CHALMERS

The role of logistics in urban tunnel construction projects

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

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ABSTRACT

The tunnelling construction operations in urban environment are about to increase due to an increased density within major cities. The construction of tunnels in urban areas is to a large extent carried out in confined sites, which enhances the importance of an effective logistics system. The concept of construction logistics has been utilized within the housing sector to a greater extent than within the infrastructural construction sector.

The purpose of this thesis is to investigate in which way the contractors and clients in the tunnelling industry are dealing with logistic issues and to find out areas that can be subject of improvement. Eventually, the purpose is to declare what issues that cause the most challenges and how to deal with those from a logistics service provider's point of view.

In order to find out areas that cause challenges for contractors and clients, literature has been studied and comparisons have been made to an in depth interview with site managers and client's representatives. This has enabled a review of both the existing literature on the matter together with experiences and views that are rarely shared amongst contenders within the construction sector.

Findings have shown that contractors in general are well aware of the importance of an efficient logistics handling when constructing underground constructions in urban areas. The approached contractors were using a great amount of planning and time to avoid problems due to the complexity of tunnel construction.

Conclusions are that the key issue that must be addressed when assessing the logistics of a tunnel construction is to utilize access tunnels to such a large extent as possible.

Key words: Tunnel, urban, logistics, confined site, just in time, construction

Logistikens betydelse för tunnelbyggen i stadsmiljö
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SAMMANFATTNING

Det här examensarbetet behandlar logistikens betydelse för ett framgångsrikt tunnelbygge i stadsmiljö. Då mängden storstäder ökar, samtidigt som de förtätas världen över ökar även behovet av tunnlar i stadsmiljö för att tillgodose de ökade transportbehoven. Tunnelbyggnad i stadsmiljö utförs på platser där utrymmet är begränsat, både gällande tillgängliga markytor och nere i själva tunneln. Det ställer krav på en väl fungerande organisation med fokus på logistikhantering för att genomföra den här typen av projekt. Arbetssättet med ett ökat fokus på logistiken och implementeringen av Just-In-Time i byggbranschen har succesivt ökat, framförallt inom husbyggnation men även inom infrastrukturbyggnation.

Ambitionen med det här examensarbetet är att ta reda på hur entreprenörer och beställare arbetar med logistikhanteringen vid tunnelprojekt och att hitta områden som kan förbättras. Vidare är ambitionen att upptäcka vilka utmaningar som är störst och hur ett företag verksamt inom bygglogistik kan hantera dessa.

För att ta ta reda på vad som skapar utmaningar för entreprenörer och beställare har en litteraturstudie utförts och jämförts med en serie djupintervjuer med ansvariga platschefer och projektledare. Utöver det har ytterligare observationer genomförts på ett antal pågående tunnelarbetsplatser. Detta har möjliggjort en studie av ny och äldre litteratur tillsammans med erfarenheter och synsätt som sällan delas mellan olika företag inom byggbranschen.

Resultaten har visat att entreprenörer i allmänhet är väl insatta i problematiken och frågorna gällande logistik vid tunnelbyggnad i stadsmiljö. De intervjuade entreprenörerna har ägnat mycket tid åt att planera för att försöka undvika problem som uppkommer på grund av de svårigheter som finns inom tunnelkonstruktion.

Slutsaten är att den viktigaste frågan som gällande tunnellogistik är att säkerställa en god tillgänglighet via arbetstunnlar. Även då detta innebär en extra kostnad och kan vara problematiskt rent politiskt har det visat sig att kostnaden är motiverad på grund av ett ökat flöde genom arbetsplatsen.

Nyckelord: : Tunnel, stadsmiljö, logistik, begränsat utrymme, Just-In-Time, byggande

Contents

Preface

This master thesis was written during the spring of 2014 based on a need by Svensk Bygglogistik AB that emerged into the actual subject highly relevant with the upcoming construction of Västlänken.

We would like to thank our supervisor at Chalmers, Jan Englund, who has been a good support and advisor during the entire process.

Also, a great thanks to our supervisor at Svensk Bygglogistik, John-Niclas Agerberg for being supportive as well as keeping the thesis in the relevant direction throughout the process.

Finally, thanks to all of the companies that have assisted with their time and staff and whose experience and knowledge have been essential for this thesis.

Göteborg, May 2014

Fredrik Johansson Rickard Törnqvist

Definitions and abbreviations

LSP Logistics Service Provider

JIT Just in Time

TBM Tunnel Boring Machine

CC Consolidation Centre

WDP Work Disposition Plan

1 Introduction

1.1 Background

The importance of construction logistics for achieving a successful project has become more and more apparent within the construction industry during the recent decade. The concept has been known and applied to a greater extent within the house construction sector than in the infrastructure construction sector. Due to an increased efficiency within the house construction sector, there is an interest among infrastructural construction companies (Low and Shang, 2011). With the major tunnel construction project, Västlänken, in the central parts of Göteborg upcoming, there are many logistical challenges ahead. The nature of the project includes construction in urban congested areas as well as the problems regarding construction in confined sites.

1.2 Purpose

The purpose of this thesis is to investigate the importance of logistic management in urban tunnel construction project and to identify key factors that can enhance the supply-chain management. It is also to evaluate whether the construction industry is aware of these and if not, to decide which areas that demand a bigger focus.

The expectation is that the results from this thesis can serve as basic data both for Svensk Bygglogistik but also be helpful to other stakeholders involved in the Västlänken project as well as tunnelling projects in general.

1.3 Delimitations

The thesis will mainly focus on logistics during the preparation of the tunnel such as constructing stations and installation facilities. It will focus on tunnels in urban environments since the confined sites and lack of space are the basic conditions that contribute to the complex of problems that is aimed to study. It will not cover the construction work of the tunnel itself, such as drill and blast or TBM since it is a different kind of logistics that does not relate directly to the subject that is to be examined. The delimitations have been set to focus on a certain type of materials that can be handled and transported in a similar way.

1.4 Method

The method consists mainly of two parts; a literature review and a number of interviews. In order to emphasize what issues there are at on-going construction sites and demonstrate this in a more distinct fashion there is also a part of site observations.

To examine the current knowledge and awareness of construction logistics a literature review is carried out. The literature has been collected from books, papers, reports and articles together with mere electronic sources such as websites to get a broad understanding of the subject. The final part of the literature review considers the mutual views regarding logistics and sums up the knowledge into a number of factors that are to be compared with the outcome of the interview study.

The interviews that are performed are semi-structured interviews, meaning that the interviewee is aware of the theme of the interview but has a possibility of flexibility concerning the answers. The interviews are recorded and there has been both telephone and live interviews which all have been recorded to enable a word-for-word analysis. The interviewees must give their consent for this to happen. The questions are regarding their experience of constructions logistics and their philosophy on the matter and possible changes that are necessary to improve the business. The interviewees are either team leaders or site managers representing contractors within tunnel projects or project managers from Trafikverket that is the client organisation. Depending on the interviewee's experience of the construction business and logistics during tunnelling project in particular, it is likely that their answers and knowledge of the subject differs. It is also expected that their answers differ depending on if they are contractors or clients. However, this does not present any problems for this study, as its main goal is to gather as much knowledge as possible of the subject rather than compare the answers and reasoning of the interviewees. This is the main reason why the interviews are semi-structured, aiming at starting a discussion with open questions about the subject rather than to ask specific comparable questions. This approach is expected to gather as much of the knowledge about logistics as possible to later compare to the knowledge presented in research.

The thesis is based on a comparative study of semi-structured interviews in order to examine the differences with the literature that has been studied as well as the information from the interviews. This is then discussed in a way to confirm whereas the different parts are valid for upcoming projects and what is already known within the industry although it has not reached the subject of research. This is the distinct originality of this paper and hopefully it will enlighten some important factors to be considered during future underground construction projects.

To complement the literature study and the interviews free observations were made at the visited construction sites. The observations were made with construction logistics in mind but lacked structure otherwise and are limited by the experience of the authors. The main idea was to get a better understanding of the logistic challenges during a tunnel construction project in an urban area and to give a context to the interviews. The free observations were also used to compare it to a project in a rural area. For the comparison two types of sites were visited, Hallandsås and the projects within Citybanan together with Norra Länken, a project in a rural area and an urban area respectively. These sites were visited in connection with the interviews.

2 Literature review

2.1 Construction logistics

Logistics is defined by the Oxford English dictionary as "the branch of military science relating to procuring, maintaining and transporting material, personnel and facilities". However, when applied to the construction industry logistics refer to the planning and controlling of an efficient flow of materials. Logistics, as mentioned here, were developed by the manufacturing industry to increase the efficiency of the production and ensure a predictable material flow. Originally it included only internal logistics at the factory but it has expanded to focus on both external logistics and relations with external suppliers.

Inside the logistics concept two main methods is used, logistics by planning and logistics by consumption. The first method relies on a forecast of the consumption and goods are thereby produced according to the forecast. Logistics by consumption is simply to produce goods when the stock reaches a predefined, low, level. Today, usually a combination of these two concepts is used (Bertelsen and Nielsen, 1997).

For the construction industry, the concept logistics is mainly about taking deliveries at the right time as well as the management of materials at the construction site. The construction industry has been known for its earlier chaotic approach to logistics. Material are often procured as cheap as possible and then delivered as whole truckloads, even if only a fraction of the delivery was needed at the time. Lots of material where therefore stored at the site and got "buried" and was broken when needed. Unplanned express deliveries were the answer to this problem, which only further added to the chaos at the construction site. The result of this behaviour is great loss in productivity in comparison to a well-planned project (Bertelsen and Nielsen, 1997).

According to Koskela (1999) the construction work suffers from two types of congestion in production, part congestion and workstation congestion. At a typical construction site there are several places where multiple crews at the same workstation conduct work simultaneously, thus creating workstation congestion resulting in lower productivity. At the same time these workstations can be cluttered with unnecessary material, parts congestion. Avoiding parts congestion would obviously create a better working environment leading to a higher productivity.

Material management in the construction industry has been researched frequently over the last years and authors agree that effective material management have great positive impacts on projects (Agapiou et al., 1998) (Spillane et al., 2012), as material makes up of a large part of the total cost in a typical construction project (Spillane et al., 2011). According to Koskela (1999) materials procured and delivered to the site amounts to around 45% of total project costs, emphasizing the need of correct management. In case studies, cost savings made by good material management has shown to be as much as 5% of the total project cost (Agapiou et al., 1998). Furthermore, poor material management leads to severe wastage in projects and studies have shown a loss of productivity due to this of up to 40% (Spillane et al,. 2011). It is also the most dominant cause of disruptions to work, documented in more than 125 projects (Thomas et al., 2005). Material management includes:

- Procurement of material
- Delivery of material to the site
- Unloading
- Storage of material before usage
- Handling and transports at site
- Using material in construction works

Good material management practice should be included in the project from the beginning. To ensure an efficient flow of materials from manufacturer all the way to site-installation the planning for procurement of quantities and deliveries are preferably integrated in to the design process. This early focus on "buildability" with the logistics in mind has proven to be successful in construction projects (Agapiou et al., 1998). Several authors also emphasize the importance of early involvement of all parties involved in the project (Agapiou, et al., 1998) (Spillane et al., 2011). As the building process is a collaboration of several contractors with the same goal, to finish the project at the right time and to the right cost, all contractors and suppliers needs to be on board to reach the best effect.

Delivery of materials to the site is a well-recognized factor affecting productivity. Ideally, materials arrive directly prior to use for construction (Bertelsen and Nielsen, 1997). Deliveries should be planned to match the actual consumption at the site and arrive to the place of work just before work is planned to begin. The delivery should contain all material specified for the work to be accomplished successfully. This approach greatly reduces the handling and transportation within the construction site (Agapiou et al., 1998). A planned delivery also ensures that the right equipment for handling the material is ready to use upon the delivery (Low and Mok, 1999) (Low and Shang, 2011) (Koskela, 1999) (Ogunlana et al., 1996). Unplanned deliveries, which either mismatch the schedule or contains too large quantities, may lead to severe delays in the schedule or interruptions to the on-going construction. Material arriving in too large quantities in comparison to the schedule has to be stored at the site. The construction site in general is not a good storage facility, thus resulting in breakage and losses of material and extra handling in comparison to using it directly after delivery (Agapiou et al., 1998).

On-site storage could also lead to interruptions and problems with the on-going work, as material may be stored adjacent to places of work at the construction site. It is of great importance not to store material too close to the place of work as it leads to problems of access and obstructs any delivery to the workplace (Thomas et al., 2005). Unsuitable storage locations are also recognized by Spillane et al. (2011) to have decreasing effects on the overall productivity. Despite the ideal of JIT delivery, some material has to be stored on site depending on the type of construction project. To prevent production to be disturbed or material destroyed, a site with well-defined unloading and storage areas is preferred for work to proceed smoothly. This is easily seen when visiting a construction site, logically a less congested site provides easier working conditions.

In addition, a case study conducted by Thomas et al. (2005) made at a construction site clearly showed the importance of managing on-site material. The bad arranged site, with no plan for storage, suffered severe drops in productivity when work was conducted in the congested areas at the site. Poorly organized construction sites is a well-known problem in the industry, although the problem is widespread the solution seems simple. By dividing the site into specified areas depending on the type of storage, some order in the chaos can be established. For instance, inside the building or structure to be built, only material used at the time should be stored. Material awaiting next days work could be stored outside in a waiting area. Material storage is also a joint effort between all contractors and everyone must participate to achieve a good result (Thomas et al., 2005).

2.2 Site layout and planning

A site can be divided into three primary areas, there is the semi permanent area, usually outside, where material is initially stored. Then there is the staging area, which is close to the exterior of the building and the place where material is lifted into the building. Finally there is the workface, where the construction takes place and where the material is used (Thomas et al., 2005). A similar way to describe this supply chain is to talk about point of delivery, break point and receiving centre that corresponds to the three primary areas mentioned above. This division is a necessary part to know in order to understand how a logistic chain can be optimized and they constitute a global logistic network. And the higher level of global logistics that is considered, the greater the optimization potential becomes (Voigtmann and Bargstädt 2010).

The different supply chain areas are essential to take into account when planning a construction site, to create a working supply chain considering material and machinery. There is also a need of separating horizontal and vertical logistics in order to decide which solution that is suitable for each type of the supply chain (Thomas et al., 2005).

The use of a construction site logistic network approach can be useful when planning for a site, in addition to this; a simulation model can be used. It consists basically of seeing which activities that are dependent of each other and how to optimize the construction site logistics (Voigtmann and Bargstädt, 2010).

A popular solution for urban construction projects when space is scarce is to use a consolidation centre, which is a site preferably in the outskirts of town without being too far away. It is used as a buffer and to make sure that trucks that arrive to the construction site are fully utilized and to minimize the number of transports. Additionally these sites can be used to finish parts of construction, which would have been too space demanding to do at the construction site as well as in a warm and dry environment, which can be arranged at the consolidation centre. Additionally, the quality of the goods is inspected already at the consolidation centre and a major part of packaging is removed to reduce waste that has to be handled on site (Mossman, 2008).

2.3 Just in time

The concept of Just-In-Time originates from the manufacturing industry, mainly promoted by Toyota during the early 1950s. JIT is a part of The Toyota production system created by Mr Taiichi Ohno and was successfully implemented in the car manufacturing process.

The main focus of JIT is efficient handling of materials in the manufacturing process. Its main principle is to deliver the needed material at the exact time it is needed in the manufacturing, eliminating the need for storage space and enhancing the efficiency of the manufacturing space, ultimately reducing waste in the manufacturing process (Low and Shang, 2011).

According to Bertelesen et al. (1997) JIT is a type of logistics by consumption, where the inventory can be close to zero before fill up and the size of the following order can be close to one.

Lately the concept of JIT has arrived to the construction business and has been proven beneficial to several projects (Low and Shang, 2011). Among some of the positive effects mentioned, some are highly relevant to a confined construction site. Holding a minimized level of inventory reduces the cost of inventory and fewer inventories at site also mitigate congestion problems and leave the site tidier.

As the construction business is striving towards Lean construction and higher sustainability, JIT is one of the important tools in this process, since reducing material waste and unnecessary transportation is key (Ogunbiyi et al., 2014).

The typical practice before has been to order large quantities at the same time to save money on shipping costs. This practice is also preferred by the manufacturers and as they do not consider the further handling at the site (Low and Shang, 2011) (Bertelsen and Nielsen, 1997).

However, as materials make up to as much as 50% of the total building costs and 10% of that costs is made up by handling. Given these figures, more focus on material delivery and handling is needed (Bertelsen and Nielsen, 1997).

To test if and how JIT is applicable to the construction practice several case studies has been made on projects where JIT principles have been integrated. The results are varying but most of them have experienced overall improvements (Low and Mok, 1999) (Bertelsen and Nielsen, 1997). Several factors are of importance when implementing JIT to a construction process and studied reports show that some have great influence on the result. As mentioned earlier and the main idea of JIT, frequent deliveries of needed material with the right quality is key. To achieve this, careful planning of the project is required, where all the involved participants meet and an extensive time schedule with required materials is set-up and followed-up during the construction. Apart from the main time-schedule more detailed planning closer to the manufacturing is key to be able to handle delays and problems. For materials to be order and delivered at the exact time a close follow up of the progress should be carried out as construction proceeds.

Bertelsen (1997) suggest that material is delivered in specified units packed for the specified work and only reported as delivered when the construction workers begin using them at the specified place.

For material to be delivered on schedule and with the correct specifications a long-term relationship with the suppliers and fewer suppliers is preferred. Several authors agree that establishing a local supply-chain with fever partners is crucial for JIT to be successful (Low and Mok, 1999) (Low and Shang, 2011) (Bertelsen and Nielsen, 1997).

Among other factors mentioned proper training of both design staff and workers at site is of great importance for the result. Operations at the site should be as standardized as possible and the quality controlled on a regular basis (Low and Shang, 2011).

2.4 Third party logistics

Instead of providing the function of material handling in house, a company can choose to outsource the service to an external logistics provider (Deepen, 2007). The benefit with this is that the firm can focus on its core business and its core competencies. A successful relationship between a logistics service provider and a client can give both parties a competitive advantage in the marketplace (Deepen, 2007). Long-term relationships for the entire supply chain are preferable and needed to make all parts to learn and improve their product (The Construction Task Force, 1998). The evoultion of third party logistics providers has given the providers responsibility for delivery and distribution of finished products (Ying, 2011). Additionally Ying (2011) states that metro construction enterprises could use third party logistic handlers to be responsible for inspection and supervision of the material supply and in that way unburden the contractor, thus enhancing the overall efficiency. However it is important to have realistic expactations of the relationship, since the lack of this is a common reason for failure in theses relationships (Deepen, 2007).

2.4.1 Advantages of using third party logistics

At first, the most obvious benefit with utilizing third party logistics is that it reduces the logistic costs for the firm. Additionally, it makes opportunities for higher efficiency visible, which perhaps has not been possible to realize as the logistics have been handled in house (Deepen, 2007). It also helps reducing the costs by creating a reduced need for capital investments. It is not only in mere economic terms beneficial to use a logistics service provider, the knowledge they inherit helps the client achieving faster transit times, less damage and improved on-time delivery (ibid). It has also been pointed out that one of the main drivers to improve the performance of the construction industry is to integrate the supply chain, including clients and manufacturers and making them work closer together (Sobotka and Czarnigowska, 2005).

2.4.2 Disadvantages of using third party logistics

A client who hire a logistics service provider looses that set of skills over time thus also the ability o be sure whereas the quality of the service provided (Deepen, 2007). Basically at the same time as the client is dependent on the logistic service provider, it

is the same source that derives the data of whether they are successful or not (ibid). A concern for the logistics service provider is that once for example a tunnel project is finished, the location for a new tunnel is somewhere else, thus causing the logistics service provider to set up a new supply chain somewhere else (Ying, 2011).

2.5 Urban Construction

There is an on-going expansion of urban city centres across the world due to increased population and increased costs of acquired development sites in urban areas (Spillane et al., 2012). Today, a majority of construction is executed in urban areas rather than new development sites and confined site construction is becoming the norm for construction (Spillande et al., 2011). Initially, it must be stated that a confined construction site refers to a site where permanent works is carried out above as well as under ground level leaving spatial restrictions of where to operate personnel and material. This is often confused with confined spaces within a construction site, which on the other hand are areas that are large enough for an employee to enter but is not suitable for working in for a longer period of time (Spillane and Oyedele, 2013).

As stated before, material management is an important part of any construction project. Especially when operating in urban inner city environments where the lack of space is often evident. Therefore, when operating in such conditions, effective logistical and supply chain management is essential (Spillane et al., 2011). In an urban environment it can be hard, and is sometimes even forbidden, to transport construction materials, such as cement, masonry and steel during the day. This creates different demands for the supply chain (Ying, 2011).

According to Spillane (2013), construction in confined sites differs from open space projects in several ways. There is less time available to the whole project that leads to a compressed working schedule and challenges of managing material on site. The productivity on these sites is often lower; there are more frequently occurring accidents. (Koskela, 1999) also recognizes lack of space and congestion as being one of the major conditions affecting the productivity at the site. A confined site in urban settlements also faces more restrictions than projects in less populated areas, e.g. restrictions on allowed noise levels during both day- and night-time and restrictions on vibration levels. A common problem is disputes with the neighbours surrounding the project (Ogunlana et al., 1996).

Due to the lack of space, confined sites are in general more challenging than larger construction sites. Common for studies conducted at confined sites is the concern for moving material around the site and the lack of storage space, both concerns of safety and the problem with handling (Spillane et al., 2012). Poor material management becomes even more obvious at confined sites for several reasons, the ability to hold inventory is small, thus increasing the risk of shortages during production. Bad management of the storage at the site further increases congestion if unnecessary large quantities or material not matching the schedule is held at the site (Spillane et al., 2011). The need for management is also required as construction projects involve many sub-contractors and third parties in the production. As more parties become involved the need for coordination becomes even more important to synchronize the needs of all groups.

2.6 Subsurface construction logistics

Tunnelling construction projects are, besides from being carried out in confined sites also constructed below ground, thus adding several parameters that complicate the operations. Such parameters are obviously limited access and space both horizontally and vertically, which has to be taken into consideration when operating machinery and planning material storage. The absence of daylight and natural inflow of fresh air affects the safety and working conditions for the personnel and has to be dealt with during the planning (Occupational Safety and Health Administration, 2011). When materials arrive to the site, the location of the site entrance makes delivery of materials particularly difficult due to lack of space. The other fact is that there most likely is only one entrance that has to be clear in order to enter the material (Spillane et al., 2011).

When a tunnel is constructed there are a lot of additional installations such as different kinds of control and surveillance systems and lighting installations that are to be transported into the construction site. When constructing a train tunnel there is a number of special components that is unique for the railway and has to be handled accordingly. This, together with a variety of gravel and concrete elements demands that the logistics handler must be well known with the processes of tunnel construction and have knowledge of the different types of materials and their proper handling (Trafikverket, 2011).

2.7 Logistic problems when constructing tunnels

Handling projects as large as tunnel construction in urban areas requires extensive planning and managerial resources. Not only because of the size and economics of the project, but also considering the congested urban environment and the confined construction site. As stated in the above chapters, the material management is of great importance at confined construction sites. Preferably material is delivered just-in-time for usage to save space at the site. If inventory has to be held at the site it needs to be well managed and stored properly. When constructing tunnels, this is of even greater importance, as only one entrance may be available.

Reviewing the available literature on tunnel construction, most of it concerns geological problems and the logistics of handling the excavated material from a TBM or other excavation methods. For example, (Köpf et al., 2013) recognizes the greatest challenges at tunnelling projects as rock conditions, water ingress and stress on machinery used for excavation.

The same authors emphasize the importance of logistics at the site. As tunnelling often has only one point of entry, material deliveries to and from the workface have to be carefully planned.

Only one entrance creates a severe bottleneck and any planning mistakes would result in delays for the project. Balmer (2012) also identifies this problem, where one of the largest challenges of the tunnelling project was the limited access to the workface. The coordination of work in the tunnel is also listed as a challenge. Work is conducted at several separate places in the tunnel and the work at these stations is in different project phases. And since it's a tunnel, material supplying the different workstations

needs to pass other workstations without interfering with the on-going work there. A creative solution to this problem was used in a delayed tunnelling project in Switzerland, where a mobile bridge was used in the tunnel, creating a transport route over the on-going workstations (Balmer, 2012).

3 Site visits and interviews

The sites that have been visited are the Hallandsås project, Norra Länken, Stockholm and numerous parts of Citybanan, Stockholm. Initially the site Station Odenplan, operated by the constructor Q-gruppen was visited and a team leader responsible for the Vanadis entrance was interviewed. The process included the construction of the entire station, including stores and a ticket office. By the time of the visit, the work had just begun with the completion of inner walls. An additional visit was performed at the adjacent contractor who was in the finishing phase of the reinforcement of the rock tunnel and the casting of the major tunnel elements prior to the handing over of the work area to Q-gruppen. Subsequently, the construction site of Norra Länken 41, Frescati was visited, and the project executive was interviewed. The project included primarily the construction of a cut and cover tunnel, together with the construction and casting of a trench plus a minor part of conventional rock tunnel. The project was in the finishing stages, with only minor finishing works remaining. The following site visit was at the construction of Södermalmstunneln, a part of Citybanan constructed by the contractor Züblin where the production manager of the project was interviewed. The tunnel is a conventional drill and blast tunnel that is connected to the immersed tunnel below Riddarfjärden. The project was in the finishing stages, with finishing works of the tunnel and concrete cable ducts that were to be installed. The biggest project studied has been the construction of Norrströmstunneln, Citybanan by the contractor NCC. The site visit did not include entry into the on-going work, but a number of interviews were performed. The interviewees were the head of logistics from Svensk Bygglogistik, a team leader from NCC responsible for the completion of inner walls on the mid level and the project manager from Trafikverket responsible for the part City. The work was running at multiple faces thus one entry was not possible. The final visit was performed at project Hallandsås, where the contractor cooperative Skanska-Vinci is constructing a rock tunnel using a TBM producing concrete lining. The interviewee was the planning engineer for Trafikverket. The project was in the final stage of construction, with primarily rail and overhead contact lines remaining to be installed.

Most of the interviews were conducted with site managers and team leaders involved in the projects above. One part of Citybanan has already used Svensk Bygglogistik as a LSP, whose representative also was interviewed. The remaining interviewees were a former site manager and client involved in the construction of Götatunneln, Göteborg. Besides from the interviews, time was given to make observations during the visits to the sites. The managers had allocated a generous amount of time and gave a walkthrough of the whole, often large, construction site.

The interviews were held to serve as a comparison and complement to the above literature review and to get further understanding of how the management is working with the logistics in these projects. Interviews were held with both contractors and the largest client regarding these types of projects in Sweden, Trafikverket. Although the responsibility for the logistics in general lies with the contractor it is also interesting to gauge the client's interest in logistics as it has a large impact on the cost. Some of the interviewees on the client side were also former contractors with solid experience of the business. To gather relevant information from the interviews some criteria for the interviewees were used when they were chosen. The main criterion was that they were involved in the management of logistics at the current or prior projects and had a

solid experience of the construction business overall. Another criterion that was qualifying was if the interviewee had been involved in prior tunnelling projects. The interview that were held consist of four major parts as listed below:

1. Opening questions about position, current projects and prior projects
2. Questions aiming to identify success factors
3. Questions regarding handling of material
4. Ending questions and reflections

The interview, as a whole, is presented in the Appendix. The interviews were, as stated before, semi-structured and the interviewees were allowed to freely elaborate within the subject. Before the interview the scope of the master thesis was presented to the interviewees and to help keep the interview within the subject, the aim was shortly presented. The subject logistics and its meaning for this work was defined using keywords as:

1. Material supply
2. Delivery
3. Management of material on site
4. Store-keeping on site

Additionally, the interviews with the clients involved questions about their specific role in the process to get their view and to find out to which extent they are able to, or are choosing to, control the logistics on site.

4 Findings

The results presented here are based on the interviews conducted with the contractors and clients of major on-going tunnel projects in Sweden.

The findings consider a wide range of issues within the logistics concept and consist of areas that all are essential to have in mind for a LSP representative that is about to be responsible for the logistics on site.

4.1 The one entrance/ bottleneck

The main difference between a tunnel project and a regular surface construction project that has been pointed out by all of the interviewees is the fact that a tunnel often only has one entry, which also serves as exit. The challenge is to allow for transports to turn inside the tunnel and to meet due to the limited space. Access is important, which is why the planning of at least one extra access tunnel is crucial in order to avoid a standstill to the largest possible extent. It is important to consider the size of the access tunnels, not only because of passing vehicles, but also for the available selection of pre-fabricated elements. Waiting periods due to limited access has proven to result in a major decrease in productivity. Planning of access tunnels is important to establish well working logistics, however there are factors such as lack of space or economic reasons that prevent additional service tunnels to be constructed. In the case where the possibility of construction additional tunnels does not exist a widening of the existing access tunnel could be considered instead.

The head of logistics must be well aware of the building process and the fact that the bottleneck problem increases along with the increased amount of installations that is finished in the tunnel. The logistics cost increases due to the use of unloading at specified times, however this is the only way possible for most of the projects, especially when there is only a single entrance available. It is important to emphasize that even though every single transport becomes a bit more expensive and the total cost of logistics overall increases, it results in a decreased total cost for the project, as stated by a majority of the interviewees.

4.2 Subsurface construction

One of the key factors that has been pointed out by the interviewees that separates underground construction from surface construction is the lack of storage space and of course the limited access. The exception is the construction using the ‘cut and cover’ technique where a regular crane can be utilized. Otherwise the transportation on site is limited to horizontal transports. The utilization of material storage must consider that the storage area is only available along a line and with limited vertical storage space and also that work is on-going along this line within the whole project. Therefore the subsurface tunnel construction can be viewed as a one-dimensional process rather than three-dimensional which is the case for regular construction. A temporary bridge was used in the trench once a casting had to be made close to the entry at the same time as work had to be performed at the far side of the trench. The major concern when using the tunnel for material storage is the fire hazard, there are a number of regulations regarding flammable material and that kind of material is avoided to such

a great extent as possible. One of the greatest fire hazards is the cars on site, which have to be parked with a spacing of 10 meters and has to run on diesel fuel or similar.

Subsurface construction implies some important limiting factors for the contractor that requires more extensive logistics. The rule for the contractors that is performing crafting and completions of inner walls and such, is that nobody is allowed to bring more material into the tunnel than they will use in one day. Storage of material underground is avoided to large extents due to the fire hazard. However some sawn goods can be stored on site as well as gravel and concrete parts. This leads to more and smaller transports every day compared to a surface construction site. These factors aside, there are some benefits of subsurface construction, such as the ability to work around the clock without disturbing the surroundings (blasting excluded).

4.3 Confined site

The main difference that almost all contractors have pointed out between a surface project and a tunnel project is the limited amount of space in the tunnel. The way of working can be compared to working among a line, meaning that the abilities of passing on-going work can be limited. This becomes apparent especially during the installation phase when work is conducted at several places along the line.

The limited amount of space forces the contractor to minimize the number of transports arriving at the site since the unloading of a transport down in the tunnel most likely blocks the tunnel or the work face. Basically the same amount of material going into the tunnel must be removed sooner or later, such as wrapping of material and pallets. These two factors demand a good planning of material supply and transports. The same goes for flammable and explosive material such as containers of gas and similar that must be removed from the tunnel in the end of every working day. One solution used to minimize the storage of wood inside the tunnel was to have a sawing station that produced casting formwork on the surface.

When working at a confined site in an urban area there is a problem to acquire storage areas and areas of establishment at the surface level, hence deliveries must be unloaded inside the tunnel right away.

4.4 The project planning

The implement of a well-mastered plan is crucial, especially due to the large amount of traffic often present in an urban area. The planning also affects and ensures a decent work environment. One of the benefits with an appropriate plan is to be able to save time and money. As stated in one of the interviews where a contractor came up with a different idea on how to arrange the temporary rerouting of the traffic during the construction time. This enabled for the construction to finish 6 months before time and save a significant amount of money.

The complexity of problems regarding planning an underground construction is that there can be a great deal of uncertainty regarding the geotechnical or geological circumstances. This often affects the time plan, thus a good relationship with the suppliers is desirable, with a possibility to enable changes in the Just-In-Time planning. Generally this flexibility with suppliers that contractors are looking for can be accomplished by creating a long-term cooperation. Additionally the management

together with the head of logistics should always have an alternative option ready to cope with unexpected changes to ease the logistic handling.

One key factor to be able to deal with the access issue is to have a long term planning with daily follow-ups and to be alert for changes that can occur on a daily basis. Major deliveries that are crucial for the critical path in the time plan are planned a long time ahead while material for completion of inner walls and similar can be ordered with shorter notice.

It is important for the contractor and its' subcontractors to agree on a common time plan to avoid situations where subcontractors may be using another way of working than the main contractor has been planning on. The same goes for deliveries and types of material that arrive to the tunnel.

4.5 Consolidation centre

Even though the property that serves as a consolidation centre often can be expensive and that an extra storage area yields an increased amount of smaller transports the view is that it still can be a good idea. Often the alternative is to seal of the tunnel or to occupy usable area at the construction site which is worse than using a consolidation centre. A major part of the projects investigated has been using a consolidation centre to at least some extent, in order to use JIT for the workplace. This is especially pleasant when handling installations for the railroad and equally specific items that can have a long delivery time and thus must be bought in an early phase.

4.6 Just in Time

The majority of contractors interviewed state to be using the concept of JIT, however often not denoted by a certain label. The mind-set often comes naturally, for example concrete that arrives at the site has to come just prior to the casting and has to be used immediately. The lack of space already forces the contractors to be cautious about the amount of material stored at site and they cannot afford not to utilize the space in the most efficient way possible.

The contractors that are building stations and performing completion of inner walls tend to be using JIT on daily basis where material generally arrive the day before it will be used. This is due to the usualness of the materials used, why the risk when making late orders is very small.

A common misunderstanding is that the construction sector is bad in practicing JIT, which is not true, every time a casting is to be made the delivery has to arrive at the right time and dealt with right away or the concrete will be wasted. Altogether throughout the interviews, it was clear that the contractors frequently practise JIT to at least some extent.

4.7 Delivery schedule

A common practice among the contractors is to synchronize the need of material with the time schedule and coordinate the different transports once a week. Again the need for risk management with action plans and alternative activities are crucial. The logistics planning of arriving materials require a minute per minute planning due to

the limited access and space inside the tunnels. At two of the sites this was done by the use of a delivery planning system called LogNet, developed by Svensk Bygglogistik.

At the biggest project where the contractor has had the closest cooperation with the client using partnering, a whole year was used as a planning period. During this time the logistics manager together with the different subcontractors scheduled the major deliveries. It had also been possible to put demands on how material was to be packed.

4.8 Supply chain

In longer on-going projects it can be hard for the site management to be aware of the need of material for the entire process and thus, all material cannot be purchased from the start. This can result in a situation where material that quickly must arrive at the construction site becomes a lot more expensive. Contractors request a supplier relationship where changes and flexibility can be executed whenever the need for that occurs.

There are different levels of possibilities for the contractor to influence the supplier in how to pack different materials, for example the weight of arriving materials are considered in the early projection of the project regarding major installations. When designing floor structures it becomes dimensioned to how big packs of materials that can be transported within the structure. This implies that major shipments of installations such as escalators can be split up in appropriate parts to allow transportation within site without risking overloading the floors.

When it is possible contractors try to order a service that include transport to the site together with lifting parts to the correct place, this is especially requested when ordering prefabricated elements. The main benefit is to be able to hire the entire process to another company and only be responsible for the final assembly.

The use of prefabricated goods is a key to rationalize the process and contractors often request rebar that already are cut and bent, and made for a certain part of the tunnel to avoid waste, especially because waste inside the tunnel requires transportation to the surface.

One of the issues where the contractor can affect the supplier is on how to pack material considering the type of wrapping; this can be done already in the early purchasing phase of the project. The fire hazard conducts the wrapping to be as stripped as possible when arriving, and the use of wooden pallets are avoided to such a great extent as possible.

4.9 Planning of the site

It is common to try and plan the work site with a unloading area close to a storage are to such a great extent as possible. It is also desirable to enable arriving transports to pass through the site without having to reverse at any point.

A matter that has been raised by one of the interviewees is that the available amount of space is one of the largest compared to a regular housing project in an urban area

where space on site is even more limited. For instance, the areas inside the tunnel do not constitute a cost for the contractor such as utilizing an external stock area or renting a piece of adjacent pavement from the municipality.

Many of the contractors were using a tent adjacent to the tunnel entrance for interim storage to avoid blocking transportation and work inside the tunnel. This is a good example of the disposition of the site into three areas, where this example represents the staging area. All of the contractors interviewed practiced this planning of the site.

4.10 Logistics of staff

When working in a confined site with long entry paths such as a tunnel, the logistics of the work force must be taken into account. All of the contractors agreed on the matter but had some different ways of dealing with it. One issue is the transportation to and from breaks, which can be really time consuming due to the long distances. One solution way of dealing with this is to place shanties underground that can be used during break hours in order to minimize travelling time. Another way to solve this problem has been to use a bus that travels the tunnel at certain times; an additional benefit with using a bus is that it minimizes the amount of cars in the tunnel. A decreased amount of cars saves a great amount of space and causes a lesser impact on the air quality.

A way to decrease unnecessary movement of the work force is to use small tool sheds close to the work phase. Using a tool shed underground also reduces the number of transports for tools, as it is forbidden to leave tools at the workface when no work is conducted.

4.11 The contract

There is a need of a contract that allows one contractor to be in charge and have the final saying once there is shortage of space or time. Especially in order to minimize upcoming situations where different subcontractors try and claim their right to utilize the space available. From the client's point of view is it important for the contract to give the right incentives for all parties involved to strive against the same goal and for the contractor to be efficient and come up with clever solutions.

4.12 Areas that can be improved

Work around the clock to a greater extent if that is possible considering the surroundings. Try also to consider the idea of "delivery spaces" in time during the day where all deliveries must arrive, as this will tend to interrupt the on-going work in the tunnel to a less extent.

One contractor pointed out the importance in logistics of information as well as general logistics handling. Since the main problem in projects with a lot of actors on a confined site is the events of contractors blocking the way or workspace for other contractors. This must be addressed and dealt with from the beginning so it can be avoided.

Today there is no existing possibility to combine different goods on the same truck since most of the delivery trucks come straight from the manufacturer. Another

important factor concerning suppliers is to specify in the contract the importance of arriving right on time so that a contractor does not have to pay for waiting lorries on site.

One idea mentioned among the contractors could be a small transport service on site, for example a wheel loader that can travel back and forth from the tunnel entrance carrying a sufficient amount of material to each work phase. The material that is needed for the next day is ordered the previous evening.

4.13 Request for a LSP

The demand by a contractor for a LSP is to be well aware of the different challenges and safety regulations that come with tunnel construction. To be involved in big projects such as Citybanan, but in a sense be clear about what the area of expertise is. Additional areas that a contractor could use a LSP are to handle delivery inspection and eventually logistics of staff in the tunnel concerning entrance control. Another request that has been raised is the need for an overall logistics solution including waste management.

The main view amongst the contractors is that a LSP could be utilized to aid with the minute by minute planning of logistics and transports needed for tunnel construction. The optimal service is to have a person that is in charge of everything regarding materials and logistics, from what is to be put in interim storage and what is to be transported into the tunnel. However the design of a WDP is an area where contractors claim to be confident on their own.

A major part of the contractors tend to be a bit dubious to however a third party can be as informed and well grounded about their projects as the contractors demand. They mean that it is easier for the staff that has been involved in the bid process to be responsible for purchases and planning. The request is that a LSP is well aware of the process and have some sort of background and experience from the contractor sector.

5 Site observations

The visit to Stockholm was where the majority of the interviews were held and site visits at tunnel construction projects took place. The sites were at the north and south end of the tunnel. To enter the tunnel it was required to first take note of the safety information, use proper safety clothes and be equipped with at special tunnel-tag. The tag made it possible for the administration to see how many people that were present in the tunnel at the time and where they were.

The construction site at the north end was complex as a station was to be built with several levels underground. The site was located near Vanadis in Vasastan and was one of the passages to the new station Odenplan. Most of the underground concrete works and inner wall framework were finished and the work with installations had begun. Material deliveries to the station arrived at ground level and then lifted down through an opening in a scaffolding tent. To access the lower level, as the

Figure 1 Subsurface level one, Ticket office

underground station had two levels; a lifting shaft between the two levels was used. Two separate lifts had to be made, as the shaft was a few meters away from the opening in the scaffolding tent.

The material handling at the station could have been improved in at least two ways. First the scaffolding tent was difficult to open and needed separate scaffolding personal to open it and it took a while to do it. A sliding hatch that could be operated by the personal at the site covering the opening to the station would have been preferred. Second a shaft from ground level all the way down to sublevel 2 would have saved time handling material, although this was not possible at this site. Overall the site was tidy in comparison to other parts of the tunnel construction.

Well below the station the construction of the tunnel and the platform was on-going. The platform is located in a large cavern and the rails are then separated into two separate tunnels. Massive concrete works was on-going in the platform cavern, for example a 3 level house in concrete was almost finished.

As seen in the pictures the lack of space down there is obvious. With work at several places in the cavern with different tasks the coordination of vehicles serving with material is of great importance. The concrete for example is delivered by truck, thus when a large casting is on-going no other transport can be allowed in the tunnels.

Figure 2 Truck delivering gravel

Figure 2 well illustrates the problem with logistics in tunnel construction. The truck is delivering gravel to the level above the platform level. The gravel was lifted in a small bucket operated by the telescopic arm on the truck and this proved to be a time consuming activity. During the delivery one of the tunnels was blocked and all transports had to be directed to the other tunnel. While not a problem in this case the management at the project made an example of an earlier event where one of the tunnels were blocked and the gate to the other tunnel broke down. At the specific time, casting was on-going in the tunnels leaving the concrete trucks on hold outside the tunnel while the gate was repaired. This is a good example of how sensitive the logistics in tunnel construction can be and emphasizes the need of extensive planning and risk-analysis.

Figure 3 illustrates one of the storage sites in the tunnels (the left tunnel is the one being blocked by gravel delivery). Reinforcement bars is stored in one part of the tunnel were no construction was on-going at the moment. Even if the storage did not obstruct the transport or construction work the site was very messy and no particular sorting of the different prefabricated bars could be seen.

The contractor responsible for installations, wall framing and completion work at the station and platform will use another solution with storage above ground. A tent at one of the entrances where cargo not delivered just-in-time will be stored for further usage.

Figure 3 Reinforcement bars stored underground

The other site that was visited is at the south end of the tunnel, located below Södermalm in Stockholm. The specific contract ranged between the immersed tunnel in Riddarfjärden and the connection to Western mainline at the station Stockholm Södra. The route had no stations and therefore the installations were less extensive here. The contract was almost finished and the completion work was on-going so there was not much work in the tunnel during the visit. Overall this site was tidy with little material stored in the tunnels, could be a function of a good WDP or just the fact that the work was almost finished.

In the parallel tunnel, made to ease work and for rescue during breakdowns, a couple of relatively large shed were set. The sheds are made to house support systems for the railway and are completely prefabricated according to specifications by Trafikverket. As seen in Figure 4, the sheds are relatively large compared to the tunnel and has to be installed on pillars elevated from the tunnel floor (the manager was not sure why, maybe to prevent flooding during a catastrophic event).

Figure 4 Sheds housing installations

Installation of these sheds had been a logistic challenge, as they require a large vehicle for transport, special equipment to be lifted inside the tunnel and are not easy to move once placed in the tunnel. To overcome the problem the pillars was ready before delivery and the sheds were delivered just-in-time for installation and lifted into position from the truck.

The far-reaching and legendary tunnelling project in Hallandsås was also visited. This site is, in comparison to Citybanan, situated in a rural area outside Båstad. The project is, now, after it start-up in 1992 in its final phase where railroad installations are to begin.

Figure 5 The somewhat endless tunnels in Hallandsås

The project has been delayed several years, however for other reasons than logistics. As mentioned before, the site is situted in a rural area so storage was obviously not a problem here. Outside both the north and south portal large areas was dedicated to storage for the project. Material could be delivered and sheltered here for later JIT delivery to on-going work in the tunnels. Walking through the tunnel, the earlier mentioned concept of counstruction on a line became truly obvious. As seen in Figure 5 during this phase and forward the tunnel is narrow and vechiles will have a hard time passing each other here.

6 Discussion

The purpose of the thesis has been to find key factors to enhance logistics handling in tunnel construction projects in urban areas.

6.1 Site layout planning

As stated in the literature review it is important to divide the working site into three main areas that are the semi permanent area, staging area and workface. All of the interviewees were using the model in some way even though the different sites offered different conditions. Even though some of the sites lacked a proper WDP, the idea of a divided site for work and storage was used, however the borders were more diffuse than proposed for by the literature. Since all of the urban sites lacked space for storage on site, the semi permanent and staging areas seemed to be a bit too narrow for their purpose, but the existence of these areas were still essential to enable an efficient workflow. This can be compared to the rural site where storage on site was nearly unlimited and the problem did not appear.

The use of consolidation centres was most briefly mentioned in the literature that was studied, however it has been a very popular solution for the type of material that are hard to come by with short notice. As deliveries often was ordered from specific suppliers, and in some cases in small quantities, the need for a consolidation centre did rise in order to redistribute the goods into one truck instead of several to have a lesser amount of transports arriving to the site. The literature advised that a CC could be used for final prefabrication of construction units, but this was only practised at one of the projects. The closest example was the prefabrication on site of casting formwork at one of the sites.

6.2 Just In Time

The use of JIT has been recommended throughout the literature review and there were numerous examples on how it has been implemented within the manufacturing sector and what benefits it could cause to the construction sector. Between the lines it can be stated that the authors mainly looked at JIT as something that needed to be implemented within the construction industry but the main impression as stated earlier is that the concept of JIT was well used within infrastructural projects. Due to the limited storage space and hardening time of concrete the contractors have been forced to apply JIT for a long time. The impression throughout the interviews has been that JIT is implemented amongst a majority of the contractors, but more as the most pragmatic solution to an existing problem. The use of JIT seemed to be more obvious than what was stated in the literature, even though the term JIT has not always been used, the way of working has been similar to it. Another observation made is that the overall view in the literature of the construction sector as old fashioned and inefficient seems to be a bit exaggerated in the case of JIT.

6.3 One way entrance

During the literature review the issue with a one-way entry has been addressed several times together with the demand for a thoughtful planning of arriving deliveries. The issue was frequently discussed during the interviews as one of the most limiting factors. The discussion was mainly about whether the cost of an extra access tunnel would be profitable for the project due to the benefits of both a well working logistics and the possibility of a shorter construction time.

6.4 Multiple work faces

The concept of multiple work faces has been addressed in the literature review, but mostly in a sense of how to drive a tunnel with multiple work faces during the drill and blast phase. Another example that has been mentioned is the use of multiple workstations in a single room. Although as discovered during the interviews, the concept of working along a line has not been discussed in the reviewed literature. The concept of working along a line has occurred during many of the interviews and is applicable on how to describe the tunnelling process and the challenges that rise when planning the work. Further investigations on how this affects the productivity would be desirable.

6.5 Third party logistics

Within the interviews it became clear that a majority of the contractors were dubious to utilizing a LSP since they had the view that third party companies lacked the experience needed for complex tunnel construction projects. This might not be a sound doubt though the examples of LSP on site have proven to be beneficial to the project, in the case of Norrströmstunneln. On the contrary, the higher degree of specialization within a LSP can be beneficial to a construction firm, compared to having an in-house employee handling the logistics alone. The representative from the LSP can always gather information from colleagues and experiences from previous projects performed by the LSP firm. However the challenge for a LSP is to convince contractors that they possess the necessary competence within the field. Additionally it has proven to be beneficial for the relationship between a contractor and the LSP to let the LSP be part of the process already from the procurement phase.

6.6 Confined sites

The problems discovered in the literature considering confined site construction are also verified in the interviews. However, the management, according to all the interviewees, deals with the problems that arise during confined site construction. The examples from the literature regarding transportation and on-site storage seemed to be well executed at the sites. Only one of the sites at Citybanan seemed to be a little more chaotic than the others, following the bad examples discussed in the literature, though this was only at one of the contractors. The site lacked proper storage areas and well-planned transport routes, however this was only discovered from free observations at the site and there is no measured or known drop in productivity. To verify this, more frequent observations and/or measurements of the productivity would have to be made. In this specific case, we were unable to reach persons responsible for the construction to be able to take any further steps. Even if, a

comparison seeking to investigate the productivity would not be easy as the contracts were very different in their nature of work.

7 Conclusions

The report indicates that there are a few important key factors for a successful tunnelling project in an urban area that finishes on time and within budget. We conclude that these few factors are closely linked to the result in the terms of budget and ability to maintain the time schedule. A LSP could help to prioritize theses factors early on in the project plan. It's also concluded that some of the criticism found in the literature is a little bit exaggerated, at least when considering these kind of high prestige projects.

One of the main challenges discovered in this report is for a LSP to convince the contractors that they have the required knowledge to deliver a good solution regarding the construction logistics. There is a widespread misunderstanding within the building contractors that a LSP would lack the proper knowledge and that an in-house logistics manager is the only option. The LSP needs to promote themselves better within the field and point to the successful projects they have been involved in.

Considering underground logistics, one of the most important factors, discussed in both literature and during interviews, is the importance of access. This translates into the importance of the access tunnel. Since this tunnel shall serve all transports to the construction site it needs to be well planned from the beginning regarding size, curve radius and inclination. During each unique project it's also wise to consider several access tunnels as this will greatly improve the flow through the working area and thus enhance the transportation capacity tremendously. Even though an extra access tunnel will increase the cost initially it may lead to total savings in the end, as the project can finish faster.

During the interviews several creative solutions to logistic problems were found. For example, the bus service in Norrströmstunneln available for all employees working in the tunnels, there were also several other creative solutions at the construction sites. Still having the bus service as an example, it was not introduced in the beginning of the project, they idea rose when the car traffic in the tunnels led to congestion. It is of great importance for future complex urban underground projects to learn from on-going projects and be able to introduce these solutions in the beginning, as it is easier to implement then. Additionally, one of the main impressions is that within the different contractors, the transfer of experience is fully utilized. The problem is the same between different contractors, where an increased transparency and exchange of experiences would be beneficial for the whole industry.

Another topic from the interviews that introduced us to a new philosophy, not found in the literature, was the concept of building along a line. Although this may seem obvious to the reader, just having this idea in mind when planning for underground construction might help to discover both problems and possibilities. We think this is an interesting philosophy that needs further investigation.

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Appendix

Interview questions

Inledning

Din roll

Tidigare tunnelprojekt

Kontraktssumma

Antal anställda

Tidsplan

Entreprenadform

Hur följer ni tidplan/budget?

Med logistik menar vi materialförsörjning, leverans, hantering och eventuell lagerhållning på byggarbetsplatsen.

Framgångsfaktorer

Vad är det som skiljer ett projekt under jord från ett ovan jord?

Kan man använda samma typ av arbetssätt eller måste man till stora delar tänka om?

Vilka är de största logistiska utmaningarna?

Vilka anser du vara de största flaskhalsarna med avseende på logistiken i projektet?

Vad är det viktigaste för att ett tunnelbygge ska genomföras på ett smidigt och lyckat sätt?

Finns det någon typiskt faktor med avseende på logistiken som gör att projekt blir dyrare eller går sämre än förväntat?

Materialhantering entreprenör

Hur gör ni med materielleveranser?

Använder ni en extern logistikentreprenör? Om ja/nej varför?

Vad efterfrågar du från en logistikentreprenör, tjänster o.d.?

Använder ni Just-in-time?

Har materialförsörjningen varit med i den tidiga planeringen av projektet och är den samkörd med tidsplanen?

Har ni planerat och utsett särskilda materialupplag eller undviker ni att hantera material under jord?

Är byggarbetsplatsen planerad med hänsyn till att material ska lossas, lagras och användas, vad är tankarna kring detta?

Ankommer materialet när det ska monteras eller tidigare?

Ställer ni krav på leverantörer att de ska packa på ett sätt som passar er?

Skiljer ni på hur ni hanterar bergmaterial etc. och liknande med hur ni gör med installationsmaterial med tanke på lagerhållning och beställning?

Materialhantering beställare

Är ni som beställare involverade i logistiken i projektet?

På vilket sätt?

Har du under tidigare projekt varit involverad i logistiken?

På vilket sätt?

Tycker du att logistiken spelar en viktig roll i byggprojekt?

Avslutning

Vad kan man göra bättre eller fokusera extra på inför projektet Västlänken i Göteborg tycker du?

Vad skulle du gjort annorlunda om du hade fått göra om ditt projekt?

Har du något förslag på någon vi kan intervjua?