveries were packed and labelled according to the location i.e. the floor or part of the building, where the specific material or components were supposed to be installed (Foreman, 2015a). Sudden changes in the production sequence meant that material needed to be moved from one place to the other. However, some materials and components were unique to the specific location which meant that these needed to be stored until production returned to those locations (Foreman, 2015a). Additionally, splitting the packages was problematic since this leads to extra administration and material movement later in production (Project manager, 2015c; Foreman, 2015a). For the sprinkler subcontractor this meant that their material had to be stored inside the building. However, the great volume of armatures required a more extensive solution and the electrical subcontractor was provided with space in a container close to the construction site which inevitably led to additional material movement. Another logistics problem was also described by a foreman (2015c) and a project manager (2015b). They had to store ventilation ducts at the construction site for three months since they could not proceed with the installation due to another task not being completed. The installation was dependent on this task and during the collaborative planning session it was decided that it was viable to perform the production in this sequence. However, just one week before the installation of the ducts was to be carried out, the carpenters refused to perform the preceding task which the project manager (2015b) argued: *"... has led to considerable amount of material on some of the floors"*.

This chapter contained the subcontractors' perspectives on efforts aimed at coordinating logistics in the Gårda project. This included both interactions e.g. collaborative planning session and the logistics coordinator, and complementary tools such as the delivery board. The subcontractors' logistics and production procedures regarding ordering, delivery, and installation were also described together with their view of problems and opportunities which the Gårda project entailed. In order to answer the research questions the next chapter discuss and analyse these findings with support from the theoretical framework.

5 Analysis and Discussion

In this chapter, the empirical data is analysed by applying the theoretical framework. The empirical findings are discussed and interpreted in line with the research questions.

5.1 Space and time constraints

There are strong interdependencies between the activities at the construction site (Dubois and Gadde, 2002a). In the Gårda project, these interdependencies became stronger due to time and space restrictions. The subcontractors had to perform their activities in parallel and close proximity to each other which increased the competition for site resources such as space for storage, building elevators and delivery areas. Additionally, this resulted in a greater need for adjustments between the actors at the construction site, and inventible in a greater need for coordination. Figure 5.1 demonstrates the effects of time and space restrictions on the interdependencies between activities at the construction site.

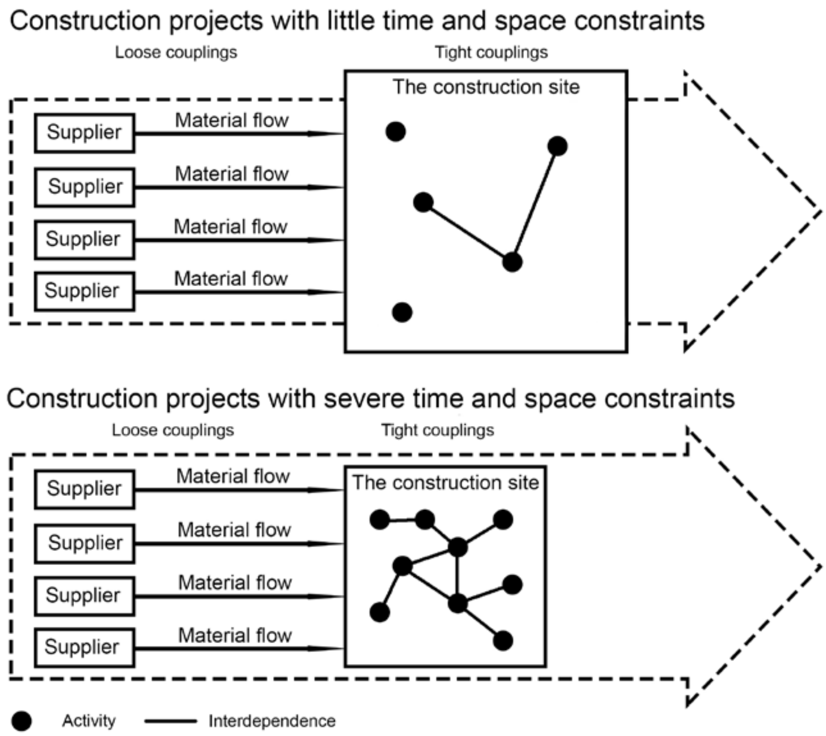

Figure 5.1- Time and space constraints and the impact on interdependencies

In the Gårda project, direct communication between the subcontractors at the construction site was highlighted as especially important for coping with the limited amount of space and the need for adjustments between the actors; supporting Bankvall et al. (2010) who argue that reciprocal interdependencies require direct and frequent interactions. Thus, the strong interdependencies were manageable since there were tight couplings between actors at the construction site. However, site and time restrictions also created stronger interdependence between the site and the supply chain. Indeed, the restrictions resulted in a need for flexibility and reliability in material deliveries, something that were lacking in the Gårda project due to deficiencies in the subcontractor and supplier relationships.

Dubois and Gadde (2002a) discuss how the loose couplings in the permanent network hampers adjustment and relationship development between actors in the construction industry e.g. between contractors and material suppliers. This was evident in the Gårda project where poor information exchange prevailed in the supplier and contractor relationships. Communication problems were identified in both directions; order changes were misinterpreted by the suppliers while suppliers and forwarders offered insufficient communication regarding deliveries. The subcontractors argued that these problems become even greater when a third party forwarder or foreign suppliers were involved. Additionally, foreign supplier was perceived to deliver poor service quality regarding labelling and packaging. Indeed, intermediaries' or foreign suppliers make coordination with the supply chain difficult since these couplings become 'looser', a consequence of suppliers expecting limited business opportunities in the future (Gadde and Dubois, 2010). These issues lead to confusion regarding when and the type of materials arriving which in turn results in redundant inventories at the construction site. However, the Gårda project also demonstrated several ways in which the consequences of strong interdependencies and loose couplings can be mitigated with reactive and proactive measures. While proactive measures were mainly provided by the collaborative planning during preconstruction, reactive measures counts for the interactions facilitating direct and frequent communication.

5.2 Creating awareness and aligning logistics procedures

The purchasing practices of the subcontractors have been influenced by the early interaction during the planning phase. This was illustrated by one of the foremen: "*we probably understood quite early that we were unable to do as usual, we cannot order everything at once and hope for the best*" (Foreman, 2015b). The early interactions, particularly the collaborative planning session, have led to a smoother flow of materials during the production with less material stockpiles at the construction site. One reason for why logistics is difficult in construction is poor alignment of logistics routines between the project participants (Sobotka et al., 2005). The discussions during the collaborative planning session have supported the subcontractors understanding of the construction sites spatial restrictions. This awareness is according to Burch (1985) essential when working on construction sites with a limited amount of space. The collaborative planning session might not have changed the subcontractors' logistics routines extensively but it has created a common understanding of the procedures in the project. Involving subcontractors in planning during preconstruction can thus be seen as a first step in integrating the construction and material supply process. This was demonstrated by the fact that those not involved in the collaborative planning was argued to be the ones that were unsynchronised with the logistics procedures of the project. Additionally, they had lower attendance at the operation meetings where logistics issues were discussed.

Extending the amount of participants to achieve a more holistic view of the interdependencies that exists between the actors at the construction site can arguably be beneficial for coordination. This is especially important in a project where strong interdependencies exist due to time and space restrictions. One foreman (2015a) noted that it was very important to know where the subcontractors will store their bulky materials. Indeed, coordination of the subcontractors' spatial requirements for material storage is a vital issue on a congested construction site (Spillane et al., 2011). It would therefore been advantageous to invite subcontractors with bulky material to the collaborative planning session since the logistics attachment received little attention.

5.3 Early problem solving

Thunberg et al. (2014) found that many of the logistics issues during production originated from the early stages of the construction process. This was also evident in the Gårda project. For example, the decision to use the crane to move the sprinkler contractor's pipes to the different floors was made during the planning phase. For some reason, the crane was not used to move the pipes. This resulted in unnecessary materials stockpiles and material movements at the construction site. However, the findings also support the argument by Thunberg et al. (2014) that involving subcontractors in an early stage offers the potential to combine expertise and information to solve issues in a proactive manner. During the collaborative planning session each participant could acknowledge critical issues which required further consideration. Some of these could be solved through collective discussions among the participants. However, some issues could not be solved on the spot due to future uncertainty and lack of information regarding drawings and specifications.

Insufficient design during the planning phase made it difficult to determine the production sequence which in turn had negative effects for the subcontractors in determining when material was required at the construction site. This has contributed to a material supply that does not align with the demand at the construction site. The issue of installation clashes originated from poor coordination between the actors creating drawings for different trades. Some of the subcontractors also felt that there are poor coordination between actors creating the drawings and actors performing the tasks at the construction site. Installation clashes in design could be "*solved on site*" (Foreman, 2015b) through frequent and direct communications between the concerned actors. In general, the subcontractors could easily move on to other activities if the preconditions for one activity did not exist which relates to the tight couplings on the construction site (Dubois and Gadde, 2002a; Bankvall et al. 2010). However, the supply of material is not as flexible due to the loose coupling between the supplier and the construction site. The problems related to insufficient coordination with regard to design can be mitigated by involving those responsible for creating the documents in the collaborative planning session or something similar. As one foreman (2015b) stated: *"they are the ones with the greatest knowledge during this stage of the project"*. Inviting the design team would have increased the coordination between design and production which in turn would have resulted in more proactive problem solving and thus a more reliable production schedule.

5.4 Creating a reliable production schedule

Both theory (e.g. Arbulu and Ballard, 2004) and the findings of this thesis illustrate the importance of a reliable production flow. In the Gårda project, delays and changes in the production sequence contributed to create a mismatch between the supply and demand, similar to the third scenario described by Arbulu and Ballard (2004). As a consequence, there have been: deliveries arriving before the materials were needed; unnecessary material movement, and; redundant material stockpiles at the construction site. Creating a more reliable production schedule could improve the match between supply and demand, thus alleviate these consequences. Subcontractor involvement in planning should lead to a more reliable production schedule (Ballard, 2000). The subcontractors' opinions whether or not this is true in this project varied.

The production schedules reliability is difficult to evaluate since it is impossible to know how the reliability would have been if the planning was not done in a collaborative way. However, one could argue that by highlighting the sequential interdependencies that existed between activities and by identifying critical problems, a more reliable production sequence was developed. The discussions during the collaborative planning session mostly focused on time and labour requirements of the different activities and the production sequence. One could argue that it would be beneficial to handle pooled interdependencies, such as space for materials and workers at the same time. Like one project manager (2014a) stated: *"... one activity can take three days if my workers are alone. However, if my workers need to share space with another contractor or if there are things in the way, the activity can take up to three weeks"*. This emphasises the importance to consider time and space simultaneously in order to accurately predict the time it takes to execute an activity.

Updating schedules and plans while at the same time adjusting orders to current demand for resources are according to Sobotka and Czarnigowska (2005) important logistics activities. Schedule updates were primarily addressed during the project progress meetings. These interactions were suitable for communication of delays or changes in the production schedule since the idea of having the reconciliation in group was that all subcontractors should be updated on how production is progressing in relation to the schedule. However, as noted by some of the subcontractors, there was little reflection on how the changes in production schedule would impact on the interdependent actors and their respective activities. Several subcontractors described a situation when the production schedule became out dated four weeks after an adjustment. This indicates a need for a more systematic way of evaluating consequences, resource flows and alternatives. An approach such as the constrained analysis in the LPS (Ballard, 1994), could be beneficial in order to make sure that the preconditions for the activities exist before the changes are made. This would change the focus from what *should* be done to what *can* be done; leading to more accurate scheduling that also would support proactive material ordering.

5.5 Coordinating orders

The production schedule illustrated starting time for the different activities, which also determined when the materials had to be delivered. When the materials needs to be ordered depended on the lead time from the supplier, which in turn is influenced by the materials characteristics: customised materials have longer lead times than standardised or small purchases (Bankvall et al., 2010). It was the deviations from the production schedule that generated the severe logistics problems during production. In the Gårda project, delays and changes in production sequence resulted in unnecessary material stockpiles at the construction site. For instance, ventilation ducts were stored for several months at the construction site and armatures for lightings were temporarily stored in a container before they could be installed. In this project, ventilation ducts and armatures were customised with longer lead times. These types of material deliveries cannot respond to sudden changes of the production schedule. This indicates the importance of considering the different supply chains characteristics (Wegelius-Lehtonen and Pahkala, 1998). Additionally, some of the subcontractors opposed using material designated for another place within the building since this procedure resulted in extra administration. Whether to use customised or standardised materials is influenced by the choices made during the design phase of a project. This further indicates that the preconditions for logistics are determined in the early phases of the construction process. In general, there seemed to be a limited amount of discussion regarding the subcontractors purchasing during the production phase.

The discussion above suggests that materials with long lead times require proactive order management and that the subcontractors ordering procedures needs to be addressed during the production phase. The production site manager (2015) noted that Peab have a limited insight in the subcontractors' purchasing procedures and the lead times for their materials. One could argue that it would beneficial to create transparency regarding the subcontractors ordering procedures and the lead times of their materials. By doing this, there can be a more proactive approach when delays occur or changes in the production sequence have to be made. For instance, subcontractors could be notified in a timely manner which could give them time to adjust their orders. If the order cannot be changed, space can be allocated so that the early delivered materials can be organised in a proactive way, which is vital when space is limited (Spillane et al., 2011).

5.6 Coordinating deliveries

Coordinating deliveries is according to Sobotka and Czarnigowska (2005) an important logistics activity during the production phase. Poor schedule reliability and the lack of precision and responsiveness of the suppliers' material deliveries implied several urgent logistics problems when material arrived to the construction site. The interactions with the logistics coordinator were important for logistics and particularly important for coordinating the subcontractors' deliveries. Having one formally appointed as responsible for the logistics was perceived as important by the subcontractors because it facilitated direct and frequent information. In addition, utilising a logistics coordinator also supported the site supervisors who otherwise, informally, would have to assume responsibility for the logistics. Similar to the findings made by Agapiou et al. (1998), it was argued that the logistics coordinators contribute to coordinated material deliveries to, and material movement within, the site. Coordination was achieved since information regarding delivery dates were collected under one central authority. The logistics coordinator could use this information to balance the amount of deliveries to the site, capacity of the surrounding roads, and the transportation equipment on the site. While a congested construction site entails smaller but frequent so called just-in-time deliveries, the surrounding roads are constrained by the urban environment where frequent deliveries can result in congestion. Hence, the logistics coordinator mitigated the consequences of pooled interdependencies by coordinating resources such as space and transportation equipment efficiently and by balancing the amount of deliveries to the site.

5.7 Coordinating material handling and storage

In addition to deliveries, Sobotka and Czarnigowska (2005) argue that coordination of unloading, transportation, and storage within the construction site is important logistics activities during the production phase. These activities were in the Gårda project all supported by using a logistics coordinator. The logistics coordinator exploited the operation meetings and the delivery board to communicate the weekly deliveries to all the participants involved on the site. The operation meetings were particularly important for the majority of the subcontractors since both deliveries and the activities on the site could be addressed simultaneously. Each participant communicated in what part of the building they were going to be working in and how much labour they would require. The delivery board contained the major deliveries arriving to the site each week and the participants could therefore get information of the possibility for additional deliveries, and whether transportation space and equipment would be congested at any point in time that week. The delivery board was visible for all participants during production which made it possible for each participant to find suitable delivery dates for their materials and components. In addition to coordinating deliveries, the coordination of the subcontractors storage requirements, identified as one of the issues with material management on congested construction sites by Spillane et al. (2011), was supported by using a logistics coordinator.

5.8 Research question 1

Which interactions between the main contractor and subcontractors are important for logistics in a construction project?

Four formalised interactions were especially important for logistics in the Gårda Project:

The collaborative planning session
The collaborative planning session was an important interaction for logistics since it supported an awareness of the construction sites restrictions and the logistics procedures that had to be followed during the construction project. Since many logistical problems during production originated from the earlier stages in the construction process, it was beneficial to combine the expertise and knowledge from various participants in order to identify and solve these problems at an early stage. The collaborative planning session increased the participants' mutual understanding and communication, which are prerequisites for coordination (Olsson, 1998).

Project progress meetings
Many of the logistics problems identified during the Gårda project relate to poor production reliability, i.e. delays or changes in the production schedule. The project progress meetings were essential for logistics since they provided an opportunity to communicate schedule changes to all participants. It was especially important for subcontractors that had material with long lead times since these require long term forecasting. Indeed, materials' with long lead times required proactive ordering procedures and the subcontractors were thus dependant on receiving information about schedule changes or delays.

Logistics coordinator
Utilising a formally appointed logistics coordinator have during the Gårda project led to better coordination of important logistics activities such as deliveries, material handling and storage. Loose couplings between suppliers and the construction site resulted in poor responsiveness and delivery reliability. This resulted in several urgent logistics problems which required direct and frequent communication between the actors at the construction site. This communication was facilitated by using a logistics coordinator. Located within the intersection between the supply process and the construction site; the logistics coordinator represented an important hub for coordinating space and equipment, thus mitigating the pooled interdependencies between the subcontractors at the construction site.

Operation meetings
Similar to the logistics coordinator, the operation meetings offered the possibility for direct and frequent communication required in a highly interdependent environment. Additionally, these weekly meetings were important for monitoring progress and coordinating the resources used at the construction site. The meetings provide the participants with opportunities to declare upcoming deliveries and where they would be working. Hence, both pooled, e.g. space and equipment, and reciprocal, i.e. adjustments, interdependencies are considered during these meetings. Consequently, the operation meetings were an important element in order to manage site logistics.

5.9 Research question 2

How can these interactions be developed in order to improve logistics?

The main purpose of the collaborative planning session was to determine the production sequence by examining the sequential interdependencies that existed between the activities. The focus has been on time and the amount of labour resources it takes to perform the activities. While space is partly considered when estimating the amount of labour resources there was little or no acknowledgement of the amount of space the respective actors' materials require. It is important to consider the spatial requirements of the different subcontractors since the time it takes to perform an activity ultimately is dependent on the availability of space. This also implies that some actors, those with a considerable amount of material volume, are more important than others. Hence, the choice of actors that should be invited to the collaborative planning session need to be made with consideration of the project prerequisites. Furthermore, creating a production sequence that is consistent through the whole project requires the identification of crucial issues in an early state. Many of these issues identified seem to be caused by poor alignment between the design team and production team. Having the design team involved in the collaborative planning session would thus be beneficial. Additionally, it is important that the session is allocated sufficient time in order to identify and discuss these issues.

The production schedule is a 'living document' since there will always be some deviations and changes as the production progresses. However, logistics problems mainly arise when major changes in the production schedule are made. It could therefore be advantageous to consider how changes to the production schedule affect the subcontractors' material flows. In order to make this possible, the transparency of the subcontractors ordering procedures and the lead times of their materials has to be extended. This transparency can be achieved by having the subcontractors declare their lead times at the project progress meetings or by establishing a joint ordering plan. One could argue that this clarifies the link between the purchase and production. It might also be advantageous to measure the production schedules accuracy and to in a more systematic way evaluate the causes for failures. This would facilitate an environment of continuous improvement.

The overview of the material flows, i.e. ordering, delivery, and installation, could be allocated to the logistics coordinator. In the Gårda project, the coordinator was primarily involved in solving the urgent logistics problems. Having the complete picture of the various participants logistics routines could arguably lead to a coordinator that works proactive rather than reactive.

6 Conclusions

The aim of this thesis was to examine construction logistics from a subcontractor perspective. The interactions between a main contractor and the subcontractors were examined in order to create a greater understanding of the coordination requirements that exist in a construction project with limited space at the construction site.

The findings of this thesis demonstrated that time and space restrictions, together with poor match between demand and supply resulted in an extensive need for frequent and direct communication between the actors on the construction site. The logistics coordinator and operations meetings were especially beneficial in this respect since these facilitated efficient information flows and transparency between participants.

In the Gårda project, poor match between demand and supply was primarily caused by poor production reliability, and loose couplings between suppliers and the construction site. This resulted in redundant stockpiles of materials and unnecessary material movements at the construction site. The match could be improved if there were better coordination between schedule changes and the subcontractors ordering procedures. The project progress meeting provided the subcontractors with information regarding project progress, but there were little consideration on how the schedule changes would affect their activities and material supply. A thorough consideration of how the schedule changes would have affected interdependent subcontractors, and proactively communicate these to the subcontractors would have increased the potential to align ordering with actual demand.

The collaborative planning session was also identified as beneficial for the logistics since logistics issues could be addressed at an early stage. In addition to improved communication during production, the early involvement also provided the subcontractors with information so that their logistics procedures could be aligned with the site prerequisites. Hence, subcontractor involvement in planning can be seen as a first step for integrating the subcontractors' logistics procedures. The findings also indicated poor information flows between actors in the design and production stage which inevitably caused logistics problems during production. Involving the design team in the collaborative planning session would support proactive problem solving and thus better schedule reliability.

Coordination between various supply chains cannot solely be facilitated through increased communication at the construction site. Instead, the result shows that proactive measures are needed and this can be facilitated through greater involvement of subcontractors. This is particularly important when severe time and space restrictions are present.

To conclude, congested construction sites require additional focus on logistics and the findings of this thesis suggest that it is especially important to; create a transparency of the subcontractors' ordering procedures; provide opportunity for frequent and direct communication during production, and; to focus on achieving a reliable production flow.

6.1 Suggestion for further research

The findings of this thesis have highlighted several discrepancies which could require further investigation. Well-functioning supplier relationships are a prerequisite for matching the material and production flow. Future research should focus on examining subcontractor and supplier relationships and the interdependencies that exist between. Furthermore, poor delivery precision and responsiveness of the material supply chains need additional attention which is in line with the emergent area of SCM in construction. It would also be interesting to investigate subcontractors purchasing procedures, including decisions of service and purchasing price, and how that affect the matching between material flows and the production flow.

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Appendix A – List of interviews

Logistics coordinator (2015), Jonas Landin, Peab Sverige AB, 2015-03-13.
Project planner (2015), David Roslund, Peab Sverige AB, 2015-03-16.
Production site manager (2015) , Klas Jerdenius, Peab Sverige AB, 2015-03-21.
Project manager (2015a), Henrik Sandberg, Emil Lundgren AB, 2015-04-09.
Project manager (2015b), Ulrik Andersson, Caverion Sverige AB, 2015-04-15.
Foreman (2015a), Oivar Karlsson, Emil Lundgren AB, 2015-04-20.
Foreman (2015b), Gunnar Åsman, NÅ Widell Rör & Konsult AB, 2015-04-22.
Foreman (2015c), Mikael Karlsson, Caverion Sverige AB, 2015-04-24.
Project manager (2015c), Mark Foster, Homesafe Scandinavia AB 2015-04-29.

Appendix B – Interview guide: project managers

1. What kind of work are you responsible for in the Gårda project?
2. Have you worked with Peab before?
3. How do you perceive the collaboration with Peab and the other subcontractors?
4. Describe how your supply logistics operations generally work
5. What information is important to achieve efficient logistics?
6. How do you receive this information?
7. What contacts, meetings or interactions with Peab and the other subcontractors are important for the project logistics?
8. How do you match your deliveries with the material requirements at the construction site?
9. How has logistics coordination between the project participants worked during the production?
10. How did you consider the logistics information received during the tendering process?
11. Is this information important when planning your logistics operations?
12. How do you perceive the initial meeting with the project planner?
13. Describe your impression of the collaborative planning session
14. Have you participated in a project with a similar approach to planning?
15. How does the collaborative approach compare to the traditional individual approach?
16. Do you think that the collaborative planning session result in a more accurate production schedule?
17. How is your relationship with Peab and the other subcontractors affected by participating in this session?
18. Is there anything that could be discussed during the collaborative planning session that could improve the project logistics?
19. When and why have you been in contact with logistics coordinator?
20. Do you think that a logistics coordinator improves your logistics operations? why?
21. What can be done better to improve logistics and coordination between the project participants?
22. How is the delivery board used? and is it a good way to coordinate material deliveries?
23. Describe your impression of the project progress meetings
24. What are the advantages of carrying out projects progress meetings in groups?

Appendix C – Interview guide: foremen

1. How do you perceive the collaboration with Peab and the other subcontractors?
2. Describe how your site logistics operations generally work?
3. What information is important to achieve efficient logistics at the construction site?
4. How do you receive this information?
5. What contacts, meetings or interactions with Peab and the other subcontractors are important for the project logistics?
6. How has logistics coordination between the project participants worked during the production?
7. Have you experienced any problems with logistics at the construction site?
8. What can be done better to improve logistics?
9. When and why have you been in contact with logistics coordinator?
10. Do you think that a logistics coordinator improves your logistics operations? why?
11. How have you used the delivery board?