Efficient Construction Logistics
A case study of an Office Block Project

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<td>Architectural Design and Construction Project Management</td>
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<td><strong>Master Thesis number</strong></td>
<td>357</td>
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<tr>
<td><strong>Keywords</strong></td>
<td>Construction Logistics, Material Flow, Project, Management</td>
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Abstract
During the period January 5th to June 5th 2015 a degree project with the aim to investigate and improve the logistic situation at a construction site situated in Stockholm, Sweden, was carried out. There is a lack of general knowledge regarding material logistics in construction projects. As a consequence there are many unnecessary movements on site interrupting production and displacing direct value-added activities. Therefore the purpose of this research was by practical observations and site interviews, earlier studies, to investigate the existing logistic approach on the construction site, as well as to provide proper logistic strategy for improving construction process. Major effort of this study has been put on material deliveries within the construction site.

The thesis concludes that despite hired subcontractor for material handling, skilled workers are being involved spending not direct value-added time while moving material. Due to inefficient logistics solutions production process is extended. The research demonstrated that by implementing other logistics solution, time and cost saving can be gained, giving time saving for 6 working days and direct saving potential for almost 20 SEK/m² of living area.

The study highlights the significance of construction logistics, also showing what consequences can be faced due to lack of proper logistic planning. At the same time getting benefits to the entire project can be possible if proper logistic approach is used.
Acknowledgement

This examination work is written for the department of Real Estate and Construction Management at the Royal Institute of Technology (KTH). The paper is carried out as collaboration between KTH and one of the leading turn-key contractor companies Skanska.

The master thesis could not be completed without supervision from there persons. A great thank to Väino K Tarandi (Professor at KTH), Roger Liderfors (Skanska Sverige AB) and Anders Wingård (Skanska Sverige AB). Also a great thank to Abdinasir Osman (Svensk Bygglogistik AB) and other workers and engineers from Skanska and other subcontractors at the construction site in Stockholm, for their help with understanding the problems occurring, and for willingness to share their knowledge during this period.

Yuriy Matouzko
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1. Introduction

1.1. Background
How do you get a supply chain to work efficiently? All industries have to challenge that question in order to succeed, but today it has proved a particularly thorny issue for the construction industry. Many reasons for this can be found. The construction industry has a low entry requirement in terms of capital and many large companies have grown progressively from the humblest beginnings. Despite the capital required to fund a construction project, the industry is not observed as capital-intensive and thus fails to get the business attention and investment that is accorded to other analogous sectors. Moreover, the result of the fragmentation of the construction industry is that everyone is focused on their own area of expertise rather than investing their resources into achieving high performance in the entire project. If you pass by the typical construction site, the wastage is immediately obvious. New materials have been damaged and lie in waste containers before they could ever be used. Even used materials are often injured or scratched because of logistics management (Sullivan et al., 2010).

The construction industry is one of the most complex industries consisting of several phases with many different actors involved during every phase. The complexity in construction originates from a number of sources: resources employed, the environment in which construction takes place, the level of scientific knowledge required, and the number and interaction of different parts of the workflow. The author distinguished between two main categories of complexity. The first is related to ‘uncertainty’, dealing with ‘the components that are inherent in the operation of individual tasks and originate from the resources employed or the environment’. The second type of complexity comes from ‘interdependence’ among tasks, and represents those sources of complexity that ‘originates from bringing different parts together to form a work flow’ (Gidado, 1996).

This study deals with logistics in the construction projects where a lot of unnecessary on-site activities take place, decreasing the efficiency of implementing construction projects. Poor construction logistics may result in e.g. increased standby and idle time, increased stress level and even the injury risk of personnel in addition to impaired working satisfaction. Improving logistics by reducing activities that do not add value to the final product could be possible solution to decrease the production costs. Not direct value-added activities are defined as “waste” which is directly related to the logistics issues. There are many earlier studies regarding waste, among others Josephson and Saukkoriipi (2007) determined that by minimizing the overall amount of waste the production costs can be decreased by one third.

1.2. Scientific problem statement
Most of construction projects suffer from unnecessary activities on site therefore giving the need of improving the logistic issues. In the construction logistics can be divided into several phases-chains, depending on how large the project is. The main logistic chains are delivery and transport of the material to the building site, direct unloading and storage of the material on the site and finally direct site transport within the site. Thus the research question that has been studied is:

- How does construction logistics for an office-block project look like in practice and what are the conditions for efficient construction logistics?
1.3. **Purpose**
The purpose of this paper is to study construction logistics process as well as to analyse and optimize the material flow and site transport. The main point is to investigate the current logistic situation within the office block project. Through practical investigation of the specific project, studies of secondary data and analogous projects, interviews the suggestions have been given for improvements that can facilitate the production process, minimizing the environmental impact within the specific construction project and decreasing construction time.

1.4. **Limitations**
The limitations with the study are:

- The research is based on Swedish construction praxis
- The research is based on the case study of hotel-office block project
- The research is based on turn-key contractor company
- The research is focusing on construction logistics, mainly site transport for material flow
- Hotel-office block is in the design phase, the production is expected to occur autumn 2015

The materials selected for this research were chosen according to following criteria:

- The materials should represent a significant part of the total construction cost
- The materials should correspond to the categories of materials that tend to have a high percentage of waste
- The materials should mainly be needed during one phase of the project (architectural phase)
- The materials should be purchased during the studied period

1.5. **Expectations**
Outgoing from previous studies the need of improved logistics in construction projects is obvious. Poor logistic solutions not only results in delayed and low performed construction projects but also gives a poor image of the construction industry.

The main expectation from this research is that it will contribute to more efficient construction process on the Swedish market and will help the companies to look on the construction logistics issue from another perspective and recognize the potential for further development within the field of material flow and gods’ deliveries. This will perhaps contribute to higher performance of construction logistics.
2. Theoretical frame of reference

2.1. General
Multiple types of scientific literature reviews have been done in order to establish theoretical framework, to discover how much and what studies have been done before within the field of building logistics and construction management. Exploration of international and Swedish books will provide a scientific foundation for the project work.

The literature review for the chosen topic is an inductive part for thesis and consists of three parts. In the first part the appropriate concepts of logistics and general definitions have been explained and identified. The second part introduces the third part logistics and it’s organized. Finally, the third highlights the research of earlier studies giving a better understanding of what has been done previously.

2.2. Definitions and concepts

2.2.1. Logistics as a concept
Logistic is the main issue of this thesis and it is worth to give the clear definition of the concept. According to the Chartered Institute of Logistics and Transport (2006) in the UK logistics is defined as “the procedure of designing and managing supply chains including purchasing, manufacturing, storage and transport”. Oxford English Dictionary (OED) defines logistics as “organization of supplies, stores, quarters, etc., necessary for the support of troop movements, expeditions, etc.” with the first recorded usage of the term in 1879. Taylor (1997) advises that the comprehensive definition of logistic developed by the US Council of Logistics Management in 1986 is: “The process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw material, in-process inventory, finished good and related information from point of origin to point of final consumption for the purpose of conforming to customer requirements” from Sullivan (2010).

Some main concepts about construction projects and construction managements have been described by Winch (2010). The author is convinced that in order to keep the project on track, decisions often have to be made before all the necessary information is available. He also states “project management is basically an organizational innovation meaning the identification of a team responsible for ensuring the effective delivery of the project mission for the client”. Also there are more concepts explained by Gould (2009) where he defined the construction as a concept of bringing together materials and products. More concepts such as SWAT analysis and critical lines are described in Hallin & K. Gustavsson (2012). The book deals with planning projects in terms of time, function and cost, managing and controlling project. The book focuses on managing the individual project and that is a case in the thesis work where the particular construction project has been studied.

2.2.2. Supply chain management and logistics management
Before defining what supply chain management (SCM) and logistics management (LM) are and how do they differ from each other, it is appropriate to define supply chain. Stevens (1989) defines a supply chain as “The connected series of activities which is concerned with planning, coordinating and controlling material, parts and finished goods from suppliers to the customer”. It concerns both the flow of material and the flow of information. In some literature there are even statements such as “logistics management and supply chain management are essentially synonymous terms involving the systematic and holistic approach to managing the
flow of materials and information from its raw material state to the end-user’s consumption”, by Sullivan (2010, p.17).

What exactly is SCM and how is it different from LM? In 1986, the Council of Logistics Management (CLM), the leading-edge professional organization with a current membership of over 13 000 (Cooper et al. 1997), defined LM as “The process of planning, implementing, and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information flow from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements”.

SCM, as a term, first appeared in the early 1980s to describe “... the range of activities co-ordinated by an organisation to procure and manage” (Pryke, 2009, p.29). The author states that SCM is not just another name for logistics, he continues that SCM goes further and includes elements that are not typically included in a definition of logistics. Some of these elements are information systems as well as the integration and coordination of planning and control activities. Logistics mainly deals with the flows to, in and out of companies, with an intra-organizational perspective, SCM is a concept that deals with the inter-organizational view of logistics in conjunction with the intra-organizational perspective. As the interest to SCM increased, it has been given a range of definitions through the time. Many definitions explain SCM as the chain linking each element of the manufacturing and supply process from raw materials to end users, including several organisational boundaries. As a result the SCM definition could be: “The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as whole” (Pryke, 2009, p.31)

### 2.2.3. Builder’s SCOR
Supply Chain Operations Reference model (SCOR), is a tool developed for companies to improve their supply chain, dividing it into different steps for further analyses. In other words, SCOR helps companies to recognize if the supply chain can be further improved. SCOR model works also as tool to compare companies’ logistical performance. SCOR was developed by a non-profit organization with over 800 members, the Supply-Chain Council, SCC (Gyllin & Thunberg, 2010, p. 15). According to Supply-Chain Council SCOR Processes consists of three levels and contains totally 200 process elements. The main processes at the first level are followed below:

- Plan – Plan the activities,
- Make – Make products,
- Source – Buy and transport raw material,
- Deliver – Sell and transport products to customer,
- Return – Return raw materials and products,
- Enable – Enable processes.

The adapted for construction industry version of the SCOR model is entitled the Builder’s SCOR model (BSCOR) (Thunberg, 2013). Thunberg is a PhD in quantitative logistics at Linköping University. While being a PhD student Thunberg’s research area is to develop and implement a construction adapted version of SCOR model. While SCOR model suggests separating material flow based on type of end product, BSCOR model separates the flow of materials based on who orders them (the main contractor or any of the subcontractors) rather than type of material. BSCOR model also suggests the organization of planning process in order to manage coordination
issues. Lastly one measurement included in the BSCOR model is to monitor whether incoming delivery of construction material is notified in time (Thunberg, 2013).

2.2.4. Logistic solutions and techniques
In order to get deeper understanding on the topic logistics some logistic solutions and techniques are highlighted in this section. There are various logistics technologies used by various companies worldwide. Some of these technologies have been presented in the report “Material Logistics Plan: Good Practice Guidance” in Waste & Resources Action Programme (WRAP, 2007). These technologies are described below (Harker et al., 2007)

**Just-In-Time Delivery (JIT)**
JIT delivery is a service of regular shipping in work packages or task loads for direct usage as a result making it possible to perform the next task without any delays. JIT deliveries can be managed externally by suppliers or internally through the Construction Consolidation Centre (see next section). This kind of deliveries decreases or even eliminates the need for material storing on site. Reduced on-site material storage decreases risk of damage and loss of the material but also reduces crowding and safety incidents.

**Construction Consolidation Centre (CCC)**
A Construction Consolidation Centre, also called Building Logistics Centre, is a distribution facility through which material deliveries are channelled to construction sites. In practice it is a temporal warehouse equipped for material handling and large enough where vehicles can be off-loaded and turned around (See figure below). Material volumes that allow “smart” vehicle loading can be accommodated and re-loaded in the CCC for further JIT deliveries to site. If a vehicle is fully loaded with large items such as steel and reinforced concrete work it should therefore be taken directly to site. Returned vehicles from the site may include waste removal to waste transfer station. While data varies from project to project, use of a CCC can (Lundesjo, 2011):

- Reduce freight traffic to site by up to 70%,
- Increase productivity of site labour by 30 minutes per day leading to a 6% productivity gain,
- Waste reduction by 7-15% through less material damage and shrinkage.
**Demand Smoothing**
Demand smoothing can be done by both clients and contractors at any level in the supply chain. It helps to identify peaks and gaps in the materials’ needs over a time period. Demand smoothing is a way of looking on the project activities in the entire chain and identifying whether the performance can be “smoothed” to decrease transport resources, materials and labour needed to carry out the activity.

**On-site Marketplaces (MP)**
An on-site marketplace is a temporary warehouse for storing materials, working tools and equipment that are daily used and shared by a large amount of workers on-site. Usually there are spikes, screws, bolts, saw blades, drill bits, nuts, anchor fixings and similar in on-site marketplaces. Each trade worker brings their tools and equipment to the MP for storage and distribution by a store-man in chief. If stocks become low they are replenished by the contractor/subcontractor himself or by the store-man who orders on their behalf.

The major advantage with MP is the guarantee of available supplies and material in the right and safe place. As a result removing the demand for contractors/subcontractors to do own material storages on-site therefore increasing production performance and reducing costs.

**Pre-assembled and offsite fabrication**
Construction of the elements on the factory contributes with higher quality of the final product. At the same time the building process is independent from the weather conditions and all tools and machines are available therefore no need to bring them to the construction site. It is efficient for materials to be delivered prepared and configured as far as possible before their final use. For instance this might be off-site fabricated wall...
elements with electrical components included or plasterboard pre-cut to needed dimension. Sometimes it might be materials prepared in packages suitable to a room, a floor, etc. The main reason of doing this is to reduce amount of time thinking during the production process on site. Standardized offsite mass fabrication contributes to lower amount of errors, better quality, lower transport and time requirements.

**Information and Communication Technology (ICT) Systems**

ICT Systems are used to keep track and monitor materials during its entire way from manufacturer through and until it is distributed and installed. “Tag systems” help to manage material deliveries with the help of different sort of information technology. Radio frequency identification allows an accurate reading of tags on site. The tag system, having relatively low cost, allows the monitoring of material to the point of final use and can offer detail information about how is it going on site.

**2.3. Third Part Logistics**

Building logistics is an important issue within construction projects that often is taken for granted. Today there are companies that are using possibilities of the third part logistics for getting financial benefits by focusing on logistics issues on the early stage of the planning processes. The main purpose of such companies is to create safe, clean and work-efficient working place by efficient and better planed logistics so that contractors and subcontractors do not need to spend more time on rework moving material within the site. The most of the material transport is done during evening when the workers are away and cranes are available. Next day workers have already material in right quantity and on the right place (Svensk Bygglogistik, 2014).
3. Earlier research in Building Logistics

Today’s process of managing material flow is often environmentally unfriendly with lot of heavy transportation to the site and a lot of machines ongoing on the site. Also material waste is high due to onsite damaged material. Therefore the need of increased logistics efficiency occurs to lower waste and environmental impact. Further solutions are partly described in the research by Dahlström & Sandahl (2010).

Poor logistics can be a condition for increasing stress rate and lower comfort on site with narrow areas due to tight material storing. Also more time is spent for replacing and hand bearing materials, which is resulting in increased cost for the construction project. Previous research by Karlsson (2009) deals with logistic problems within a particular residential project.

When dealing with large construction projects for managing material flows and transportation there can be a good solution to create a temporal building logistic centre, temporal warehouse, to store all goods flow that is delivered to the site. Afterwards in order to provide the efficient flow directly to the site, material is been unloaded in the BLC and reloaded in smaller volumes and can be delivered with high precision to the site. The more detailed research for a large residential project is done by Brunge (2013).

Earlier research by Josephson & Saukkoriipi (2007) “Waste in construction projects: call for a new approach” shows that the cost of material flows and deliveries to the construction site varies much. In extreme cases it can be up to 50% of the material price. In the report authors deal with unnecessary activities on the site that do not add any actual value to the final product. Also the report deals with visible respective hidden defects of cost which affect the cost by up to 4% during the production phase. To manage in this, researchers decide to attend the construction site to observe individuals during the work day to see how much time they spend on rework and unnecessary activities that do not contribute to the project. They also interview architects, site workers, technical consultants and managers and report the data about how the respective person uses working time. The results were classified in groups by directly created value, preparation and waste work. The results have been summarized in the figure below. From the figure follows that work directly creating value is done during 17.5% of the working time. Preparation works take all in all 45.4% of the whole time and waste or inefficient time takes 33.4% of the working time.
In the construction projects in order to improve construction supply chain collaboration and interaction between the entrepreneur and supplier is a vital process which should be taken into account. For example, temporary organizations, fragmentation, etc. can affect the time and cost as work and information among members are often delayed and even distorted. It is also recognised by many authors the planning the construction work and logistics often tainted with synchronisation and coordination problems between supply chain members. This problem has been studied closely by Thunberg (2013). Thunberg is the PhD in Linköping University in the Construction Logistic Department. This research was a further developed study of the common research project of Gyllin & Thunberg “Analysis of SCOR implementation at PEAB” (2010). The aim of which was to improve the logistic situation at the construction site in Motala, Sweden, project by PEAB. The lack of general logistic thinking and knowledge in the construction field is an important issue that is been studied in the research where the SCOR model has been created. SCOR Model includes five process groups, such as Plan, Source, Make, Deliver and Return.

The literature review showed that many studies have been done in the field of building logistics where different concepts and different problems are identified by the researchers. The previous studies also showed that there are a lot of unnecessary costs and environmental impact due to the poor logistics on site. These studies are appropriate for my research in regarding construction logistics and improved efficiency of the production process.
4. Methodology

4.1. General
The hotel-office block project is in the design phase and the production will occur in autumn 2015, therefore theoretical (inductive) research method has been used. Due to lack of time it was not possible during the thesis project to study both the design phase and production phase, thus the most of the research has been an inductive approach that can be further applied as suggestion for a logistics strategy during the project implementation in order to achieve higher efficiency of construction logistics.

The literature and earlier researches about construction logistics have been studied. Afterwards the data has been collected from the analogous project construction site by direct observations and with help of interviews and formal conversation with engineers and logistic planners. After data has been collected it has been analysed, it has also been compared to the theory to evaluate possible alternatives for improvement and recommendations.

4.2. Research method

4.2.1. Population and sample
Sampling is the statistical process of selecting a subset, called a sample, of a population of interest for purposes of making observations and statistical inferences about the population (Bhattacherjee, 2012). In this case research there was neither population nor items (units of analysis) but processes (of interest) of different activities, with different characteristics that have been studied. The processes of (building) activity, where site workers were to handle the material flow within the building project. It was not possible to study the entire construction project with all its processes of activities, logistic processes, because of feasibility and cost constraints therefore some crucial processes, critical processes, were picked from all processes for observation and analysis. The chosen processes can be called the critical lines, which are of great importance in order to complete the project. (To complete the project meaning not just to rise up the building but to fulfil the expected demands (time, cost and quality)

The next step is choosing a sampling frame. In this particular case it is not obvious while doing that. All processes are been categorized by numbers of deliveries, amount of units, number of workers handling the materials, time taken, and maybe some more. For some processes it may be rather complex to define a category but the proper technique and theory support will be provided later on. Generally, sampling techniques can be grouped into two categories: probability (random) sampling and non-probability sampling. My case will include mostly probability sampling for generalizability of result, but also there may be unique circumstances where non-probability sampling can be justified.

4.2.2. Qualitative and quantitative research
In this case research both methods have been used. The quantitative method has the starting point from the problem that has been studied and made measurable and the results have been presented numerically. The study has been conducted as objectively as possible in so to say “me and it” relationship between the researcher and the objects (logistic supply chains). The qualitative method has been created through several different types of data collection for deeper understanding of the problem. The primary goal was not to create an explanation
for how transport and logistics processes is being made but to create an understanding of how those are performing and to build up needed conditions for achieving efficiency for those activities.

While carrying out this work, an inductive approach combined with the quantitative survey approach has been used. Through direct observation and a frequency study, empirical knowledge has been created helping to explain how e.g. construction worker will act when performing in different processes.

Even the deductive and qualitative methods have been used in a form of interviews and formal and informal meetings to capture the respondent’s thoughts.

4.2.3. Interpretive research. Action Research
Unlike deductive methods like laboratory experiments and survey research (theory or hypotheses testing) the interpretive (inductive) methods, such as action research and ethnography have taken place in this study. The research has started with data, focusing on building logistics and its roll in construction projects, trying to derive a theory about the concept of processes of interest from the observed data. Interpretive research turns to depend mainly on qualitative data, while quantitative data may increase precision and better understanding of the phenomenon of interest than qualitative data.

4.2.4. Sources of error
As it was mentioned before the particular project is in the design phase. While implementing the developed concepts during production phase unexpected factors can occur and affect the efficiency of construction logistics, e.g. weather conditions or economic crisis. Also eventual bankruptcy of subcontractors can decrease the feasibility of the construction.

4.3. Data Collection
The focus of the study is material deliveries and material flow. The construction site of the relevant building project has been visited regularly for observations and documentations of all large deliveries of inside wall materials. This gave solid foundation base while investigating how material transportation within the construction site is been performed. Also time has been measured for how long it takes for workers to pick right material and to move it to the proper place.

4.4. Data analysis
After the data is collected, it has been analysed and evaluated. Further conclusions and suggestions have been drawn based on available information, theory, data, evaluation and analysis.
5. Data collection and results

5.1. General
In this chapter collected data and results have been summarized. Available information comes from site observations that have been made during the period of 2 month. The observed deliveries are mostly larger deliveries of the inside wall material, including gypsum and plywood boards, metal profiles, wooden studs also inside wall insulation and interior wooden and steel doors. The main contractor workers and logistic staff have been followed for better investigation. Time for construction workers to handle materials has been documented. Observations have been made during the architectural stage of the project. Also interviews have been conducted with employees of different positions, including craftsmen, logistic staff, supervisors and managers and site managers.

5.2. Project information
Two relevant projects have been used for data collection and further analysis. The first project is an office block project that is in the architectural stage. The second project is a hotel-office block project that is in the design phase and construction is expected to start during autumn 2015. While the second project is in design phase, no site visits and observations can be done. For this reason the first project with ongoing production phase is used for site observations. Both projects are carried out by the same turn-key contractor company. Further in the paper the projects are named as Project A and Project B.

Project A
Project A is located in the City Centre of Stockholm, Norrmalm, nearby Stockholm’s Central Station. It consists of one twelve-story building with offices, restaurant, conference, lobby and underground garage. The building structure is reinforcement concrete structure with prefabricated outer walls. The total construction area is approximately 48 000 m². The construction period is from Mars 2014 to December 2016.

At Project A material deliveries are organized and planned generally through web-based platform with logistic coordinator, also called planning engineer, responsible. Logistic coordinator creates an online schedule for material deliveries with regular intervals so that no clashes can occur when trucks with material are arriving to the construction site. Also supervisor from carpenters and craftsmen can access the software and give suggestions and reserve time for needed material which can simplify logistic coordinator work when organizing material flow schedule. Material flow from trucks in to the building is carried out by the same subcontractor company that is responsible for traffic safety and gate keeping also for waste disposal and cleaning. Further in paper the subcontractor’s workers responsible for traffic safety are named as logistic staff due to all on-site logistics and material handling is done by the same subcontractor.

Project B
Project B is located in the north-western part of Stockholm’s downtown in Vasastan. It consists of one eighteen-story building. Stories 7-15 consists of hotel with 221 hotel rooms, stories 2-6 includes offices and stories 0-1 restaurant, conference and lobby, also underground parking. Technical and equipment rooms are in basement and on the roof plan. The building’s bearing structure is performed as reinforcement concrete structure with prefabricated outer walls and floor joists. The façade is made of glass sections which merge smoothly together
giving a feeling of one entire façade wall. The total construction area inclusive underground garage is approximately 15 000 m². The construction period is from November 2015 to November 2017.

Stories 2-6 with offices have open floor plan and do not need special logistics techniques. In this case study the hotel section, stories 7-15 with 221 hotel rooms are of interest due to large volume materials needed.

Project B does not have optimal logistic strategy and at the moment material deliveries to Project B are designed in the traditional way. In this case the supply chain is organized in form of lorries coming directly to the construction site with no specified time for delivery. The contractor does not know what time materials are arriving to the construction site. Construction Consolidation Centre, also called Building Logistics Centre (BLC), will be used primary for bathrooms modules, prefabricated bathrooms. BLC is situated within the Stockholm area and is carried out by subcontractor DHL.

General conditions for material deliveries Project A, B

General conditions for material deliveries and material flow are analogous for both projects. Both projects are located in densely built central district of Stockholm, with relatively tight traffic during rush hours and quiet traffic during evenings. The assumptions can be drawn that during day time accessibility to the construction site can be limited and less efficient than during the evening. After investigations and analysis of construction area, comprehensive plan as well as the working place disposition plan the common conclusions have been drawn and summarized according to following:

- Due to densely built district there are restrictions regarding land use for site office establishment
- Only one tower crane established on the construction site
- Only one unloading zone available on the construction site
- Only one major truck/lorry can be unloaded simultaneously with material flow through the construction elevator
- The second major truck/lorry can be unloaded in addition with the help of tower crane, if available
- Due to limited area within the construction site there is no opportunity to store materials on site instead direct transportation to the building will occur.
**Figure 4.1** Comprehensive plan (Comprehensive plan, Project B, March 2015)

**Table 4.1** Project information

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<th>Project</th>
<th>A</th>
<th>B</th>
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<td>Location</td>
<td>Norrmalm, Stockholm</td>
<td>Vasastan, Stockholm</td>
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<td>Total Area incl. garage (m²)</td>
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</tr>
<tr>
<td>Number of Floors (hotel)</td>
<td>-</td>
<td>9 (7-15)</td>
</tr>
<tr>
<td>Number of Floors (office)</td>
<td>11</td>
<td>5 (2-6)</td>
</tr>
<tr>
<td>Project</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>---------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Building purpose</td>
<td>Office-boutiques-restaurant-conference</td>
<td>Hotel-office-conference-restaurant</td>
</tr>
</tbody>
</table>

5.3. **Observations and collected data, Project A**

Further follows detailed explanation for different material deliveries to Project A. Generally there are two larger deliveries for board materials, interior wooden and steel doors every Monday and Wednesday between 16:00 – 19:00. Further there are two deliveries for minor materials such as baseboards, wooden studs, metal profiles, mineral wool and mineral fiber also sometimes plywood boards every Tuesday and Thursday between 07:00 – 08:00.

As mentioned before focus is set on the materials that represent a significant part of the total construction cost and correspond to the larger material volumes in comparison with other materials. After interviews with production site managers the decision was drawn to investigate and study deliveries of inside wall materials and interior material. Inside wall material includes gypsum and plywood boards, metal profiles, insulation material in form of mineral wool. Interior material includes baseboards, wooden studs, interior wooden doors and steel doors, floor parquet. Working time spent for handling the material was documented.

5.3.1. **Gypsum and plywood boards**

Materials as gypsum boards, metal profiles, plywood and mineral wool represent main part while building inside walls. These materials correspond to large material flow and are handled by the same staff responsible for traffic safety and goods receiving. Bundles of board material are unloaded one at a time directly from the truck on the electric wheelbarrow (Figure 4.2) and moving through the construction elevator into the building by the staff. Further the material is put to on the first floor along the outer walls so that it is not in the way for other workers. The general idea is in order to shorten working time to move material from the truck to the nearest possible free space in the building so that the next day carpenters and craftsmen can further move the material to the current working place and use it. Bundles with gypsum and plywood are placed next to each other on bucks (Figure 4.3). This logistic solution differs from the traditional method where the material is lifted up in to each plan floor ongoing while rising up bearing structure of the building, floor by floor. The traditional way of lifting up inside wall material by tower crane has usually been considered as the simplest one, meaning that material is moved to the right place in advanced and been stored for several months. The preferred unlike traditional logistic solution waked curiosity and the decision was made to investigate this situation. The interviews with workers and engineers involved in the project have been done and conclusions have been drawn below.
Figure 4.2 Logistic staff is moving gypsum bundle with the help of electric wheelbarrow. (Gypsum bundle, Project A, March 2015)

Figure 4.3 Gypsum bundles are placed on bucks alongside in order to save place (Gypsum bundles, Project A, March 2015)
The conclusions drawn in the current situation are followed below:

Disadvantages with the traditional logistic solutions (Lifting up the materials with crane while rising up building)

- Materials are sometimes put in unsuitable place making accessibility to the working place limited. Also the amount of stored gypsum boards is so big that it is impossible to put it somewhere else. As a result the carpenters and craftsmen spend extra not direct value-added time while moving materials from one place to another.
- The actual amount of needed material for inside walls is often not so precise. This could be discovered while working with the material. Often happens that materials are not enough resulting in extra time for supervisor to order additional deliveries. Also workers spent some time on estimating how much material is lacking and further bring inside ordered materials.
- Additional deliveries with trucks cost 650 SEK for major truck and 350 SEK for minor trucks. Extra deliveries are ordered once per two weeks (Interview with logistic coordinator, Project A).
- In order to keep material save plywood and gypsum boards are delivered covered in plastic folio which should be further cut to provide ventilation of the material otherwise moisture can occur and damage the material.
- Sometimes materials are placed on each other in order to save working place. It can complicate working with material due to its high but also this significantly increases the point load on the floor joist, resulting supporting structures under floor.
- Gypsum and plywood boards are usually ordered in standard size when ordering in advance. In some cases the material can be too long from the beginning which further means that workers may be able to spend unnecessary time when cutting the materials before use (Interviews with carpenters, Project A).
- The additional material deliveries should come to the construction site as fast as possible. It can occur that supplier cannot deliver the proper material dimensions when running out of time. The material could be delivered in standard size which is often bigger than needed. This means that carpenters need to spent more time to cut every board or stud, which is not direct value-added work (Interviews with carpenters, Project A).

Advantages with logistics staff against traditional lifting by crane in advanced:

- Materials are put in to a suitable place and don’t impact negative on the carpenters working efficiency. If it occurs that material was placed in the unsuitable for carpenters or other craftsmen place, they can simply move the material that is placed on bucks away with the help of electric wheelbarrow.
- Logistic staff takes plastic folio away from the material after it is unloaded and put on the right place. This further excludes moisture problems keeping board material ventilated.
- No material is placed on each other excluding the need in supporting structure under floor when rising bearing structure of the building.
- Materials are ordered in good time when the bearing structure is already built. This decreases risk of ordering the wrong dimensions for materials. At the same time this increases accuracy of the estimated material for inside walls which significantly lowers need for ordering additional materials (Figure 4.4) (Interview with carpenter, Project A).
Additional deliveries of board materials and extra work

After investigation it turned out that ordering deliveries with additional material takes in average 0.5 hour each day from site supervisor (Interview with site supervisor, Project A). Also investigation showed that carpenters spent some time, not direct value-added time, for moving temporarily stored board materials on the first floor to the actual working place. It takes between 0.5 – 1.0 hour for one worker to move each bundle depending on the distance to the needed working place (Figure 4.5). Further the average of 0.75 hour has been used (Table 4.2). Extra deliveries are ordered once per two weeks with additional charging for transportation. The total amount of bundles with board material observed during the period of two months or eight weeks is documented in the table below.

**Table 4.2** Working hours spent on moving board materials to working area from the first floor, Project A

<table>
<thead>
<tr>
<th>Observed material</th>
<th>Observed deliveries</th>
<th>Boards per bundle</th>
<th>m² per bundle</th>
<th>Hours to handle one bundle</th>
<th>Amount of bundles</th>
<th>Turn-key contractor hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum boards</td>
<td>8</td>
<td>42</td>
<td>94.5</td>
<td>0.75</td>
<td>165</td>
<td>124</td>
</tr>
</tbody>
</table>
5.3.2. Steel doors and interior wooden doors

Steel doors and interior wooden doors are delivered once per week with minor trucks during mornings. Doors are delivered on pallets, usually six doors per pallet. Number of pallets during delivery varies between two and four. The doors are too wide to be handled through the construction elevator that is why they are placed on thebucks on the entrance floor or in the garage (Figure 4.6). Later they are handled by hired carrying men to each floor. It takes 8 hours for 2 workers to handle one delivery of doors of four pallets. One delivery of 24 doors is equivalent of 16 working hours (Table 4.3). Two deliveries of doors have been observed.
Table 4.3 Working hours spent while handling door deliveries, Project A

<table>
<thead>
<tr>
<th>Observed deliveries</th>
<th>Amount of doors per delivery</th>
<th>Number of workers</th>
<th>Hours</th>
<th>Working hours</th>
<th>Turn-key contractor hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st (Steel doors)</td>
<td>24 (4 pallets)</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>2nd (wooden doors)</td>
<td>12 (2 pallets)</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 4.6 The pallet with 6 steel doors is placed on bucks on the entrance floor for further moving to each floor. (Door delivery, Project A, March 2015)

5.3.3. Baseboards
Baseboards are delivered in larger deliveries once per two weeks with minor trucks. Baseboards are in bundle of approximately 0.3 meter in diameter so that two workers can carry materials into the building. The material is also placed in the first floor for next day to be moved by craftsmen to the working place where material will be used. Bundles usually include approximately 30 baseboards of 4.0 meters in length. Further for moving baseboards to needed floor for using materials two carpenters spent 5.0 hour for first delivery (Table 4.4). In other words 1200 meters of baseboards took 10 hours to handle. Two deliveries observed.
Table 4.4 Working hours spent on handling baseboards, Project A

<table>
<thead>
<tr>
<th>Observed deliveries</th>
<th>Bundles per delivery</th>
<th>Number of workers</th>
<th>Hours</th>
<th>Working hours</th>
<th>Turn-key contractor hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>10 (1200 m)</td>
<td>2</td>
<td>5.0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>2nd</td>
<td>12 (1440 m)</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

5.3.4. Metal profiles and wooden studs

Metal profiles and wooden studs are delivered twice per week with minor trucks. Ordered studs are delivered in bundles so that logistic staff can simply move it with electric wheelbarrows to the first floor. There are 80 metal profiles of 4.0 meters length per each bundle. Wooden studs are of 3.0 meters in length and 100 units per bundle. Metal profiles’ and wooden studs’ bundles are placed temporally on bucks on the first floor opposite to board materials (Figure 4.7). Next day carpenters handle bundles with studs with help of electric wheelbarrow to needed floor where materials will be used. Time spent for one worker while handling the first delivery is 5 hours (Table 4.5). Two deliveries observed.

Table 4.5 Working hours spent on handling metal profiles and wooden studs, Project A

<table>
<thead>
<tr>
<th>Observed deliveries</th>
<th>Bundles per delivery</th>
<th>Number of workers</th>
<th>Hours</th>
<th>Working hours</th>
<th>Turn-key contractor hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st (metal profiles)</td>
<td>10 (320 m)</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2nd (wooden studs)</td>
<td>8 (300 m)</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
5.3.5. **Mineral wool**

Insulation material is delivered twice every second week with minor trucks, together with plywood (Figure 4.8). Mineral wool use to come on pallets where each pallet consists of 25 packages insulation. There are 81.9 m² of mineral wool per each pallet. Pallet with material is too large to be handled through the construction elevator or front door that is why it is unpacked and handled by three at a time with electric wheelbarrow and placed in the entrance floor temporarily. Analogous other material, next day carpenters move material further to needed location where material will be used. It takes additional non-value added time for carpenters to handle insulation material. The investigation showed that it took in 7.5 respectively 5.5 working hours for two workers to handle two materials of 3 and 2 pallets of insulation (Table 4.6). Two deliveries observed.

**Table 4.6** Working hours spent on handling mineral wool delivery Project A

<table>
<thead>
<tr>
<th>Observed deliveries</th>
<th>Pallets per delivery</th>
<th>Number of workers</th>
<th>Hours</th>
<th>Working hours</th>
<th>Turn-key contractor hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>3 (245.8 m²)</td>
<td>2</td>
<td>7.5</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26</td>
</tr>
</tbody>
</table>
5.3.6. **Floor parquet**

Parquet is usually delivered on long pallets where each pallet consists of several packages. One delivery may consist of 3 long pallets with totally 81 packages which is equivalent of 235 m² of floor parquet. During uploading floor parquet, pallets are put on electric wheelbarrow one at a time and handled through the construction elevator into the building and placed on bucks on the first floor. Analogous other material, floor parquet is temporarily stored along with baseboards and studs for further to be moved to needed floor by carpenters. It takes in average 2.0 working hours to handle delivery of 3 pallets material for two workers. One parquet delivery of 235 m² is equivalent of 4.0 working hours (Table 4.7).

| Table 4.7 Working hours spent for handling floor parquet delivery, Project A |
|---|---|---|---|---|---|
| Observed deliveries | Pallets per delivery | Packages per delivery | Hours to handle one pallet | Working hours | Turn-key contractor hours |
| 1st | 3 | 81 (235 m²) | 4 | 12 | 24 |
| Total | | | | | 40 |
5.3.7. Other material deliveries
In addition to above listed materials there are more deliveries to the construction site to perform other sort of works, such as tilling, plastering, painting, plumbing and installations but also electrical works. For these activities subcontractors hired by turn-key company are responsible. As a result, subcontractors are also responsible for material handling which further means that turn-key contractor does not need to worry about the material flow for this sort of work.

5.4. Observations and collected data, Project B
Further follows detailed inventory for materials that are needed during the architectural stage for one out of nine hotel floor plans, Project B (Table 4.8). The first hotel floor corresponds to the 7th floor plan of the building. Data is collected after visiting site office establishment for Project B and interview with production manager. As mentioned before, materials represent a significant part of the total construction cost and also correspond to the larger material volumes. In the next chapter given data is been further analysed and compared to data collected from Project A. Outgoing from deliveries observed in the Project A and material inventory from Project B the economical conclusion have been drawn.

Table 4.8 Inventory for material quantity needed during architectural stage of the 1st floor of hotel section, Project B (Interview with production manager, Project B)

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum boards</td>
<td>3 075.1</td>
<td>m²</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>896.0</td>
<td>m²</td>
</tr>
<tr>
<td>Steel doors</td>
<td>10.0</td>
<td>Pieces</td>
</tr>
<tr>
<td>Interior wooden doors</td>
<td>82.0</td>
<td>Pieces</td>
</tr>
<tr>
<td>Baseboards</td>
<td>1 444.7</td>
<td>m</td>
</tr>
<tr>
<td>Metal profiles</td>
<td>3 143.8</td>
<td>m</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>1 150.9</td>
<td>m²</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>432.0</td>
<td>m²</td>
</tr>
</tbody>
</table>
6. Data analysis and discussion

6.1. General
In the previous chapter data from site observations from Project A has been collected. In this chapter results regarding material handling and additional time spent on extra work have been studied and further analysed. Also some assumptions and cost estimations have been done while investigating materials needed for hotel section for Project B.

6.2. Explanations, assumptions and calculations
Project B, the hotel-office block, and Project A, the office block, have common structure and floor plan, even though the area of Project A is more than 5 times larger. Floor plan of Project A is in form of long broad corridors through the whole floor plan with many enclosed office rooms on both sides of the corridor. In this research it is assumed that the floor plan of Project A is similar to the floor plan of the hotel section of the Project B, where there are many hotel rooms with a broad corridor between the guest rooms. Unlike residential and apartment block project due to larger spaces in Projects A and B it is possible to handle both gypsum and plywood materials without unpacking it. It is possible to drive the whole bundle with board material with electric wheelbarrow from the unloading area through the construction elevator up to needed floor. Every material described in the previous chapter except of doors can be freely driven with electric wheelbarrow through the whole building and to any floor plan through construction elevator.

In the economical calculation standard cost per working hour has been used as followed below (Interview with planning engineer, Project B, April 2015):

- Carrying man 245 SEK/h
- Logistic staff 345 SEK/h
- (Turn-key contractor) Site worker 385 SEK/h
- Site supervisor 385 SEK/h

Time spent for material handling and not direct value-added time spent by site workers while moving materials to needed working place can be further calculated from observations documented in previous chapter. During eight weeks the general concept of working approach has been obtained as a result there is no need to observe until architectural phase is done.

Gypsum and plywood boards
Gypsum and plywood boards correspond to one of the larger material flows in the project. Observation showed that board material is delivered twice a week with major trucks. Totally eight observations for each material have been done. Further carpenters were followed while handling bundles of board material with electric wheelbarrow. Gypsum and plywood material usage is not constant during architectural project, it can depend on different factors, including amount of carpenters during the working day and activity time plan. The decision was made to follow single bundles of board material instead of timing large amount of bundle during each working day. Investigation showed that in average it took between 0.5 – 1.0 hour to move one gypsum or plywood bundle to the right place. Variation depends mostly on two factors, the first is how long time it takes to travel
with elevator and the second how many obstacles were there on the way due to a lot of site workers during the day. For calculation the average time of 0.75 working hours has been used.

**Steel doors and interior wooden doors**

Steel and interior wooden doors are delivered once per week to the construction site and stored temporarily in the garage. Two deliveries have been observed. Working time spent for unloading one delivery and placing it on bucks is 16 hours. Time to handle another delivery of 12 doors is 8 hours. To handle both deliveries took 24 hours. After dividing total time of 24 hours with the amount of doors during two deliveries the average time per door handled is calculated for 0.66 working hours.

**Baseboards**

There are two deliveries of baseboards to the project. Material is put on bucks in the first floor after unloading from truck. Further it took 5.0 hours for two workers to handle delivery of 10 bundles to the required floor. By dividing total time it took for handling two materials deliveries with total number of bundles the average working time is calculated. It is equivalent of 1.0 working hours per bundle of baseboards.

**Metal profiles and wooden studs**

There are two deliveries of metal profiles and wooden studs. Observation for delivery of each material has been made where materials were handled through construction elevator to the first floor and stored on bucks temporarily. It took 5 respectively 4 hours for one worker with electric wheelbarrow to handle each one delivery of 10 respectively 8 bundles. Average time spent for handling each bundle with studs is 0.5 hour. It is equivalent of 0.5 working hours for handling 300 meters of wooden studs or 320 meters of metal profiles.

**Mineral wool**

There are two deliveries every second week to the project. The observation is done for two deliveries where insulation sacs are unpacked and handled with help of electric wheelbarrow through construction elevator and placed temporarily in the first floor. To do that it took 7.5 and 5.5 hours for handling deliveries of 3 respectively 2 pallets with insulation material. With simple calculation the average time for handling one pallet with 25 packages insulation is obtained. It takes 2.6 working hours to move one pallet of 81.9 m² of mineral wool to the right place.

**Floor parquet**

To calculate time spent for handling floor parquet the average time for one delivery has been used. Two delivery observations have been made. The first parquet delivery was to floor 5 and 6. It took in total 12 hours to handle this delivery. The next delivery was to floor 10 and 11 and took 10 hours. The working approach is absolutely the same, the only difference in time depends on how long workers are staying in the construction elevator while moving material. The average time spent for handling one pallet materials is 4.5 working hours. It is equivalent to say it took 12 working hours for handling 81 packages (235 m²) parquet. Knowing this after summing total amount of working hours for two deliveries and further divided with sum of packages of parquet the average working time per package of parquet (2.9 m²) is calculated to 0.16 working hour.
Summery

Below is shown the summary of all observations and assumptions regarding working hours spent on material handling for inside wall materials and interior materials to Project A (Table 5.1). In the table it is shown that the total number of hours spent on moving material such as floor parquet, baseboards, insulation, gypsum and plywood etc., is 302 hours performed by turn-key contractor. Time it took for handling steel doors and interior wooden doors is 24 hours spent by carrying men. The interesting is that working time spent per unit handled material is calculated directly from observations and for one worker, without taking the entire length of the production stage for Project A into account. It makes it possible to estimate time needed to handle any amount of inside wall material and interior material. Later this approach is used for calculating estimated time for material handling for the hotel-office block project, Project B.

Table 5.1 Summery of total time and hours per bundle spent on material handling for the Project A

<table>
<thead>
<tr>
<th>Material/Product</th>
<th>Hours (Carrying men)</th>
<th>Hours (Turn-key contractor)</th>
<th>Hours per bundle handled material</th>
<th>Units of handled material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum boards</td>
<td>0</td>
<td>124</td>
<td>0.75</td>
<td>1 bundle (94.5 m²)</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>0</td>
<td>81</td>
<td>0.75</td>
<td>1 bundle (131.8 m²)</td>
</tr>
<tr>
<td>Steel doors</td>
<td>16</td>
<td>0</td>
<td>0.66</td>
<td>1 unit</td>
</tr>
<tr>
<td>Interior wooden doors</td>
<td>8</td>
<td>0</td>
<td>0.66</td>
<td>1 unit</td>
</tr>
<tr>
<td>Baseboards</td>
<td>0</td>
<td>22</td>
<td>1.0</td>
<td>1 bundle (120 m)</td>
</tr>
<tr>
<td>Metal profiles</td>
<td>0</td>
<td>5</td>
<td>0.5</td>
<td>1 bundle (300 m)</td>
</tr>
<tr>
<td>Wooden studs</td>
<td>0</td>
<td>4</td>
<td>0.5</td>
<td>1 bundle (320 m)</td>
</tr>
<tr>
<td>Mineral wool (Insulation)</td>
<td>0</td>
<td>26</td>
<td>2.6</td>
<td>1 pallet (81.9 m³)</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>0</td>
<td>40</td>
<td>0.16</td>
<td>1 package (2.9 m³)</td>
</tr>
<tr>
<td>Additional ordering By site supervisor</td>
<td>0</td>
<td>0.5h/day</td>
<td>0.5h/day</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24</strong></td>
<td><strong>302</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The total amount of working hours and cost estimation for handling inside wall material and interior material for Project B is been calculated (See Appendix) and presented in the table below. From table 5.5 it follows that total amount of hours needed to handle the material for Project B is slightly above 1 500 hour or 190 working days. In
other words almost 38 working weeks or 8.6 months of full-time work if consider 8 working hours per one day. Also cost difference for turn-key contractor site worker is more than 211 TSEK higher than if involving carrying men for material handling. On the other hand if involving logistic staff the price is almost the same.

Table 5.5 Final cost for material handling for hotel section for Project B

<table>
<thead>
<tr>
<th>Service</th>
<th>Cost SEK/h</th>
<th>Total hours to handle all material</th>
<th>Final cost for material handling (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrying man</td>
<td>245</td>
<td>1 511</td>
<td>370 232</td>
</tr>
<tr>
<td>Logistic staff</td>
<td>345</td>
<td>1 511</td>
<td>521 347</td>
</tr>
<tr>
<td>Site worker</td>
<td>385</td>
<td>1 511</td>
<td>581 793</td>
</tr>
</tbody>
</table>

6.3. Carrying services
Every delivered material has been divided in two groups: inside wall material and interior materials. Inside wall material includes gypsum and plywood boards, metal profiles as well as mineral wool. Interior material includes steel doors, interior wooden doors, baseboards, wooden studs and floor parquet. The suggestion that follows further in this chapter is to use carrying services, logistic staff and carrying men, for transportations and handling these materials on site and to do that during evening. Handling material with carrying services allows main contractor skilled workers to increase their performance during the day time therefore to decrease not direct value-added time spent for carrying and moving materials. Using carrying services instead of skilled workers gives even more benefits such as:

- Reduced amount of not direct value-added time done by skilled contractor workers;
- Reduced waiting and unused time;
- Reduced production period;
- More efficient and safe working environment;
- Reduced congestion due to no material stored on site for long period

6.4. Inside Wall Materials

6.4.1. General outlook
Gypsum and plywood boards as well as metal profiles are main materials when building inside walls. With traditional logistics techniques these materials are been lifted up on to each floor continuously while building up the bearing structure of the building, storey by storey. The analysis of this solution of handling inside wall material flow showed following:
- Usage of tower crane is rather expensive
- Storing materials for long time makes investment put out of action;
- Site workers reduce amount of direct value-added work when spending additional time for moving materials from one place to another.
- Putting more than one bundle of gypsum boards (e.g. two gypsum bundle and one metal stud bundle) on each other needs additional supporting structures, increasing production cost. Also workers spend additional time to put down materials before usage, which decreases work satisfaction;
- All board material should be of right dimensions in order not to spend extra time for e.g. carrying material due to wrong dimensions instead of using electric wheelbarrow;
- Ordering additional deliveries and handling extra material increases production cost
- If not taking away plastic folio, gypsum boards can be damaged due to moisture resulting in increased production costs.

### 6.4.2. Suggested logistic approach for handling inside wall material

The suggestion is to involve subcontractor in form of carrying men or construction logistic staff instead of traditional lifting up inside wall materials by tower crane. In order to increase efficiency of construction logistic instead of booking time for delivery through web-based platform as in Project A to organize material handling during afternoons when all the workers finished and exited the site. During observations from Project A most of material flow occurred during afternoons for more “smooth” material flow. In addition it is important for subcontractors while handling the material to place it in the area of final usage instead of temporally placing it somewhere else. The placement of inside walls should be taken into account in order not to move material once again when building inside walls. Main point with this is not to reduce direct value-added time for carpenters searching and moving inside wall material. It is worth to mention that most of morning deliveries were delayed due to high traffic during rush hours.

### 6.4.3. General strategy

- **15:00**: Lorries full loaded with inside wall material coming to the unloading zone on the construction site one hour before all workers are finished and left the site. Lorries are coming directly from the supplier and start to unload by themselves with the help of one turn-key contractor worker. Bundles of material are put on bucks outside the construction elevator.
- **15:30**: 30 minutes before material is unloaded two subcontractor workers come. Turn-key contractor site supervisor together with carrying workers going through the working process, showing what material and to what place should be moved, taking inside walls’ placement into account.
- **16:00**: When all the material is unloaded, the subcontractor workers start transporting material with the help of electric wheelbarrow. Often it is enough to have one machine for each worker to have constant material flow through one construction elevator. Amount of workers varies depending on the volume of material deliveries.
- **18:00**: The right material is moved to the right place.

### 6.4.4. Strategy for Project B

Inside wall material deliveries usually start after bearing structure is raised and the architectural phase occurs. The period of building inside walls is approximately 24 weeks. There are 355 bundles of gypsum and plywood boards, 95 bundles of metal profiles as well as 127 pallets with insulation. Deliveries with gypsum, plywood and
metal profiles can be ordered twice per week. One fully loaded lorry contains 12 bundles of gypsums and/or plywood and 4 bundle of metal profiles. Totally it will be 30 deliveries, 24 fully loaded deliveries with gypsum, plywood and metal profiles and 6 deliveries with only gypsum and plywood. Deliveries with insulation material, mineral wool, can also be ordered twice per week with 6 pallets loaded per lorry, resulting in 21 deliveries in total. In the table below the final result of number of deliveries and working hours for handling inside wall material is presented considering two subcontractor carrying workers when handling the material. Total cost for material handling is shown in 2 alternatives, considering carrying workers and turn-key contractor.

Table 5.6a Total amount of deliveries and working hours to handle inside wall material for Project B.

<table>
<thead>
<tr>
<th>Material delivered</th>
<th>Number of deliveries needed</th>
<th>Quantity of bundles</th>
<th>Hours needed for handling material</th>
<th>Working days for material handling (1 worker)</th>
<th>Working days for material handling (2 worker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum &amp; plywood metal profiles</td>
<td>24</td>
<td>288 95</td>
<td>216 48</td>
<td>33</td>
<td>16.5</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>6</td>
<td>66</td>
<td>54</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>21</td>
<td>127</td>
<td>329</td>
<td>41</td>
<td>21.5</td>
</tr>
</tbody>
</table>

Table 5.6b shows total cost for material handling. From the table follows that total amount of working hours the inside wall material is 646 hours (the sum of hours needed for handling material from Table 5.6a).

Table 5.6b Total cost for material handling for two alternatives for Project B

<table>
<thead>
<tr>
<th>Title</th>
<th>Amount of working hours</th>
<th>Cost/hour</th>
<th>Total cost (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrying men</td>
<td>646</td>
<td>245</td>
<td>158 368</td>
</tr>
<tr>
<td>Turn-key contractor site worker</td>
<td>646</td>
<td>385</td>
<td>248 864</td>
</tr>
<tr>
<td>Saving potential (SEK)</td>
<td></td>
<td></td>
<td>90 496</td>
</tr>
<tr>
<td>Saving potential (SEK/m²)</td>
<td></td>
<td></td>
<td>12.57</td>
</tr>
</tbody>
</table>

Total cost for suggested logistic solution if involving carrying workers is 158 368 SEK, which is 90 496 SEK lower comparing to site workers transporting inside wall material by their selves. Besides decreasing production costs by almost 90 500 SEK if not involving turn-key contractor site workers suggested solution. The saving potential is
12.57 SEK per m² of hotel living area (Table 5.6b). It is not so high, however suggested solution helps not to decrease direct value-added work done by skilled workers and as a result not to extend but secure production time for architectural phase. If the material handling occurs to be likely in Project A, there is a “hidden” risk of increasing the production for architectural phase and also additional costs.

Below follows advantages and disadvantages for our logistic solution.

**Advantages:**

- Reduced time spent for extra work;
- Saving potential if involving carrying workers up to 90 496 SEK or 12.57 SEK per m² living area;
- Possibility of “securing” the production time, identifying “hidden” risks of additional costs and increased production time due to extra work;
- Possibility to reduce production time for construction inside walls by almost one week (Table 5.6b, 646.4 hours / 20 site workers = 32 working hours corresponding for 4 of 5 working days of a week);
- Transportation and material handling will be finished before 18:00 with no additional fees for evening work;
- No disturbances from the construction site due to last lorry gone before 16:00;
- Carrying men work on their own and do not disturb other construction activities;
- No material stored on site for long time, meaning more profitable investment
- Better follow-up of the architectural process. Delivered material is used directly making it possible to recognize if there is enough material or if it should be additional delivery the next day;
- Bundles will be placed one by one on bucks, no need for additional cost for supporting structures;
- More efficient and safe construction site during the day time.

**Disadvantages:**

- Carrying workers should be aware of where to place the material. This puts more demands for efficient communication between site supervisor and carrying men;
- If large material volume there is a risk of need of extended working capacity by 4-6 carrying workers and 2-3 electric wheelbarrows in order to handle large material flow;
- If large material volume there is a risk of working during late evening, later than 18:00, with additional fees;
- Requires space for unloading material, if free unloading zone is unavailable no smooth material flow can be organized;
- Such material flow requires changes for improvement in project coordination;

This logistic solution will not only contribute to more efficient construction process, decreasing project costs and improving performance but also will increase safety and work satisfaction. At the same time it makes the whole construction process more environmentally friendly. Less damaged material causes less waste as well as full loaded trucks will decrease heavy transports reducing carbon emissions. Finally the suggested strategy gives the
process of rising inside walls better opportunity to make changes during construction. With increased flexibility there are better chances to manage unexpected problems that can occur.

6.5. Interior material

6.5.1. General outlook
Carrying men are hired for carrying works in order to keep labour costs low and not to decrease direct value-added time of skilled site workers. Even if turn-key contractor workers are not supposed to transport interior material on site data analysis showed that skilled carpenters and craftsmen spend relatively much time for moving the material. Observations from Project A showed that carrying men were involved to carry in door sections which are too wide to be transported by electric wheelbarrows. Total amount working hours and costs to handle interior wall material are presented in table below.

Table 5.7 Amount of hours and cost for handling interior material deliveries for Project B

<table>
<thead>
<tr>
<th>Title</th>
<th>Working hours</th>
<th>Cost SEK/hour</th>
<th>Total cost (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrying men</td>
<td>546.5</td>
<td>245</td>
<td>133 770</td>
</tr>
<tr>
<td>Turn-key contractor site worker</td>
<td>322.9</td>
<td>385</td>
<td>124 317</td>
</tr>
<tr>
<td>Total</td>
<td>869.4</td>
<td></td>
<td>258 087</td>
</tr>
</tbody>
</table>

Data analysis shows that turn-key contractor site worker spends 322.9 working hours for handling interior material. By involving only subcontractors for moving the materials, carpenters and craftsmen could spend more time for direct value-added work. This would increase construction performance and reduces project labour costs for 45 206SEK (322.9*(385-245) = 45 206 SEK).

6.5.2. Suggested logistic approach for interior materials
The suggestion is to appoint carrying men to handle whole flow of interior material. The material handling will be organized during afternoons when most of site workers leave from the construction site. Interior material includes steel doors, interior wooden doors, baseboards and floor parquet.

6.5.3. General strategy
- 15:00: Lorries with interior wall material coming to the unloading zone on the construction site one hour before all workers are finished and left the site. Lorries are coming directly from the supplier and start to unload by themselves with the help of one turn-key contractor worker. Bundles of material are put on bucks outside the construction elevator.
- 15:30: 30 minutes before material is unloaded two subcontractor workers come. Turn-key contractor site supervisor together with carrying workers is going throw the working process, showing what material and to what place should be moved.
- 16:00: When all the material is unloaded, the subcontractor workers start transporting material with the help of electric wheelbarrow. Often it is enough to have one machine for each worker to have constant material flow through one construction elevator. Amount of workers varies depending on the volume of material deliveries.
- 18:00: The right material is moved to the right place.

6.5.4. Strategy for Project B
Interior wall material deliveries start after bearing structure is raised and the architectural phase occurs. The period of interior works is approximately 24 weeks. Deliveries for interior material can be ordered twice per week. There are 828 door sections, considering 6 doors per pallet and 4 pallets load capacity at the same time for one truck. As a result there should be at least 35 deliveries with door sections. There are also 109 bundles of baseboards and 1 341 packages of parquet to be delivered for Project B. Baseboards can be split in 4 deliveries of approximately 30 bundles per delivery. Floor parquet can be transported with 4 full loaded lorries in total. Interior material can be delivered directly from the supplier due to large material volumes.

Table 5.8 Total amount of deliveries and working hours for handling interior wall material for Project B.

<table>
<thead>
<tr>
<th>Material delivered</th>
<th>Number of deliveries needed</th>
<th>Quantity of bundles</th>
<th>Hours needed for handling material</th>
<th>Working days for material handling (1 worker)</th>
<th>Working days for material handling (2 worker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel and interior wooden doors</td>
<td>35</td>
<td>828 units</td>
<td>546.5</td>
<td>68.3</td>
<td>34.2</td>
</tr>
<tr>
<td>Baseboards</td>
<td>4</td>
<td>108.35</td>
<td>108.4</td>
<td>13.5</td>
<td>7</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>4</td>
<td>1 340.7</td>
<td>214.5</td>
<td>26.8</td>
<td>13.4</td>
</tr>
</tbody>
</table>

Cost for the suggested solution is 213 003 SEK if involving carrying men. It is calculated by multiplying the total number of working hours from Table 5.7 (869.4) and the actual cost per carrying man hour (245 SEK/h). Saving potential for handling interior material is slightly above 45 000 and equivalent to 6.25 SEK per m² of living area. It is rather insignificant, still suggested logistic solution has other profits except of decreasing project costs. One example is reduced time for waiting and interruptions by more than 20% of normal working time for construction worker (See figure 2, Josephson et al., 2007).

Advantages and disadvantages for suggested logistic solution are presented below:

**Advantages:**
Reduced time spent for extra work

o Saving potential if involving carrying workers up to 45,000 or 6.25 SEK per m² living area;

o Possibility to reduce production time for interior activities up to 0.5 week (Table 5.7, 322.9 hours / 20 site workers = 16 working hours, corresponding for 2 week days of 5);

o Increased work satisfaction due to less damaged material resulting in less waste;

o Better on-site accessibility for workers due to no material stored on site;

o Better working place due to less activities during daytime and as a result the minority of interruptions;

o No disturbances from the construction site because lorries are gone after 16:00;

o Increased safety on site

Disadvantages:

o Better communication between carrying men and site supervisor required;

o If large material volumes there is risk of need of more carrying men working during evening with additional fees;

o Requires space for unloading material, if free unloading zone is unavailable no smooth material flow can be organized;

o Such material flow requires changes for improvement in project coordination;

6.6. Cost and time benefits

According to calculations for inside wall material and interior material on site transportation there is a possibility to shorten production process during the architectural phase by more than a week. If considering 20 turn-key contractor site workers the total construction period can be decreased by 6 working days. Suggested logistic solutions make it achievable to save 4 days during handling inside wall materials and slightly over 2 days when transporting other interior wall material. For larger construction projects 6 days may give rather high profits if to consider all activities on-site, including labour costs, hired machinery and equipment costs, temporary project offices etc.

6.7. Discussion

The results of this study show large saving potential for construction logistics and for both projects in whole. During the calculation the most of material needed for architectural phase was taken into account except of offsite prefabricated elements as well as façade walls and windows. From start the case study was an investigation of a particular project where all the findings and data have been collected by practical site observations and site interviewed. All larger deliveries during two months have been observed and all key managers and construction workers were interviewed, both from turn-key contractor but also from subcontractor. Several senior production managers and logistic planners were interviewed and shared their valuable knowledge about construction logistics, that contribution was priceless.

Even both construction projects are carried out by the same turn-key construction company, the practical approach regarding construction logistics solutions for these projects differs. During this study interesting details
were discovered, some of the logistics solution and techniques can increase production performance of one project and at the same time can be less efficient when applied to another project.

From previous research it is known when dealing with construction projects and construction logistics a lot of waste and environmental impact occurs and there is always a large potential for improvements in those areas. During this study it was shown what consequences can be due to inefficient logistic planning. In this research the potential for an office-block project is demonstrated as a time and cost savings. Another suggestion for material deliveries to the construction site is also given.
7. Conclusions and recommendations

7.1. Conclusions
The purpose of this study was to examine construction logistics for an office-block project and to identify the conditions required for efficient construction logistics. After practical investigation of material flow on the site alternative logistic strategy has been generated for higher performance of the production process.

During this thesis work it was found out how much direct value-added time is spent by skilled workers while handling material and what can be improved for not reducing this time. The study showed that construction logistics is underestimated by construction companies and that construction logistics may impact a lot of factors including waste, environment, production performance, etc. Even leading construction companies on Swedish market are not aware of how significant construction logistics is and what consequences could be due to low logistic performance.

For the period of this research it was discovered that today still traditional construction logistics solution are used, e.g. long-time on-site material storing, hiring skilled workers to move material as a result reducing their value-added working time. The study showed that with insignificant effort by planning engineer major improvements on the whole construction process can occur. This saves cost and time but also increases working satisfaction and safety on site.

While investigating the material flow for architectural material it was explored that inside wall materials and other interior material are transported by subcontractors and stored on the site for longer time. This was of handling material was considered to be the most suitable. The study showed that there is a large potential for improvement while handling inside wall and interior materials. The suggested construction logistics solution facilitates increased production performance and helps to avoid unnecessary activities and to decrease production cost. In this case study by the proper on-site logistic approach for Project A the direct saving potential was achieved by 12.57 SEK/m² and 6.25 SEK/m² while handling inside wall material and other architectural material. As well as saving potential there is a possibility to reduce production time for the entire project. With improved logistic solution the production time can be reduced by 6 days.

7.2. Recommendations for future research and for contractor companies

Recommendations for contractor companies

The first recommendation for construction companies is to hire subcontractors for carrying the materials. If instead involving skilled workers for material handling, much of direct value-added time is being lost. The second recommendation is not to order usual material deliveries during day time, especially if the construction site is in the city centre, due to this large material delays can occur. The third recommendation is to organize material handling during evening for more “smooth” material flow. The final recommendation that was drawn after interviews with site workers is if possible beyond civil servant to involve construction site workers and/or site supervisors already during the planning phase. Their practical knowledge could help logistics coordinators and planning engineers when estimating and ordering material in order to save cost and increase precision.

This thesis clearly illustrated that the additional investment for construction logistics development in building projects is sensible since the return on this investment is significant. Every construction company should have its
own resource in form of logistics expert, likely other areas, such as building technology, structural engineering, etc. Such experts could be planning engineers, logistic coordinators with only task of focusing on creating conditions and maintaining uninterrupted material flow within the construction site as well as to it.

**Recommendations for future research**

This case study deals with office and hotel-office building projects performed by a turn-key contractor company, focusing on larger material deliveries for inside wall material and interior material. The research has been carried out during the short period of the production phase and as a result with very limited possibilities to practically influence the working process when giving suggestions for improvement. Today there is much theory and earlier researches with solid knowledge regarding construction logistics and supply chain management. It can be of interest to make a research during the early stage, during planning or even design phase of the project and to investigate the logistic situation from the holistic perspective, not only on the site, but outside of it. On the early stage there is a constant communication within all the planners and managers therefore it can be easier to come up with the best suitable solution for the particular project.
8. References

Text Books


Reports


Gyllin Glenn & Thunberg Micael, 2010. Analysis of SCOR implementation at PEA. Linköping University, Sweden.


Lundesjo Greger, 2011., *Construction Consolidation Centre*, The Old Academy, Oxon UK, July 2011


**Internet**


**Interviews**


9. Appendix

Calculating material quantity for architectural stage for Project B

Below in the Table 5.2 all inside wall material and interior material volumes needed for architectural stage for one hotel floor and for entire hotel section for Project B are presented. Material for the entire hotel section is calculated simply by multiplying the volumes of materials needed for one hotel floor, \((x)\), by number of hotel floors, \((9)\).

**Table 5.2** Inventory for material quantity for the entire hotel section of the building for Project B

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity per floor 1 out of 9</th>
<th>Quantity per 9 floors</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum boards</td>
<td>3 075.1</td>
<td>27 675.9</td>
<td>m²</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>896.0</td>
<td>8 064.0</td>
<td>m²</td>
</tr>
<tr>
<td>Steel doors</td>
<td>10.0</td>
<td>90.0</td>
<td>Pieces</td>
</tr>
<tr>
<td>Interior wooden doors</td>
<td>82.0</td>
<td>738.0</td>
<td>Pieces</td>
</tr>
<tr>
<td>Baseboards</td>
<td>1 444.7</td>
<td>13 002.3</td>
<td>m</td>
</tr>
<tr>
<td>Metal profiles</td>
<td>3 143.8</td>
<td>28 294.2</td>
<td>m</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>1 150.9</td>
<td>10 358.1</td>
<td>m²</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>432.0</td>
<td>3 888.0</td>
<td>m²</td>
</tr>
</tbody>
</table>

Calculating material quantity to be ordered for Project B

In the table 5.3 all inside wall material and interior material quantity needed for architectural stage for the entire hotel section for Project B is calculated. To do these the material volume for 9 floors, \((X)\), is divided by amount of material per bundle, \((Y)\).
Table 5.3 Inventory for material quantity to be ordered for the entire hotel section of the building for Project B

<table>
<thead>
<tr>
<th>Material</th>
<th>Material volume for 9 floors</th>
<th>Quantity per one bundle</th>
<th>Quantity to order (Project B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>X/Y</td>
</tr>
<tr>
<td>Gypsum boards</td>
<td>27 675.9</td>
<td>1 bundle (94.5 m$^3$)</td>
<td>293 bundles</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>8 064.0</td>
<td>1 bundle (131.8 m$^3$)</td>
<td>61.2 bundles</td>
</tr>
<tr>
<td>Steel doors</td>
<td>90.0</td>
<td>1 unit</td>
<td>90 units</td>
</tr>
<tr>
<td>Interior wooden doors</td>
<td>738.0</td>
<td>1 unit</td>
<td>738 units</td>
</tr>
<tr>
<td>Baseboards</td>
<td>13 002.3</td>
<td>1 bundle (120 m)</td>
<td>108.35 bundles</td>
</tr>
<tr>
<td>Metal profiles</td>
<td>28 294.2</td>
<td>1 bundle (300 m)</td>
<td>94.3 bundles</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>10 358.1</td>
<td>1 pallet (81.9 m$^2$)</td>
<td>126.5 pallets (25 packages each)</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>3 888.0</td>
<td>1 package (2.9 m$^2$)</td>
<td>1 340.7 packages</td>
</tr>
</tbody>
</table>

Calculation of total amount of hours to handle the material for Project B

Total amount of hours to handle inside wall material and interior material for the entire hotel section for Project B is calculated with the help of data calculated in Table 5.1. Hours per bundle spent on the material handling, (S), from Table 5.1 have been multiplied with amount of bundle to order for Project B. Total amount of hours for handling material for Project B is calculated and is equal to 1 511. If consider a working day of 8 hours the total amount of hours corresponds to almost 190 working days (1 511h / 8h = 188.9 days), equal to 38 working weeks. If consider 175 working hours per month total amount of hours corresponds to almost 9 (8.6) months of full-time work.

Table 5.4 Total amount of hours to handle the material for the entire hotel section of the building for Project B

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount of bundles to order (Project B)</th>
<th>Hours per bundle handled material</th>
<th>Total hours to handle all material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>S</td>
<td>R*S</td>
</tr>
<tr>
<td>Gypsum boards</td>
<td>293 bundles</td>
<td>0.75</td>
<td>219.75</td>
</tr>
<tr>
<td>Plywood boards</td>
<td>61.2 bundles</td>
<td>0.75</td>
<td>45.9</td>
</tr>
<tr>
<td>Material</td>
<td>Amount of bundles to order (Project B)</td>
<td>Hours per bundle handled material</td>
<td>Total hours to handle all material</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Steel doors</td>
<td>90 units</td>
<td>0.66</td>
<td>59.4</td>
</tr>
<tr>
<td>Interior wooden doors</td>
<td>738 units</td>
<td>0.66</td>
<td>487.1</td>
</tr>
<tr>
<td>Baseboards</td>
<td>108.35 bundles</td>
<td>1.0</td>
<td>108.4</td>
</tr>
<tr>
<td>Metal profiles</td>
<td>94.3 bundles</td>
<td>0.5</td>
<td>47.2</td>
</tr>
<tr>
<td>Mineral wool</td>
<td>126.5 pallets</td>
<td>2.6</td>
<td>328.9</td>
</tr>
<tr>
<td>Floor parquet</td>
<td>1 340.7 packages</td>
<td>0.16</td>
<td>214.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1 511.15</td>
</tr>
</tbody>
</table>

*Calculation of cost estimation for handling material for Project B*

Calculation of cost estimation for handling inside wall material and interior material for hotel section for Project B is presented in the table below. Cost estimation for material handling is calculated separately for carrying man (245 SEK/h), logistic staff (345 SEK/h) and turn-key contractor site worker (385 SEK/h) to see the difference in final costs.

*Table 5.5 Final cost for material handling for hotel section for Project B*

<table>
<thead>
<tr>
<th>Service</th>
<th>Cost SEK/h</th>
<th>Total hours to handle all material</th>
<th>Final cost for material handling (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>Q</td>
<td>P*Q</td>
</tr>
<tr>
<td>Carrying man</td>
<td>245</td>
<td>1 511.15</td>
<td>370 232</td>
</tr>
<tr>
<td>Logistic staff</td>
<td>345</td>
<td>1 511.15</td>
<td>521 347</td>
</tr>
<tr>
<td>Site worker</td>
<td>385</td>
<td>1 511.15</td>
<td>581 793</td>
</tr>
</tbody>
</table>