Delft University of Technology
MSc Management of Technology

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An application of construction logistics analysis:

the case of the new Delft train station and City Hall

Cover:

Westvest Street, from South to North.

Source: Mecanoo, het nieuwe kantoor en ns station delft, definitief ontwerp

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PREFACE

"First, have a definite, clear practical ideal; a goal, an objective. Second, have the necessary means to achieve your ends; wisdom, money, materials, and methods. Third, adjust all your means to that end."

Aristotle (384 BC – 322 BC)

To the reader,

This work constitutes the final report of my Master Thesis Project and fulfills the final requirement for my graduation at the Transport, Policy and Logistics' Organization section of the Delft University of Technology, Faculty Technology, Policy and Management. The motivation behind my decision to choose the specific project lies on the character and the orientation of my studies, as well as my personal interest to explore the specific area, logistics in building construction projects, which I consider fascinating.

During my previous experience with construction projects through my occupation as a construction site supervisor after the finalization of my Bachelor studies as a Mechanical Engineer, I was always fascinated by the skill and dexterity of the trades that were working on the construction site. It was obvious that they could solve a million of problems that arise on site and deliver a spectacular end product. But still some things on the construction site always bemused me. Why was there no professional approach for logistics on site? Why do the workers have to spent time waiting for materials to arrive on site, or for materials that did not comply with the requirements and had to be replenished so as the work to proceed? I knew that these answers could only be given through a managerial approach of the problem.

This was one of the reasons that I decided on 2008 to apply for the Master of Science program of Management of Technology and here I am two years later fulfilling my last requirement for my diploma. My journey to Netherlands the past two years will be an unforgettable experience for many reasons. From an educational perspective, I have been confronted with a different point of view than the one I had been used to during my studies in Greece. The management orientation of the master program gave me the opportunity to look at the field of engineering from a different angle and made me realize how important it is to have business knowledge when it comes to engineering matters. Moreover, my contact with the field of Supply Chain Management and Logistics further enhanced my belief that an engineering project can be properly and efficiently executed when its supply chain is properly functioning. As an old military adage states, 'Amateurs talk strategy; professionals talk logistics'. I hope my friends that are studying strategy will not be offended, but apart from the humorous attempt, the statement contains something really important which is that in order to successfully implement a strategic decision it is more than important to have a professional approach towards logistics.

Aside from the educational knowledge obtained, these two years have also been full of personal lessons. The experience of a new culture and the socialization with people from so many different countries, and with so many cultural differences was an opportunity to broaden my way of thinking and confirm what I have always believed; the things that connect us are much more than the things that keep us apart.

Preface

The conduction of this research was possible thanks to the help, support and confidence of many people and at this point I would like to express my gratitude to them. First of all, I would like to thank my thesis coordinator, Ir. M.W. Ludema for his continuous support and advice during the development of this report. I would also like to express my warm thanks to the other members of the graduation committee, Prof. Dr. Ir. Lori Tavasszy and Dr. Sergey Filippov, for their critical feedback whenever requested. A special thanks to Ir. Robert Gips from ABT, who was my mentor for the finalization of this project, for his guidance and the valuable knowledge he provided about the proper realization of construction projects. I am also indebted to Ir. Thibald Holscher from Ontwikkelingsbedrijf Spoorzone Delft B.V. for giving me the opportunity to be involved with the project of the construction of the new Delft train station and City Hall.

This research could never have been completed without the help of all the interviewees of the various private parties. They were willing to share their experiences and knowledge about construction logistics and the case that has been studied, and they provided information and documents which were very important as part of the research. Many thanks to all the interviewees involved who gave their assistance to the research.

Furthermore, I would like to express my hearty feelings for my friends and colleagues for being supportive and tolerant. Exceptional thanks to my “family” here in Delft, Kostas, Tassos, Giannis, Pepe, Monika, Rose, Bea, Flavia, Sandra, Ioanna and Eva who made my stay in Delft outstanding. Love you guys!

Above all, I would like to thank my father who was the person that motivated me to attend this master program, my mother for all the love and belief on me, and my sister for all the support all these years. This report is dedicated to you.

I hope you enjoy reading this report.

Yours sincerely,

Dimitris Papaprokopiou — Delft, November 2010

SUMMARY

Construction is an exciting sector, which consists of a complex mesh of relationships between increasing accelerating processes, decisions and actions. Simultaneously, there is development towards sustainable design approach that leads to buildings providing the best possible connection of functionality and architecture, energy efficiency, and healthy construction materials that can be recycled while at the same time achieving the best possible economic benefits. Construction delivers complex and bespoke projects, often in challenging and constrained environments, so the need for a professional approach of logistics is essential in order to realize the project scope in terms of time, cost and quality.

Despite this fact, logistics have not been addressed thoroughly for constructions and few things have been written regarding the best way of organizing and supplying a construction project. This is a result of the lack of close collaboration between the professional communities of logistics and construction.

The logistics processes related with construction projects and their proper application are the main direction of this research. The research is conducted in collaboration with Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS). OBS has the task to manage the construction of the new Delft train station and City Hall, and has assigned ABT, the construction consultant, to investigate the construction logistics of the design phase of the project. ABT will develop a logistics plan for the construction site which will be used as a reference for the future contractor of the project.

RESEARCH CONTEXT

During the last years the global economy suffered a lot from the results of a prolonged credit crisis. Construction industry suffered from the effects of the crisis since the early 2007 when the industry posted a decline of 4.9%, the sharpest drop in the sector in the past 20 years. Into this turbulent construction environment clients and contractors are looking into every possibility that could improve their projects' efficiency. Moreover, construction projects have the tendency to create a disorder in the surrounding environment of the construction site. During the last years there has been a noticeable increase in public concern about issues related with congestion, miles traveled, energy consumption and CO_2 emissions. In addition health and safety is a critical issue for constructions which is connected with the negative external effects that may occur during a construction project. The possibilities about the enhancement of construction projects efficiency by any means and the minimization of the negative external effects in their local environment are two things that are a big concern of the industry.

Logistics involves the strategic and cost-effective storage, handling, transportation and distribution of resources. It is an essential process that supports and enables the primary business activity, like the construction of a building in a city, to be accomplished. Effective logistics management can lead to the effective execution of a construction project. Nevertheless, construction logistics management is not an easy process. Construction facilities become more complex and technological advanced and the markets more dynamic and fragmented. The outsourcing and subcontracting increases the number of organizations involved in the construction supply chain. The result of the technical complexities and the number of participants in a construction project makes the management and optimization of logistics chains quite difficult.

For these reasons, the influence that construction logistics can have on a building construction project is a very interesting area of research and is also the context of this thesis report. Moreover, the construction of the new Delft train station and City Hall gives the opportunity to conduct the research using a real construction project as a reference. The new building has very complicated logistics processes involved due to:

a) the positioning of the construction site, as it is bordered with the central tram line and the central train station of Delft

b) the scheduling of other construction activities around the site, as the whole area will be under construction during the execution period of the project

c) the logistics related with the public traffic, as the construction site is in the center of Delft and in front of the current train station which will be operating during the construction of the new building

The investigation of the process for the development of a logistics plan for the construction site can result to valuable conclusions regarding the benefits of a construction logistics analysis during the design phase of a building construction project.

RESEARCH GOAL

The goal of this research is to investigate, on the basis of the theory and practice of logistics and supply chain management, the possibility and the way to enhance buildings construction project efficiency. In addition, while enhancing the project efficiency, the research investigates the possibility of minimizing negative external effects in the local environment (traffic, economic activities, health & safety, and distortion of local citizens' life) at the same time. Subsequently, the application of construction logistics analysis in a real project is researched and guidelines and recommendations will be provided for the realization of the research goal. Related to the goal of this research, the research objective can be summarized as follows:

Research Objective:

1. a) *To explore the contribution of Construction Logistics analysis towards the enhancement of construction project efficiency, by analyzing a real case of a building construction in a residential area in the Netherlands*

b) *To explore the contribution of Construction Logistics analysis towards the minimization of the negative external effects in the local environment of a construction project*

c) *To explore the trade-offs involved in the relationship between the enhancement of construction project efficiency and minimization of negative external effects*

2. *To present guidelines and recommendations to OBS with respect to the construction logistics of the new Delft train station and City Hall, through the development of a logistics plan for the construction site*

This research is built upon a central research question, supported by five research sub-questions. The main research question is formulated as:

"*How can construction logistics analysis during the design phase enhance buildings construction project efficiency in residential areas, while at the same time minimizing negative external effects in the local environment?*"

Regarding the framework that guides this research, there are two basic concepts that characterize it. First of all, the one of qualitative research, since the research question and aim of the research is more of an explorative nature, and secondly, the use of a single case study which is the most common form of qualitative research strategy. The research methods used include unstructured interviews, archived data and semi-structured interviews.

LOGISTICS AND EFFICIENCY

Logistics in construction is a multidisciplinary process which strives to guarantee at the right time, cost and quality activities such as material supply and handling, schedule control, site infrastructure and equipment location, site physical flow management, traffic arrangements on and around the construction site and information management related to all physical and services flow. Construction logistics have different characteristics comparing to logistics in other industries that is a direct consequence of the construction industry's peculiarities. The most important differences are related with the converging supply chain, the temporary nature of supply chain and the make-to-order supply chain.

Seminal reports and reviews on the UK construction industry have highlighted the inefficiencies and waste of the industry due to poor logistical performance. The "*Improving Construction Logistics*" report published by the Strategic Forum for Construction Logistics Group (2005) recognizes the following factors preventing the industry from properly addressing logistics:

- The lack of incentive to change, as there is no real "problem owner"
- Construction projects seen as one-off and as a result difficult to optimize logistics for long term benefit
- The fragmented nature of construction industry and the lack of direct employment
- Inadequate advanced planning of projects and short lead times
- The lack of cost transparency in the construction process that hinders the identification of potential savings from improved logistics
- Inadequate information flow
- Lack of trust, confidence and understanding of the constraints of the supply chain
- Clients believe that project costs already include for appropriate logistics resources to be committed to projects

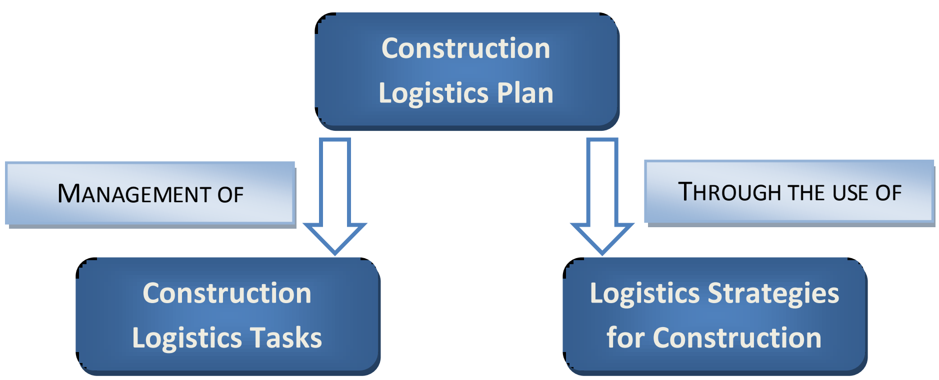
The improper consideration of logistics in a construction project may result to a high proportion of trucks moving around the road network either empty or with part-loads of materials, traffic congestion due to trucks that arrive on site and have to wait to gain access or be unloaded and skilled craftsmen that often use their skills for less than 50% of their time on site due to their involvement with non-skilled tasks such as unloading a truck or moving products around site.

The effect of the improper consideration of logistics in construction projects may result to:

1. *Unnecessary cost to the system*: The inefficiencies that occur from the improper application of construction logistics points to additional cost to the system that could be saved if the process operated more efficiently.
2. *Transportation and environmental issues*: Motor trucks parked in an inconsiderate way outside construction sites in the middle of the day, whilst waiting to unload can cause major traffic problems. Vehicles driving around empty or with part-loads result to increased emissions in the environment.
3. *Poor quality construction*: Working in a disorganized environment will inevitably make the production of quality construction more difficult.
4. *Increased project time*: Most of the features of construction projects that point to poor logistics will add to the time of construction projects.
5. *Added risks to health and safety*: Unnecessary products stored on site inevitably bring with them additional potential hazards. Additional manual handling (either because product is in the wrong part of the site or because the right equipment is not available) adds to the health risks to those on site.

CONSTRUCTION LOGISTICS IN PRACTICE

Logistics, like many other aspects on a construction project, have to be planned out in detail at the beginning of a project in order to run effectively and efficiently. In a logistics plan, a strategy on how to approach the construction work at each stage of its development is needed. The main task of an integrated logistics system is to provide just in time deliveries when needed to eliminate most of materials handling and storage on site, to shorten the time of the project completion by eliminating reasons of work stoppage and to minimize the local negative external effects. There are important logistics tasks and processes that occur at every stage of a construction project.



The management of the logistics tasks per each project phase is possible through the development of a construction logistics plan. Several logistics strategies for constructions can be used so as to optimize a logistics plan. This research has identified several logistics strategies through the literature review and interviews with experts. An overview of these strategies is presented in the following table:

Consideration of logistics issues in the design	Architects and designers make decisions during the design phase that influences logistics. An analysis of the risks that may occur when examining the preliminary design of the architect and the construction site gives input for further consideration of logistic issues in design
Just-in-Time	A service of frequent deliveries in work packs, 'pulled' just in time for the trade to perform the next task
Logistics centers – Construction Consolidation Centers (CCC)	A distribution facility for materials that receives materials, equipment and plant and delivers to the sites in consolidated loads
Prefabrication & Off-site Manufacturing (OSM)	The implementation of prefabricated elements in a construction design. The manufacturing process takes place in a controlled environment and result to less waste and product defects
Delivery management system and other IT support	A web-enabled scheduling, booking and logging system for all transport activities inbound and outbound from the site, which can also be used to book resources such as cranes, lifts and forklifts on the site. Also, an interoperable information system that tags and tracks materials through take off, manufacture, distribution, assembly and installation
Traffic management	Arrangements for the movements of vehicles on and in the vicinity of the site. Clearly defined segregation of both types of vehicular and pedestrian traffic
Early constructor involvement	A procurement process that makes possible the early consideration of logistics, through the involvement of the constructor early in design phase
Building Information Modeling (BIM)	A process of generating and managing building data during its life cycle and encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components

For the development of a logistics plan for a construction site the logistics elements that needs to be taken into account includes the mobilization and site set-up, materials delivery and handling, traffic management, managing critical risks – security, and waste management. These elements are used for the analysis of the new Delft train station and City Hall case.

LOGISTICS PLAN DEVELOPMENT FOR DELFT CASE

The process for the logistics plan development for the construction site of the new Delft City Hall has been based on a framework of construction logistics analysis which is composed of four steps. The process begins with the general assessment of the project environment (*step 1 – the general overview*), followed by the information gathering process (*step 2 – looking into the problem*) which gives the required input for the evaluation of the situation (*step 3 – coming up with solutions*). The analysis is finalized with the design process (*step 4 – optimize solutions*) which lead to the development of a drawing of an integrated approach for the logistics plan of the new Delft train station and City Hall construction site. The construction logistics analysis assisted towards the identification of areas of improvements with respect to the logistics processes and provided the proper requirements for the creation of a logistics plan that can be practical and workable on a real construction site.

The major logistical problems that had been recognized after the logistics analysis and had to be dealt with were: *a)* the fact that the basement of the new building has to be constructed next to the underground tunnel and *b)* the transportation on site of the large steel trusses that are needed for the structure assembly. The construction of the basement can lead to several risks, with the most important being the mixing of two contractors in a small construction area. The steel trusses on the other hand represent the largest construction elements that have to be transported on site, so special logistics consideration should be given to them. The design team made some decisions regarding the way of construction of the building and proposed a new plan which took into consideration these logistical issues. The new plan will result to huge time and realization benefits, but will also bring more construction traffic on site. The good organization of the construction site and the analysis of the flow of resources on site can lead to the realization of the benefits of the new planning.

For the development of a logistics plan for the construction site of the new Delft train station and City Hall, two scenarios are investigated which are taking into account two possible future states of the construction area – the "*realistic scenario*" and the "*contingency plan*". Guidelines for each area of consideration are presented and are integrated in a draft logistics plan for the construction site.

Conclusions

This research concludes that the application of a construction logistics analysis during the design phase of a construction project can set the foundations for improving the project efficiency while at the same time minimizing the negative external effects to the local environment. Decisions regarding logistics in the design phase, such as the use of prefabrication and the alternative structural design so as to allow normal construction traffic flow to the construction site made the new planning of the new Delft train station and City Hall a feasible option. The tangible results were:

- time savings of 7 months until the realization of the 80% of the building, and 15 months in total until the completion of the whole project
- cost savings in construction due to the use of one sheet pile construction by one contractor
- delivery of the 80% of the complete building after the completion of the first construction stage, which means that through the use of a temporary façade the building can be operational after the first construction stage
- the second construction stage can be realized independently without affecting the operation of the building and as a result there is an earlier return on capital invested and high degree of reduction in penalty clauses due to late delivery of the project

The intangible results regard the good organization of the construction site, the smooth material delivery and handling processes through the use of specified delivery and handling points and vehicle access points, the proper coordination of the construction vehicles movements to site and public traffic movements around site, and issues regarding the management of critical risks on site and waste management. These results can only be reflected in a qualitative manner at this stage of the project.

The main conclusions of this research with respect to the research domain and the empirical findings of the case that has been studied are summarized as following:

- During the first phase of construction, heavy traffic takes place in the construction site due to the need for large, heavy and voluminous materials. During this phase several inefficiencies can arise such as the lack of capacity of the construction site to accept heavy traffic, lack of proper material handling equipment, and inability of workers to handle materials. Having knowledge about these issues in the design phase can allow changes in material or construction elements requirements that will allow the proper resources flow on and to the construction site.
- During the design phase of a construction project, the project management team may come with a new way of constructing or with a new plan that will lead to improved project performance with less negative external effects on the local environment. Construction logistics analysis may assist this process through the identification of possible logistics constraints in the new planning and by proposing an updated logistics plan that will allow the execution of the new planning.
- Decisions that can be made during the design phase of a construction project can have a big influence in the project performance. Construction logistics analysis can identify the resources flow requirements. The analysis of these requirements may lead to alternative scenarios regarding the building construction that can be assessed by the designers so as to come up with a more efficient design solution.
- The flow of the resources needed for a construction site is a complex process that needs to be managed in detail. Effective traffic management and material delivery processes will allow the safe access and egress of construction resources in any construction site. The logistics constraints of the surrounding environment need to be assessed carefully and during an early project phase to provide the right information for the organization of the logistics processes on site.
- Negative external effects can be a result of a construction activity or by the application of construction logistics strategies so as to improve project efficiency. Construction logistics analysis can identify the risks related with these negative external effects at an early phase and accordingly propose mitigation measures based on specific management actions.

The main research question for this research is formulated as follows:

"*How can construction logistics analysis during the design phase enhance buildings construction project efficiency in residential areas, while at the same time minimizing negative external effects in the local environment?*"

The answer to this main research question is formulated among these lines:

Construction logistics analysis during the design phase of a construction project in residential areas is an important process that can lead to important benefits realization. Initially, areas of improvement regarding the resources flow on and to site (materials, people, plant / equipment, waste) can be identified. Furthermore, construction logistics analysis can be a valuable tool of assistance for project management as it can identify inefficiencies related with aspects like material delivery, transportation, and traffic management that can be diminished and lead to increased project performance. At the same time, through the identification of the risks related with negative external effects for the local environment of the project, logistics tasks and guidelines can be derived for the proper mitigation of these risks.

Constructions are always unpredictable due to the nature and the peculiarities of the industry, but it can be concluded that a proper construction logistics analysis during design phase has the potential to enhance building construction project efficiency while at the same time minimizing the negative external effects in the local environment.

The research is finalized with some generic recommendations regarding the principles and designers that are involved in construction projects, and recommendations for further research. Due to the limited scope of this research which was focused on the design phase of a construction project, the generalization of the conclusions and recommendations cannot be applied to the whole construction supply chain. Future research should expand the scope and include more actors of the construction supply chain who are involved on the whole life cycle of a construction project.

As a final remark, it can be stated that the results of this exploratory research can be considered to fulfill the expectations of the research goal and raise several questions that can be a subject for future research. The field of construction logistics still has a lot of things to be studied. It is now to be seen whether the notion of construction logistics will develop along with the construction industry in a more efficient and sustainable future.

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1. INTRODUCTION

1.1. OVERVIEW

The nature of the construction industry has been changed over time towards increased complexity. However, the major objective of the industry is the same as it was 100 years ago: to build communities, roads, schools, houses, hospitals and businesses. The construction industry accounts for around one-tenth of the world's gross domestic product, seven percent of employment, half of all resource usage and up to 40 percent of energy consumption. A unique-project delivery system is the cornerstone of the construction industry. Large and small firms, related bulk material suppliers, several support professionals are some of the elements which characterize the industry as fragmented. The typical supply chain for any given construction project can include architects and engineers, prime contractors, specialty subcontractors, and material suppliers that come together one time to build a single project for a specific owner. The competitive bidding process, in which the low bid usually win, is the pricing model that repeats in most links of the supply chain and drives the adversarial short-term relationships that characterize the complex construction supply chain. This adversarial behavior is one of the causes of dissatisfaction throughout the supply chain and results in arm-lengths, one-time, project-focused relationships.

Building projects are often large and complex to plan, design, construct and maintain and they require many specialized persons. The need for efficiency and the profitability of owners, designers and contractors are being challenged as the buildings and business processes become increasingly complex. The good cooperation of many individuals with a great variety of skills and interests is required to make construction possible and efficient.

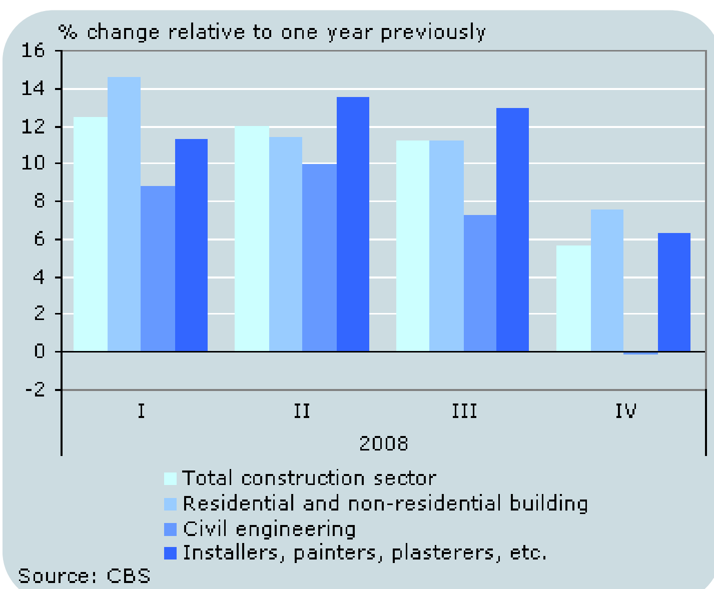

Figure 1-1: Construction turnover of 2008 (CBS, 2008)

Since the early 2007, the global construction industry suffered from the effects of the economic crisis. According to calculation from Global Insight, a market research institute, the industry posted a decline of 4.9% to US$ 5.4 trillion. This is the sharpest drop in the sector in the past 20 years (Wacker, 2009).

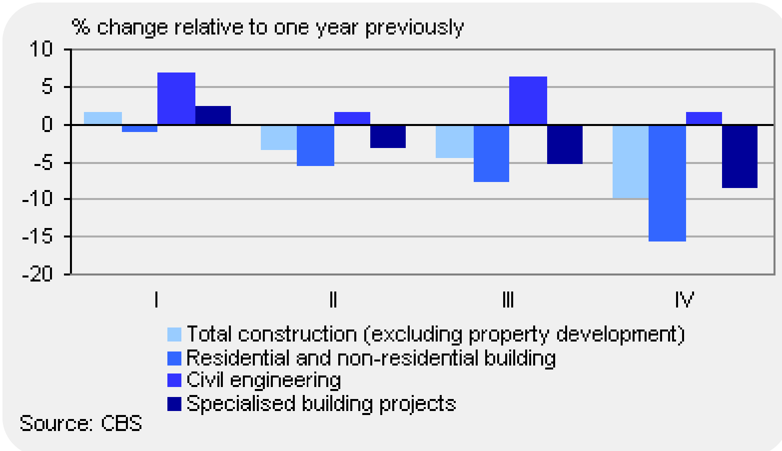

Figure 1-2: Construction Turnover of 2009 (CBS, 2009)

In the Netherlands, the impact of the economic recession felt in construction in the fourth quarter of 2008 and after years of sustained growth, turnover realized by the construction sector slumped 4.5 percent in 2009.

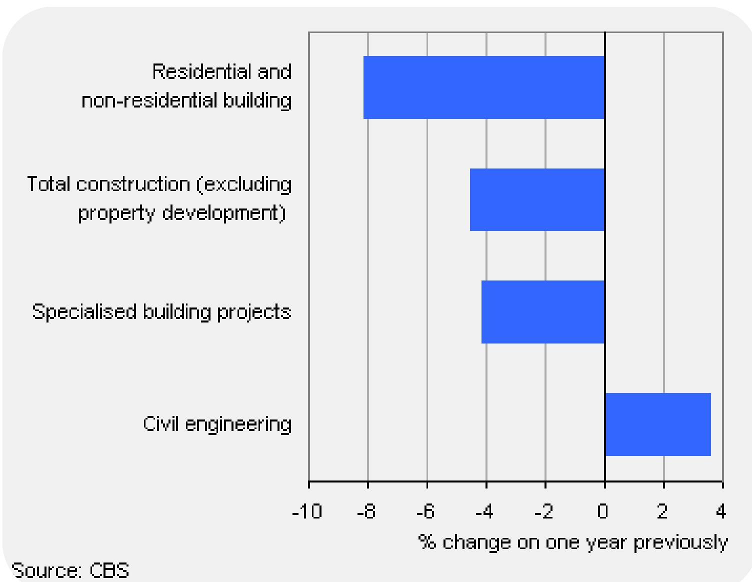

Figure 1-3: Turnover by branch in the construction sector in 2009 (CBS, 2009)

The only branch within the sector to show turnover growth was civil engineering, growth that was partly caused by government activities in order to boost the construction of infrastructure works. Residential and non-residential building, including dwellings, hospitals and offices suffered badly in 2009, as turnover reduced by 8 percent (CBS, 2009). Into this turbulent construction environment the government and the contractors are looking into every possibility that could improve their project efficiency. Construction projects have the tendency to create a disorder in the surrounding environment. Traffic congestion, noise, accidents, and local environmental pollution, are just few of the external factors that arise with a project and create a lot of trouble for the stakeholders involved in it. These external factors are very important for the smooth completion of a project especially when we are talking about large public projects, as the local citizens may have increased power and cause delays or even termination of a potential construction project.

The organization and sourcing of construction materials is becoming increasingly complex across the industry. During the last years, there are advances in transportation technologies regarding the global sourcing and assemblies of materials in addition to a shortage of skilled labor which force increasing amounts of added-value work to be conducted off the construction site. Simultaneously, construction clients are demanding faster, more responsive construction processes and higher quality facilities. For all these reasons, effective construction project execution requires more responsive production chains and closer coordination between the members of the project. Construction Supply Chain Management and Logistics is a rising area of practice. It is stimulated by the manufacturing Supply Chain Management where the emphasis is on modeling volume production. Construction Supply Chain Management is involved with the management of discrete quantities of materials delivered to specific projects. Effective management of the construction supply chain will mean effective execution of the construction project (O'Brien, Formoso, Vrijhoef, & London, 2009).

A short overview of the concepts of efficiency in construction, negative external factors involved in construction projects and construction supply chain management was essential, as a first impression of the core elements of this research. Based on this overview, the introduction of the research problem can now take place. A deep analysis of these concepts will follow later on.

1.2. RESEARCH PROBLEM

The construction process is characterized by increased fragmentation due to the total number of firms involved in the process and the heavy outsourcing towards numerous subcontractors. Many participants who represent various specialties are active in different stages of a construction process. Construction industry's fragmented nature, together with the existence of adversarial relationships and the propensity for self-interest rather than common objective, may affect the efficient and effective satisfaction of customer demands (Cutting-Decelle, 1997; Marosszeky, Jaselskis, Smithies, & McBride, 1997).

The industry is being blamed for not achieving the level of performance and productivity seen in other industrial sectors (SFCLG, 2005). One of the most important reasons for this is the people's perspective that large infrastructure projects cause planning and budget overruns. A typical example in the Netherlands was the delays on the construction of the Dutch High Speed Rail Link (HSL) between Amsterdam and Paris, which caused an estimated budget overrun of € 222 million (Badcock, 2007). At this point we should mention that there are big differences in the characteristics of the construction industry in comparison with other industrial sectors which will be analyzed later in this report.

Lack of quality, lack of focus on customer or end-user, lack of standardization, lack of supply chain integration, fragmentation of the industry, fraud and adversarial behavior are some other points of criticism aimed at the construction industry (Wong & Fung, 1999; Pries & Dorée, 2005). The lack of fundamental and understanding of the various construction processes and their interactions on construction projects is another reason for the lagging behind in comparison with other industries (Koskela, 2000). As a conclusion, it can be stated that construction industry faces problems of project inefficiencies and encounters criticism regarding the construction project performance and productivity. In recent years, especially during the last decade, the construction industry has recognized the importance of Supply Chain Management and Logistics to improve the performance of projects. As in the manufacturing context, construction companies are facing increasing competition and customers are requiring lower costs, higher quality, shorter execution durations and more reliable schedules.

Indications of basic problems in construction supply chains

Prior research has identified several construction “endemic problems” like the complexity and non-transparency of processes, low productivity and cost inefficiency, lack of involvement of subcontractors and suppliers and inferior and obsolete logistics and information systems (Vrijhoef, 1998).

Although these problem references may considered outdated nowadays where especially the large projects are organized very carefully, they give a first signal about logistic related problems during the last 10 years. The construction industry has evolved a lot throughout this time period but still there are logistic related issues which can cause project inefficiencies. Azambuja and O’Brian (2009) mention poor production planning which includes decisions on buffers, and limited planning concerning the impact of off-site production and delivery variability as the main causes of on-site production inefficiencies. Keeping large amounts of inventory on construction sites to reduce risk of delays on site production is a common practice. However this requires site space, resources to manage it and represents in most cases an unnecessary investment.

Moreover, construction facilities become more complex and the markets more dynamic and fragmented, outsourcing and subcontracting increases boosting the number of organizations involved in the project supply chain, something that is needed to deliver the required quality of the complex projects. This create additional difficulties for coordinating supply chains such as, the number of planning alternatives increases dramatically, divergent stakeholders interest which needs to be managed and lack of overall understanding of the project by the different participants (Wiendahl, von Cieminski, & Wiendahl, 2005).

Contractors in construction are usually only single links of logistic chains that provide a project with products, services, information and finance. In contrast to manufacturing industries, which profit with long-lasting partnership with suppliers and customers, logistic chains in construction are considerably more difficult to manage and to optimize due to the technical complexities, the number of participants in a construction project, and the difficulty in fine-tuning each member’s logistics routines to the logistics system of the construction project (Sobotka, Czarnigowska, & Stefaniak, 2005). The abovementioned leads towards the definition of the first problem statement that this research is being involved with and is the following:

PROBLEM STATEMENT 1:

Construction industry faces increasing problems of project inefficiencies which are partly a result of poor construction logistics caused from the difficulty to manage and optimize construction supply chains.

On-site Logistics Problems

In the previous section, problems regarding the difficulty of managing and optimizing construction supply chains which may lead to construction project inefficiencies were mentioned. This is one side of the problem related with the logistics of construction projects. The other side concerns the problems that may arise on a construction site and are related with the logistic processes of the construction site. Lack of materials on-site when required, lack of the 'right' materials on-site, and accumulation of material inventories are just some of the types of waste generated by traditional practices, hampering performance through delays, low-quality workmanship, cost overruns, and poor safety levels on-site (mainly due to materials laying around working areas). The most common approach to materials management in construction is to manage variability by accumulating large inventories on-site. This approach has implications for cost and time primarily due to (Arbulu, 2009):

- crews looking for materials within large stockpiles instead of working
- hidden cost associated with managing large materials stockpiles
- stockpiles potentially blocking workflow and risking material quality and safety on-site
- large quantities of materials delivered early to site, causing a negative impact on project cash flow (money is allocated and released too early)

The desire to benefit from economies of scale, such as cheaper by the dozen, creates an incentive to purchase and also request deliveries in large quantities. From that perspective, the larger the sizes of the delivery batch, the fewer trips are required to fulfill a complete order. Therefore, the lower the transportation cost, the cheaper the unit price. On the other hand, deliveries in large quantities can cause major problems regarding the space and warehousing requirements near or on the construction site. Especially in highly populated areas, there is a high probability that there will not be enough space on the construction site to store large quantities of materials. A solution to this problem could be to use a consolidation center near the construction site, outside the highly populated area and supply frequently from there, but this could create congestion problems due to the trucks that would move frequently to the construction site.

In modern urban societies the need for growth and expansion is urgent. This leads to increased construction activities which can have a significant undesirable impact on their surrounding environment. Types of adverse impacts associated with construction activities are grouped under four headings: *traffic, economic activities, air and water pollution, and damage to the physical environment* (Gilchrist & Allouche, 2005). Potential undesirable impacts include traffic congestion and delays, excessive generation of pollution and pollutants, disruption of economic activities, damage to sensitive ecosystems and damage to existing structures and infrastructure systems.

The scale of the environmental and social impact that construction projects create is significant. In 1998, a mass balance study of resource use, wastes and emissions in the UK construction industry revealed that 424 million tons of materials have been used, of which over 150 million tons of waste was produced. 90 tons were generated on construction sites, 60 million tons by product manufacture while 30.1 tons of emissions were generated. The study concluded that the most significant barriers to achieving improvement in resource productivity were the lack of a body that can provide strategic direction for setting priorities and policies and the increased fragmentation of the construction industry (Smith, Kersey, & Griffiths, 2003).

> **Note:** *The term 'environment' in the context of this paper will refer to the sociological, economic and ecological systems that surround construction activities*.

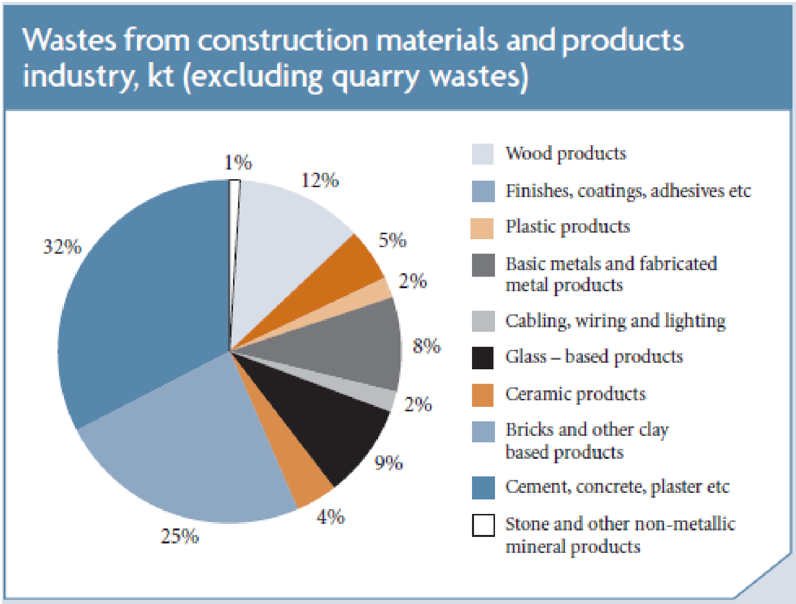

Figure 1-4: Wastes from construction materials and product industry (Smith, Kersey, & Griffiths, 2003)

The abovementioned leads towards the definition of the second problem statement that this research will be involved with and is the following:

PROBLEM STATEMENT 2:

Construction Logistics processes, applied on a construction site, which are not carefully analyzed can create several negative external effects on the local environment.

As it has become clear from the problem description, the influence the construction logistics can have on a building construction project is a very interesting area of research for the further development of the construction industry towards a more efficient and sustainable future. Following the definition of the research problem that this research will deal with, the research objective will be introduced in the next paragraph.

1.3. RESEARCH OBJECTIVE

The goal of the research is to investigate, on the basis of the theory and practice of logistics and supply chain management, the possibility and the way to enhance buildings construction project efficiency. In addition, while enhancing the project efficiency the research investigates the possibility at the same time to minimize negative external effects in the local environmental like death or serious injuries, distortion of the life of local citizens, noise, waste, and environmental pollution. Subsequently, through the examination of a real case, the applicability of construction logistics analysis will be researched and guidelines and recommendations about how can a construction project become more efficient with less negative external effects will be provided, that will specify the influence that different decisions in the design phase may have on these aspects.

The problems mentioned on the previous section are distributed across the entire construction sector and through the complete building chain. Since the research is done in cooperation with Ontwikkelingsbedrijf Spoorzone Delft B.V. (**OBS**), which is the Delft Station zone Development Company, it concentrates on the position OBS is in and the current project phase. *Section 1.4* reflects the research scope and defines the level of detail that this research is going to focus on. In order to fulfill the research objective a real case will be studied. A small description of the case is needed prior to the formulation of the research questions that are presented in *section 1.5*.

The new Delft train station and City Hall (*stadskantoor en stationshal Delft*) is a unique project in the heart of Delft next to the current train station and will be the representative case of this research. A new building will be constructed which will have two functions: a recognizable and functional train station and a representative accommodation place for the municipality of Delft. The new building will be constructed on the top of the new railway tunnel of Delft, in the interface between two different projects and in a small construction site in the middle of the city. This situation may cause several problems regarding the building logistics, the project efficiency and the negative external effects in the local environment.

The client of the project is the municipality of Delft and OBS is the intermediate between the design teams, the future contractor of the building and the other contractors that are already working on site. The project is currently on the finalization of the design phase, and the construction of the building is planned for 2011. Due to the complexity of the project, the size of the construction site, the number of the contractors involved in the project and the uncertainties that will arise from it, OBS has assigned ABT, which is also the construction consultant for the design phase to develop a logistic plan for the construction site.

Following the definition of the aim of this research and an introduction of the case that will be studied, the research objective can be summarized as follows:

Research Objective:

1. a) *To explore the contribution of Construction Logistics analysis towards the enhancement of construction project efficiency, by analyzing a real case of a building construction in a residential area in the Netherlands*

b) *To explore the contribution of Construction Logistics analysis towards the minimization of the negative external effects in the local environment of a construction project*

c) *To explore the trade-offs involved in the relationship between the enhancement of construction project efficiency and minimization of negative external effects*

2. *To present guidelines and recommendations to OBS with respect to the construction logistics of the new Delft train station and City Hall, through the development of a logistics plan for the construction site*

1.4. Reflection of the research scope

In this paragraph, some assumptions are explained in order to limit the scope of this research. Initially, the problems mentioned in the previous paragraphs are distributed across the entire construction sector and the different actors involved. Since the research is done in cooperation with Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS) it concentrates on the position OBS is in and the current project phase. In *figure 1.5*, the current phase of the project is presented. Currently the project is in the definite and detailed design phase, just before the tendering process. The contract that will be awarded will be a traditional bid and build contract.

OBS is the problem owner and their interest is spread to the following directions:

- Make sure that everything will be prepared to be able to construct the building on the top of the tunnel
- Design and reflect on construction logistics in order to be able to construct the building
- Deal with the complexity of the project, the interface between the different contractors, the small construction site and the time limit in order to finalize the project

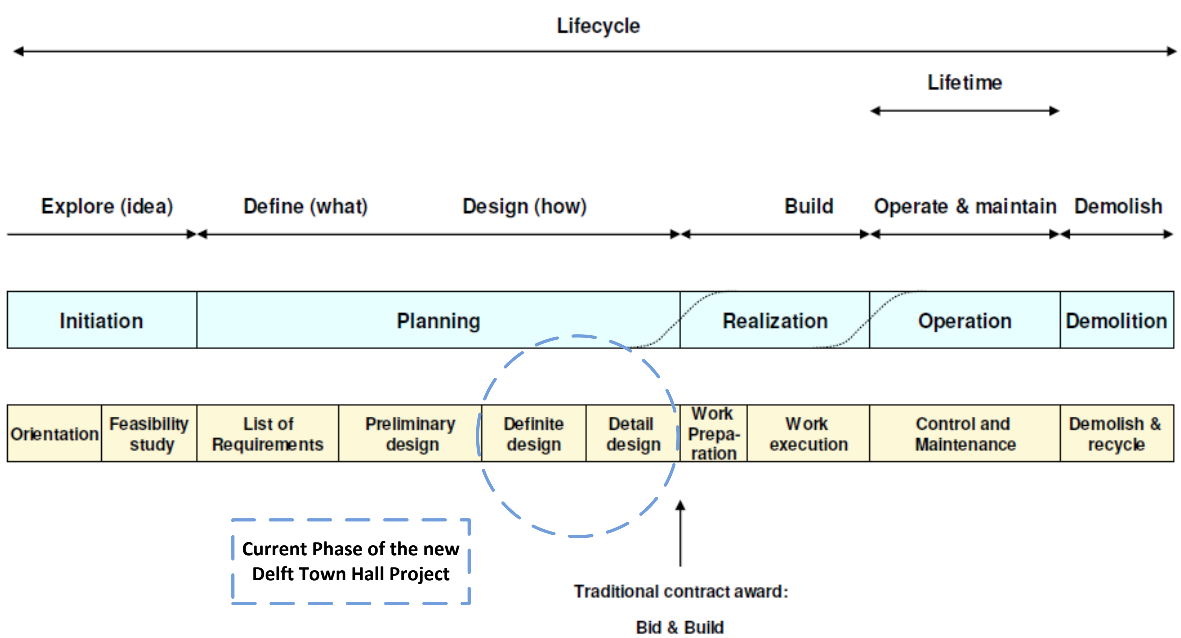

Figure 1-5: Construction processes in time, adapted from Fukken et al. (2000)

As it can be seen from *figure 1.5*, the scope of this research is limited to the direction of the design stage of a project. More specifically, the way which construction logistics analysis can be applied during the design phase in order to enhance the project efficiency and limit the negative external effects in the local environment.

The research **will not** develop a logistic model that can be applied in the whole construction project. This is not feasible for several reasons:

- The project is still on the planning stage
- The project is not tendered to a main contractor yet, as a result there is no information about the sub-contractors or the suppliers of materials who will consist the construction supply chain in the future

- Some logistic decisions and strategies can be applied on the design phase, but at the end the future contractor will be responsible for construction logistics on and to site
- The responsible party for the logistics in the whole area under development in Delft is the tunnel contractor Combinatie CrommeLijn VOF (CCL) and not OBS

The research is mainly focused on building construction and more specifically on supply and on-site logistics, although the analysis provided can be adapted and used for other kinds of construction projects. OBS has asked ABT, the construction consultant of the project, to provide a logistic plan for the construction site. This research will follow the steps taken from ABT towards the development of the logistic plan and will comprehend and analyze this process in order to investigate the relationships between logistics, project efficiency and negative external effects, and reach conclusions and give recommendations for the applicability of construction logistics in the project. The research is divided into two parts. The first part is the theoretical part which will present the theoretical aspects of construction logistics, their application and the processes included. The second part will be more practical and will include the empirical findings from the case that will be studied.

1.5.RESEARCH QUESTIONS

Following the positioning of this research and the definition of its scope, the next step is to formulate the general research question, the research sub-questions that will assist the process of answering the main question and the research design that will make this process viable. As it has been mentioned on the research scope, the research is limited to the design phase of a construction project. Moreover, logistics is one of the most important elements of a construction project, with the ability to influence important factors on construction site such as cost, speed of construction and plan reliability, and industry performance indicators like accident rates and contributions to landfill. Despite its importance, construction logistics has not been broadly researched and many of the issues and factors influenced by construction logistics has not been recognized or associated with them (Sullivan, Barthorpe, & Robbins, 2010).

Linked to its objective, the central inquiry, or else the exploration starting line, of this research is described by the following research question:

"How can construction logistics analysis during the design phase enhance buildings construction project efficiency in residential areas, while at the same time minimizing negative external effects in the local environment?"

Reading this central research question, four areas that need to be explored can be noticed:

a) *the concept of Construction Logistics and the applicability of a construction logistics analysis during the design phase of a construction project*
b) *the opportunities for improvement within the project efficiency of a building construction*
c) *the negative external effects in the local environment and the way they can be minimized*
d) *the ways Project Efficiency and Negative External Effects interact/ interrelate to each other*

In other words, constructions logistics analysis will be used as a tool of design to assess how project efficiency and negative external effects are influenced by it and the trade-offs that exist between project efficiency and negative external effects. *Figure 1.6* illustrates the domain of this research which stands in the interface of the construction logistics, construction project efficiency and negative external effects.

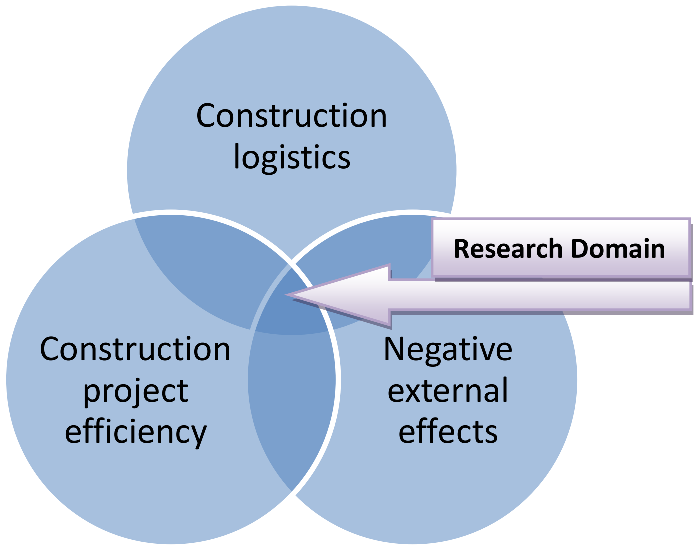

Figure 1-6: Research Domain

To contribute to the solution of the main research question, five research sub-questions are constructed:

1. ***"What is the domain into which construction logistics are applied?"***
    a. What are the characteristics of the construction industry?
    b. What kind of problems and peculiarities does the construction industry face?
    c. What kind of relationships are there between the parties involved in the construction projects?

In order to answer the first research sub-question the domain into which construction logistics are applied needs to be identified. To do so, the question is split into three sub-questions. Construction industry's characteristics and the problems and peculiarities of the industry need to be explored so as to understand the difference of logistics in construction and logistics in other industries. Moreover, the relationships between the actors involved in the construction supply chain needs to be assessed so as to understand their responsibilities and liabilities for the completion of a construction project.

2. ***"What are the most important characteristics of logistics on building construction projects that are connected with the direction of this research?"***
    a. What is the origin of construction logistics?
    b. What kind of processes does construction logistics involve and how can these processes be optimized?
    c. How is project efficiency influenced by construction logistics?
    d. What are the risks involved with negative external effects in a local environment of a construction project and how can these negative external effects reduce?

In order to answer the second research sub-question the concept of logistics with respect to the building construction projects, which is the main focus of this research, needs to be defined. To do so, the question is split into four sub-questions. The origin of construction logistics needs to be identified so as to understand the fundamental principles that surround construction logistics. Subsequently, the processes involved with construction logistics need to be identified and analyzed. Following the identification and analysis of the construction logistics processes, the relations between project efficiency and logistics will be investigated. The results of poor construction logistics and their influence on the efficiency of the project will be presented and the result of improving construction logistics will be discussed. Finally, the negative external effects will be discussed and related with construction logistics. Risks involved with the negative external effects in a local environment arise during a construction project and the influence of construction logistics towards minimizing these risks and accordingly the negative external effects needs to be investigated.

3. ***"What is the field of construction logistics that needs to be taken into account for a building construction site in a residential area?"***
   a. What are the logistic tasks according to the phase of a construction project and how can they be managed so as to develop a logistics plan?
   b. What kind of strategies can be used in a construction project in order to improve logistics?
   c. At what extent are project efficiency and negative external effects interrelated and influenced by the different logistic strategies?
   d. What are the important areas of consideration for the development of a logistics plan for a building construction site?

In order to answer the third research sub-question the practical application of logistics needs to be illustrated. To do so, the question is split into four sub-questions. A construction project consists of different phases which include different logistics tasks. The logistics tasks according to each phase of the construction needs to be managed through the development of a logistics plan. Moreover, several logistic strategies that can be used in a construction project will be discussed. These strategies have a direct relation with the project efficiency and the negative external effects. Based on each strategy, trade-offs and interrelations of these two aspects will be debated in order to gain an insight on the extent of the interrelations. Finally, the areas that should be considered for the development of a logistics plan for a building construction site needs to be identified in order to assist the analysis of the case of the new Delft train station and City Hall.

4. ***"How can construction logistics apply to the case of the new Delft train station and City Hall, in order to enhance the project efficiency and reduce the negative external effects?"***

In order to answer the fourth research sub-question the application of construction logistics in a real case will be studied. The new Delft train station and City Hall case will illustrate the way that a construction logistic analysis during the design stage can create the space so as to enhance the project efficiency while at the same time reducing the negative external effects.

5. ***"What kind of recommendations and guidelines can be given for the case of the new Delft train station and City Hall?"***

In order to answer the fifth research sub-question the empirical findings from the fourth research question will be analyzed with respect to the theoretical findings from the first three research sub-questions in order to come up with recommendations and guidelines regarding construction logistics that can be given for the case of the new Delft train station and City Hall.

Table 1.1 presents the five research sub-questions and the compatible research approach that will be used in order to answer each one of them. The research approach is used not only to guide the answering of the research sub-questions but also to structure this report. Each chapter will answer the related research sub-question through the relevant research approach, before answering the main research question at the final chapter of this report.

Research Sub-question	Research approach
RQ1: *"What is the domain into which construction logistics are applied?"*	Literature study on the domain of the construction industry, international scientific journals mostly construction management oriented
RQ2: *"What are the most important characteristics of logistics on building construction projects that are connected with the direction of this research?"*	Literature study of scientific journals, handbooks and related articles on supply chain management and logistics in construction. Input both from supply chain management and project management literature.
RQ3: *"What is the field of construction logistics that needs to be taken into account for a building construction site in a residential area?"*	Literature study of industry reports about the practical application of construction logistics, semi-structured interviews with experts on the area of construction logistics from TNO
RQ4: *"How can construction logistics apply to the case of the new Delft train station and City Hall, in order to enhance the project efficiency and reduce the negative external effects?"*	Case study on the new Delft train station and City Hall. Unstructured interviews with architects, engineers and managers involved with the project and analysis of relevant documentation provided by OBS such as drawings, material estimation and technical reports.
RQ5: *"What kind of recommendations and guidelines can be given for the case of the new Delft train station and City Hall?"*	Analysis of case study findings. Interview with expert from the consultancy company of the project to validate the results of the research before the conclusions and recommendations are drawn.

Table 1-1: Research sub-questions and research approach

Once the basic research objective has been derived and the relevant research areas and approaches have been identified, the question is how this research is going to proceed. In this respect, *chapter 2* introduces the Research framework, or else the definition of the character of this research and the description of the steps that need to be followed towards its fulfillment. On this basis, the located research problem can be systematically confronted and satisfy the research objective by answering the research questions.

1.6. Research Design

Following the definition and description of the research strategy and methods, the research design which will guide the research towards its finalization will be presented and analyzed. In *figure 1.7* the research design is demonstrated. The five phases presented on the research design will be conducted in a sequential way.

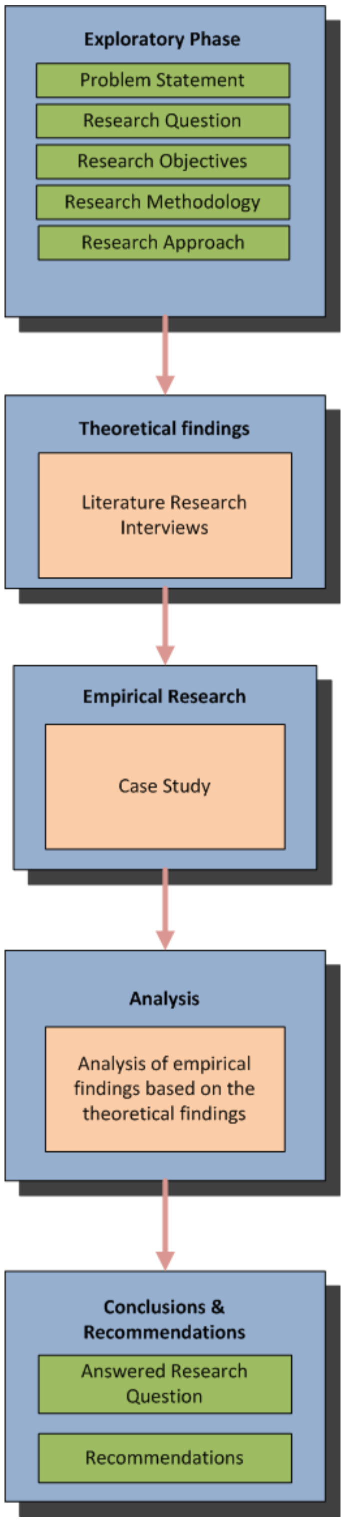

Figure 1-7: Research Design

Exploratory phase: During the exploratory phase, the research problem is formulated. Additionally, the research question, objectives, approach and methodology are designed.

Theoretical findings: During this phase, the theoretical background that will assist the empirical research is being developed, through the study of literature and interviews with experts.

Empirical research: During this phase, the case study is conducted, with the input from the theoretical findings and the experts involved in the case.

Analysis: During this phase, the analysis of the empirical findings from the case study will be conducted. The results of the analysis will be reflected based on the theoretical findings.

Conclusions & Recommendations: During the final phase of the research the main research question will be answered and conclusions and recommendation will finalize the research.

1.7. ACADEMIC AND MANAGERIAL CONTRIBUTION

The research aims to address a gap in the extant body of literature following a potential successful incorporation of the examined concepts in a real case. From the review of the relevant literature, the author realized that although there are several examples of project management in the supply chain management literature and accordingly, supply chain management examples in the construction management journals there is still not a clear body of literature for construction supply chain management and logistics. There are signs of increasing publications on this field during the last years with most significant examples the publish of the " *Construction Supply Chain Management Handbook*" by William J. O'Brien, Carlos T. Formoso, Vrijhoef Ruben, and Kerry Londonn in 2008, the "*Construction Supply Chain Management (Innovation in the Built Environment)*" by Barbara E. Fassler Walvoord in 2009, and the "*Managing Construction Logistics*" by Gary Sullivan, Stephen Barthorpe, and Stephen Robbins in 2010 (Amazon.com: Construction Logistics - Books, 2010). It is expected that in the years to come, the field of construction supply chain management and logistics will develop into a noteworthy scientific area.

Furthermore, this research is rich in its practical and managerial implications. The significance of the research is multi-aspect and can be better observed if decomposed in three main categories of relevance, them being academic, managerial and social relevance.

With respect to the ***academic contribution*** of this research, it can be found on the integration of expertise and research efforts aiming to result in the advancement of knowledge on the field of Construction Supply Chain Management and Logistics, and it may resolve theoretical questions such as whether construction logistics and project efficiency have a direct link or a mediated relationship. Bridging this scientific gap can lead in substantial conclusions and valuable practical applications.

Furthermore, the ***managerial contribution*** of this research can be seen on the number of managerial terms intervening in this endeavor. Over the last two decades, most manufacturing firms have recognized supply chain management (SCM) as a new way of doing business. The implementation of this new approach was a consequence of various changes in manufacturing environments, such as development of information technology (Internet), globalization, and sophisticated customers who demand increasing product variety, lower cost, better quality, and faster response. Competition is shifting from firm versus firm to supply chain (SC) versus SC (Vonderembse, Uppal, Huang, & Dismukes, 2006; Min & Zhou, 2002). The abovementioned lead to the conclusion that construction logistics is an interesting area for construction project managers who are seeking for higher project efficiency. The influence that logistics have on construction projects can help them understand better their projects and accordingly their planning procedure.

Finally, this research can be also seen as ***socially relevant***, since it investigates how the project efficiency can be improved while at the same time minimizing negative external effects. Sustainable logistic solutions and practices can dramatically reduce the resources used, leading in major economic gains. Reduced transportation utilization can decrease consumption of fuels and traffic congestions, bringing by this way environmental pollution down and fostering the elevation of urban living standards.

1.8.REPORT OUTLINE

This thesis report consists of 8 chapters and the report outline is depicted in *figure 1.8*. Following the introductory *chapter 1*, *chapter 2* presents the research framework and its underlying principles. The choices regarding the type of research, the research methodology and the case selection are presented. The scientific credibility and the testing of the research design, which are considered by the author quite important for the proper fulfillment of this research, and the research limitations, finalize this chapter.

Chapter 3 is the commencement of the theoretical findings, which go on until *chapter 5*. The chapter introduces the reader to the domain that construction logistics are applied, by describing the current economic situation and the main reasons that cause project inefficiencies through the increased cost of failure. Subsequently, the concept of construction project management is presented so as to familiarize the reader with terms that are used quite often in this research and have a close relationship with construction logistics. The chapter is finalized with a description of the construction industry peculiarities so that the reader can understand the difference of construction industry in comparison with other industries where the concept of logistics is leading the development and the growth of the industry, and with a presentation of the different forms of procurement procedures in construction which determine the relationships of the parties involved in a construction project.

Chapter 4 describes the origins and development of logistics as a specific discipline in the construction industry. Subsequently, the definition of construction logistics, the processes involved and the general characteristics which are different in comparison with logistics in other industries are discussed. Afterwards, seminal industry reports and reviews on the construction industry are examined in order to present the influence that construction logistics can have on the project efficiency by the proper or improper application of a logistics analysis on a construction project and the influence that the actors involved in the project can have in order to ensure the proper consideration of logistic issues during a construction project is debated. The chapter is completed with a presentation of the construction related external effects that are influenced by construction logistics.

Chapter 5 is an illustration of the practical applications of construction logistics. The chapter begins with a demonstration of the basic logistic tasks according to the project phase and continues with a description about what needs to be taken into account for a logistic plan and what is included in such a plan for a construction site. Subsequently, a range of strategies that can be applied in order to improve the logistics of a construction project are presented followed by an analysis about the extent that project efficiency and negative external effects are influenced by the different strategies. The chapter is completed with a discussion about the most important areas that should be analyzed for the proper development of a logistics plan for a construction site.

Chapter 6 presents the empirical findings from the case study of the new Delft train station and City Hall. The chapter familiarizes the reader with the Delft case, by presenting information about the project and its organization and by identifying the scope of the project. Subsequently, the building design is being assessed and the main risks that may lead to negative external effects are being analyzed. The chapter is completed with the assessment of the building structure in order to get deeper insight on the actual structure of the building which is the part that construction logistics have a big influence during the design phase.

Chapter 7 analyzes the empirical findings from the case study, identifies the key areas for improvement. Several solutions for the case are presented and analyzed in reflection with the theoretical findings. This chapter finalizes the case that has been studied for the conduction of this research through the analysis of the empirical findings that have been identified in *chapter 6*. Initially, the areas of consideration for the progress of the construction logistics analysis are introduced. Subsequently, each area is being analyzed and recommendations and guidelines for the development of a logistics plan for the construction site are presented. At the end, two integrated approaches for the logistics plan of the new Delft train station and City Hall are demonstrated.

Finally, *chapter 8* presents the conclusions of the research and answers the main research question. Besides that, recommendations are given with respect to the concept and to further research about the topic.

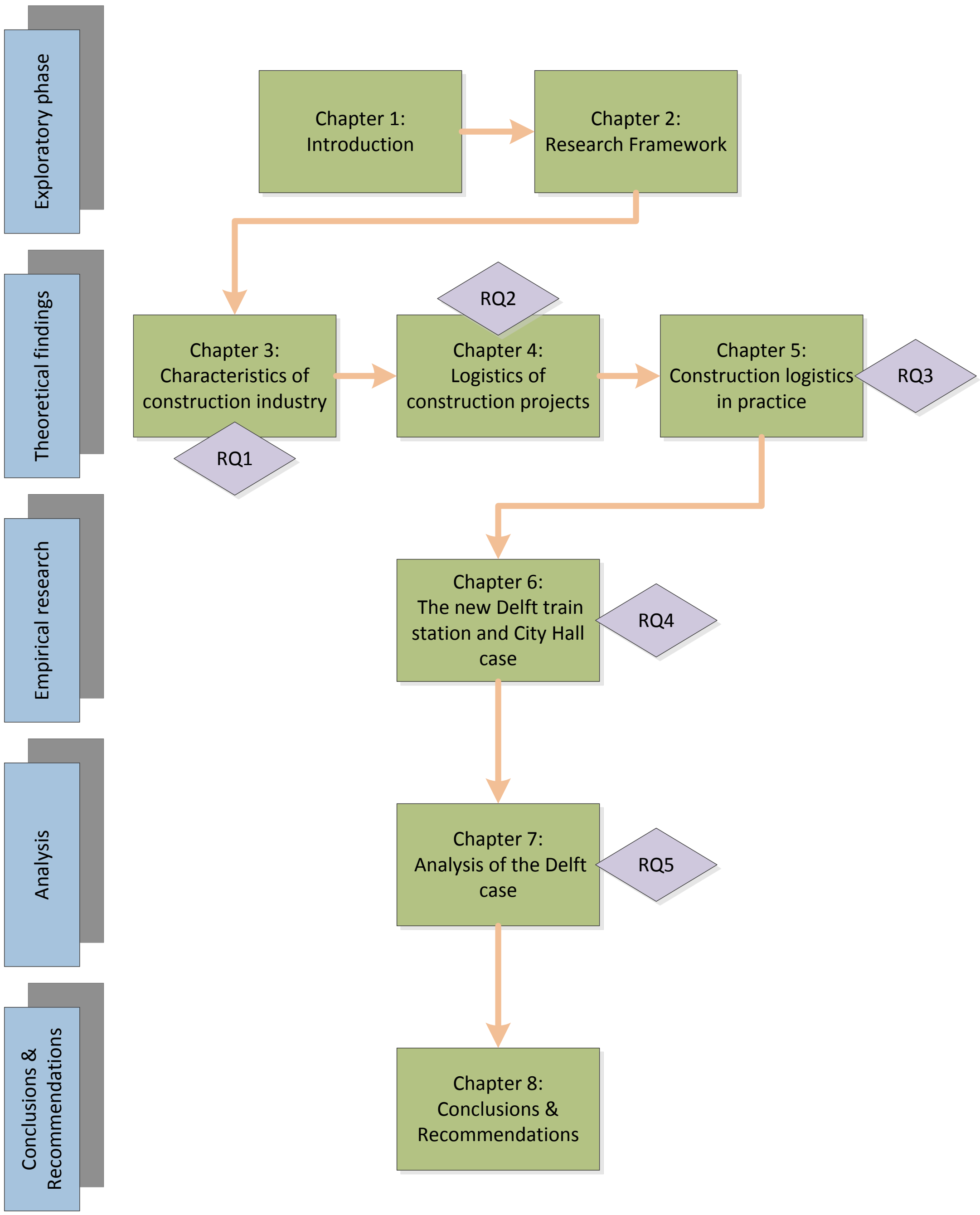

Figure 1-8: Report outline

1.9. Summary & Sub-conclusions

In this section, a first introduction to the orientation of this research is given. A quick overview of the construction industry domain illustrates the role of construction logistics, which is the core element of this research. On this basis the research problem is formulated, followed by research scope, the research objective and research questions. The section is completed with three complementary paragraphs regarding the research design, the contribution of the research and the report outline. The research framework chapter that follows is used to set further the course of this research. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

<table>
<tr><th>Topic</th><th>Description</th></tr>
<tr><td>Research Problem</td><td>Construction industry faces increasing problems of project inefficiencies. In addition cities face increasing disturbances from construction sites which result to several negative external effects in the local environment. Construction logistics carefully applied on and to a construction site may lead to improvements in project efficiencies and minimize the risks for negative external effects in the local environment.</td></tr>
<tr><td>Research Objective</td><td>1. a) To explore the contribution of Construction Logistics towards the enhancement of construction project efficiency, by analyzing a real case of a building construction in a residential area in the Netherlands
b) To explore the contribution of Construction Logistics towards the minimization of the negative external effects in the local environment of a construction project
c) To explore the trade-offs involved in the relationship between the enhancement of construction project efficiency and minimization of negative external effects
2. To present guidelines and recommendations to OBS with respect to the construction logistics of the new Delft train station and City Hall, through the development of a logistics plan for the construction site</td></tr>
<tr><td>Research Questions</td><td>Main Question:
“How can construction logistics enhance buildings construction project efficiency in residential areas, while at the same time minimizing negative external effects in the local environment?”
Sub-questions:
1. What is the domain into which construction logistics are applied?
2. What are the most important characteristics of logistics on building construction projects that are connected with the direction of this research?
3. What is the field of construction logistics that needs to be taken into account for a building construction site in a residential area?
4. How can construction logistics apply to the case of the new Delft train station and City Hall, in order to enhance the project efficiency and reduce the negative external effects?
5. What kind of recommendations and guidelines can be given for the case of the new Delft train station and City Hall?</td></tr>
<tr><td>Potential Significance</td><td>This research is all scientifically, managerially and socially relevant.</td></tr>
</table>

Table 1-2: Summarizing Key Elements of the Chapter

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2. RESEARCH FRAMEWORK

2.1. INTRODUCTION

The purpose of this chapter is to establish the research methodology and research methods that are used towards the conduction of the qualitative research that has been previously introduced. The previous chapter set the direction and scope of this research, and recognized the gaps that should be bridged. It is the object of this section now to build upon the described research orientation and establish a scientific and systematic qualitative manner to assess the selected research topic.

Initially, the type of research and the reasons why this type of research fits the character of this endeavor are being defined. In that way, it is constructively justified why the specific research approach has been adopted, and it becomes clear how the selected research elements connect to each other. The next step focuses on the research methodology, which coincides with the adoption of the triangulation method. The triangulation method is defined and it becomes clear how it contributes to the quality of the research. Subsequently, the research strategy and the research methods are chosen, defined and described. On the basis of the type of research and the research methodology, a case study is chosen. The research involves three research methods – unstructured interviews, semi-structured interviews and archived data. Finally, the process that will be used towards the evaluation of the results and the limitations of this research are described.

2.2. TYPE OF RESEARCH

The research question and aim of this research are of an explorative nature. The aim of the research is the investigation of possible causes or influencing factors for attributes or objects. The research investigates how the concept of construction logistics influences the construction project efficiency and the negative external effects on the local environment of the construction projects. The following table presents the explorative research elements that will guide the reader through the research methodology (Velde, Jansen, & Anderson, 2007).

Research Type	Research Question	Research Aim	Research Theory	Research Strategies	Data Collection
Explorative	How? Why?	Development of Hypothesis	Not Well-Established	Qualitative (Case Studies or Theoretical Research)	Mostly Interviews (Unstructured & Semi-structured

Table 2-1: Explorative research elements

It has already been mentioned why the type of the research is explorative, an argument that is confirmed by the main research question of this research which begins with a "How". The output of this research, or the research aim, also fits the described research type, since it consists of advisory guidelines and recommendations for the logistic plan of a real construction project.

Furthermore, as it has been claimed in the introduction and is shown in the 'Research Problem' *section 1.2*, the research theory is not clear and well-established. Therefore, a case study research strategy is more than justified. In this respect, interviews, unstructured and semi-structured, is an appropriate data collection method.

Both quantitative and qualitative data will be gathered for this research. The quantitative data will help to determine what kinds of problems are actually present in construction projects regarding the logistics, the project efficiency and the negative external effects, while the qualitative data will help to determine the reason that these problems occur, and help to develop some logistic strategies that can be used to deal with these problems.

It has been shown that the research conducted here is, indeed, of explorative nature. Thus, the design of this research should comply with the corresponding theory about explorative research. The next step now is to define and describe the adopted research methodology, according to which the data collection methods are selected later on.

2.3. Research Methodology

As it was described in the introduction, the second step of this section emphasizes on the adopted research methodology, which coincides with the triangulation method. Denzin (2006) has identified several types of triangulation. One type involves the convergence of multiple data sources. This approach of triangulation will be used for this research. In other words, triangulation method aims to increase the confidence of subsequent findings through cross examination of a single research topic.

A multiple confrontation of the researched topic is suggested instead of approaching the topic through a single research channel. Thus, the level of confidence to the result of the research is considered to enhance, as a result of diminishing the limitations of one research method by using the advantages of another.

This conclusion justifies the selection of the triangulation method within the explorative context of this research, as it will be used as a main direction of the research in order to answer the main research question.

With respect to the characteristics and dimensions of the triangulation method that are used in this research, they are described later on this section. These include the definition of the research strategy and research methods and all the other elements that are considered by the author critical when it comes to increasing the trustworthiness of this research. As regards the research strategy in use, according to Yin (2003) the case study is known as a triangulated research strategy.

Triangulation encourages a researcher to collect information from multiple sources but aims at corroborating the same fact or phenomenon. In the case study methodology, triangulation could be done using multiple sources of data (Yin, 2003). As regards the research methods in use, they target specific data sources that have been chosen as essential pieces of the triangulation puzzle that is constructed here around the topic of the influence of Construction Logistics on the construction project efficiency and negative external effects. These data sources are assumed to be satisfyingly covered by relevant articles and other literature sources, and managers that have experience on the topic. Finally, specific research methods are used to extract the required data from the relevant data process. This process is depicted in *table 2.2* where the data collection methods are presented.

Data sources	Covered by	Research Method
Expert knowledge	Experienced project managers that have dealt with the issue of construction logistics in construction projects	Semi-structured interviews
Practical experience	Project managers that are involved with the case that is going to be studied	Unstructured interviews
Scientific background of construction logistics, project efficiency and negative external effects	Articles and other literature sources that are directly or indirectly related with the concept of construction logistics, project efficiency and negative external effects	Archived data

Table 2-2: Data collection process

With regard to the research methods that are adopted in this research, three different types are selected: unstructured, semi-structured interviews and archived data. In the context of this research, semi-structured interviews are being used initially to expand the theory that is introduced in the next chapter, and is comprising of the relevant literature regarding the concepts that are being discussed in the research, and to establish the practical application of these concepts. Afterwards, unstructured interviews along with the investigation of archived data are being used to conduct the case study. *Table 2.3* presents the list of interviews that were conducted for the completion of this research.

Name	Company	Position	Type of interview	Date
Bart Luiten	TNO	Head of department at TNO Bouw en Ondergrond	Semi-structured	7/6/2010
Jasper Tonk	Mecanoo	Architect / Project leader	Unstructured	9/6/2010
Nienke Maas	TNO	Senior Advisor spatial development	Semi-structured	11/6/2010
Thibald Holscher	OBS	Project Leader	Unstructured	18/6/2010
Bas van der Moolen	TNO	Consultant at TNO Mobility & Logistics	Semi-structured	22/6/2010
Carla Scheffer	ABT	Chief structural engineer	Unstructured	12/7/2010
Maarten van Uem	ABT	Risk Manager	Unstructured	14/7/2010
Robert Huisman	OBS	Risk Manager	Unstructured	23/9/2010

Table 2-3: List of interviews

2.4. Research Strategy – Case Study

According to Yin (2003), case studies are preferred when ”how-and-why questions” are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within a real-life context. A case study is a research focusing on one or a few occurrences that are analyzed into detail. Case study is the most common form of qualitative research strategy; however there are also quantitative forms of case studies. Different forms of case studies are divided into (Yin, 2003):

- Exploratory case studies (formulating hypothesis)
- Explanatory case studies (either developing or testing theory)
- Descriptive case studies (giving examples and illustrating)

One of the benefits of case studies is that the researcher is studying real cases and is able to collect a lot of information and knowledge from a real situation.

When designing case studies the researcher needs to decide whether to use a single case study or a multiple case study. Single case studies are used to confirm or challenge a theory or as a representative or typical case. As Yin (2003) points out, one single case study may well meet all conditions required to confirm, challenge or even extend already existing theory.

> **Note:** *The chosen case study is an* ***exploratory single case study*** *of a real construction project and will be described in the next paragraph. The choice of a single case study is justified due to the fact that this research is being conducted in cooperation and with the support of Ontwikkelingsbedrijf Spoorzone Delft B.V., which has a specific interest on exploring how construction logistics can be applied in their project, and due to time restrictions which made impossible the examination of alternative cases.*

2.5. Case Study of the new Delft train station and City Hall

Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS) was established by the municipality of Delft in 2007 in order to implement the project “Spoorzone Delft”. OBS has the task to implement the agreements established with the stakeholders of the project, in the field of urban development and the hub of public transport. The case that will be investigated is the construction of the new Delft train station and City Hall.

OBS is currently at the phase where it finalizes the designs for the new building and takes into account all the possible solutions that will make the New City Hall a reality. The initial plan was to build the New City Hall in two phases equally distributed. Due to the fact that the building is positioned on top of the construction of the rail tunnel, OBS is trying to make the project more independent of the planning and schedule of the new railway tunnel project that is running underneath the building.

In order to achieve this, the first phase of the project needs to be extended at such level where the building will be able to start housing people, because the second phase will be possible only after the demolition of the existing railway. There are several problems that need to be dealt with due to the large complexity of the project and the schedules. The construction area keeps changing and this creates a lot of problems related with the logistics. Moreover, many contractors are involved in the project and this creates more congestion on the construction site. The company is interested to investigate the optimum construction sequence, given a specific time schedule for the completion of the project and considering the total logistics of the project, and with an orientation towards the minimization of negative external effects on the city of Delft. In addition, the company believes that part of this research can support the procurement process in such a way that future contractors can look upon it as a support reference model for the future logistic plan of the construction site.

Case Study Approach

The Case Study will be conducted in cooperation with OBS and more specifically with the company that is currently involved with the development of the logistic plan, ABT, and under the supervision of Mr. Robert Gips who is responsible for the development of a logistics plan for the construction site.

The proposed approach for the case study represents the steps needed to obtain the data required so as to develop a logistic plan and is based on the practical experience of the construction consultancy company and on theoretical findings that will be presented in the following chapters. The approach is the analytical model that will be followed for the conduction of the case study and is presented in the following steps:

- ***Analysis of Project Planning:*** Assessment of the current state of the project planning. Identification of the Project Scope and determination of the appropriate methods for completing the project. Gathering of the relative documents, drawings and specifications.
- ***Assessment of the Building Design:*** Assessment of the current building design. For this step, the architectural drawings will be assessed in order to get deeper insight on the actual project, the volume of the building, the main elements and the most important materials that will be used. Interviews with the involved architects will be conducted during this step.
- ***Analysis of the main risks:*** Analysis of the main risks of the new Delft City Hall project and the negative external effects that can occur on the local environment. This step is very important in order to get insight about the influence the logistics can have on these risks. Interviews with the risk managers involved with the project from the side of the municipality and the engineering company will be conducted during this step.
- ***Assessment of the Building Structure:*** For this step, the structural drawings will be assessed in order to get deeper insight on the actual structure of the building which is the part that construction logistics can have a big influence during the design phase for the potential project efficiency. From the assessment of the building structure, key areas of improvement can be noticed both from a design point of view and from a logistical point of view. Interviews with the involved structural engineers will be conducted during this step.
- ***Identification of key areas of improvement for the assembling process:*** This step involves the identification of key areas of improvement. After the assessment of the structure, the construction logistics can influence the assembling process of the large construction elements, the ways of transportation, the number of elements, etc., while at the same time taking into account the risks for negative external effects.
- ***Proposal of an Optimized Plan:*** A new optimized Logistic Plan will be proposed at the end.

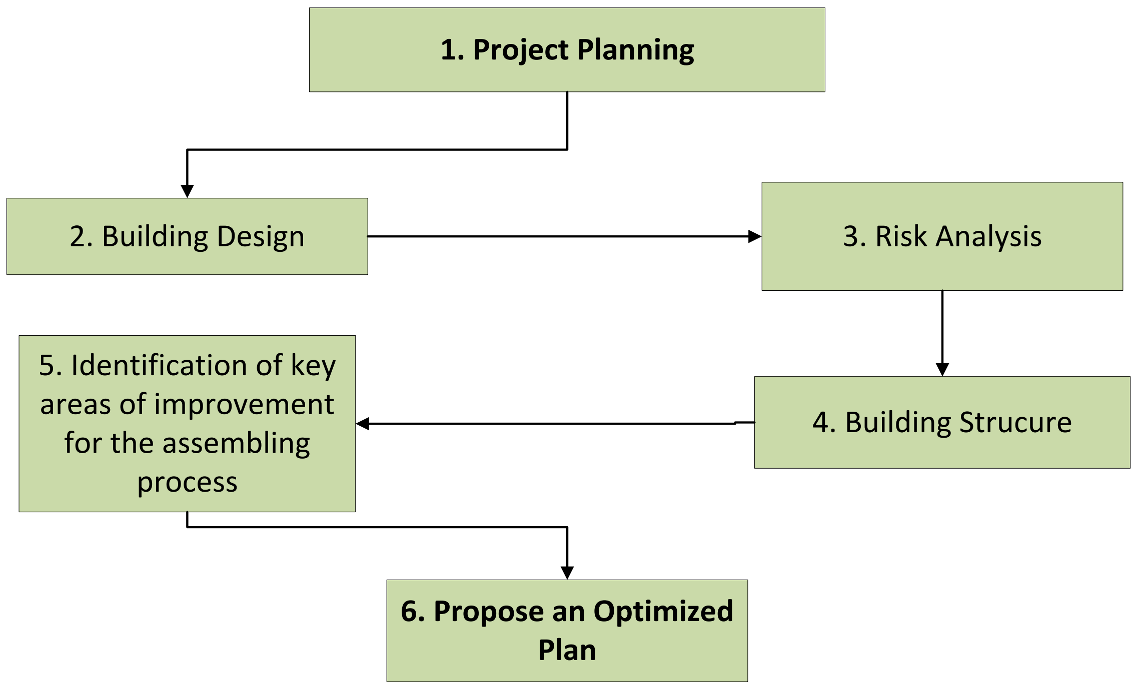

Figure 2-1: Analytical model

2.6.Scientific Credibility – *Testing of the Research Design*

According to Yin (2003) the development of case studies designs needs to maximize four conditions related to design quality: (a) *construct validity*, (b) *internal validity*, (c) *external validity*, and (d) *reliability*.

Validity can generally be defined as "*the extent to which an instrument measures what you want to measure; or the extent to which a research strategy results in the type of conclusions that you want to draw ('reality value')*" (Velde, Jansen, & Anderson, 2007).

Construct validity

It refers to using measuring methods that captures the problem in a correct way. The measures should be able to collect information that captures information related to the objective of the research. Construct validity is especially problematic in case study research. It has been a source of criticism because of potential investigator subjectivity. Yin (2003) proposed three remedies to counteract this: using multiple sources of evidence, establishing a chain of evidence, and having a draft case study report reviewed by key informants.

In order to ensure high construct validity a number of different sources have been used during the data collection phase, as it has been described through the triangulation process.

Internal validity

It refers to explaining relations between variables, to analyze cause and effects e.g. if a change of variable y is a result from variable x. If the researcher does not take into account that a second variable z could be the cause of the change in y, there is low internal validity. Considering internal validity is only relevant when conducting explanatory case studies (Yin, 2003).

It is only a concern for causal case studies (explanatory case studies) so it does not apply to the current research.

External Validity

It refers to generalization of a case study results to other cases. If the findings of a study can be transferred and applied to a similar case, there is a high external validity. With case studies, generalization is problematic, because it is not certain the results from the case study could be transferred and applied to another case. The results might be case specific. However, a clear distinction should be made between statistical and analytical generalization (results from a case study is generalized on a broader theory), which makes it possible to generalize even when using case studies (Yin, 2003).

As Yin (2003) *suggests there might be difficulties generalizing findings from case studies to other areas of research. One possible solution is to use theory in single case studies as can be seen in table 2.4. The problem lies in the very notion of generalizing to other case studies. Instead a researcher should try to generalize findings to "theory" analogous to the way a scientist generalizes from experimental results to theory. The results from this case study should be able to be generalized to other construction cases with similar types of space constraints and congestion.*

Reliability

The objective of reliability is to make sure that if a later investigator follows the same procedures as described by an earlier investigator and conducted the same case study all over again, the later investigator should arrive at the same findings and conclusions. This places requirements regarding the documentation and descriptions on how the study was done in the first place. The goal of reliability is to minimize the errors and biases in a study. Two ways of overcoming reliability issues are the use of protocols and databases (Yin, 2003).

If a similar study would be conducted once again with the same sources the results would probably be the same. The chance of being able to replicate the study is high since there will be thorough documentation on how data was collected and analyzed. The boundaries of the case study were also specified into the detail. This leads the author of the thesis to believe that the reliability of the study is high.

Table 2.4 presents suitable tactics for ensuring scientific credibility in different phases of research.

TESTS	CASE STUDY TACTIC	Phase of research in which tactic occurs
Construct Validity	• Use of multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection Composition
Internal Validity	• Do pattern-matching • Do explanation building • Address rival explanations • Use logic models	Data analysis Data analysis Data analysis Data analysis
External Validity	• Use theory in single-case studies • Use replication logic on multiple-case studies	Research design Research design
Reliability	• Use case study protocol • Develop case study database	Data collection Data collection

Table 2-4: Case study tactics for four design tests (Yin, 2003)

2.7. Research Limitations

As any type of research, this endeavor presents some limitations; it has been based on some assumptions and is framed by a number of constraints that affect the magnitude of its impact. Whether this affect is major or minor, this is to be decided individually, by the actual reader. The purpose of this paragraph is to recognize and enlist these limitations, so as to declare knowledge of their existence and, thereby, reduce their effect.

In this regard, the main issue constraining the impact of this research is the nature of the research. Although it contains both qualitative and quantitative data gathering, the essence of the research is mostly qualitative. In other words, it is not always possible in qualitative terms to capture the essence of the problem and provide tangible solutions or recommendations. There is a possibility at the end to be left with a lot of unrelated data which should not be forsaken and extra attention is required towards this directions. In order to mitigate this limitation, a systematic research approach has been chosen including a case study execution. The limitations of the case study are being described in the previous paragraph and regards issues of reliability and validity. Moreover, all single case research designs involve the risk of focusing on unique conditions and events, rather than on general concepts and trends (Brady & Collier, 2004). The best way to avoid this threat is to analyze additional cases. A carefully developed research design is considered sufficient to direct the collection, organization, analysis and synthesis of data towards valuable conclusions and tangible solutions.

Another limitation that arises is the way to evaluate the final results of this research. Apparently, apart from common sense, the point of view of the company that is being involved with this research would be of substantial contribution in this evaluation process. In this respect, ir Robert Gips, consulting engineer and head of the project management department of ABT –the company that is being involved with the design of the new Delft City Hall, is an ideal prospect for a number of reasons. First of all, he is an experienced highly-positioned engineer in a management position; secondly, he has experience of several construction projects since he has been working in the construction industry for many years and has dealt with several complex construction projects, and he has a clear understanding of the problems and solutions related with construction logistics and thirdly he is familiar with this research approach and its purpose, as he is involved in the graduation committee as the external supervisor of this thesis. The evaluation process is quite straightforward. Following the completion of the data collection and the analysis of the data, the derived observations and conclusions are being discussed with the external supervisor who judges the completeness and potential of the recommendations and solutions respectively. His remarks and comments are recorded and used towards the assessment of the research results and the enhancement of the research quality.

A final issue limiting the effectiveness of this research is the overall context within which this research is taking place. That is, as an MSc dissertation, this research is seriously limited by time and budget constraints. Along with the unpredictable and hard to schedule nature of explorative research, there could be a problem created at this point. However, dedicated work and well-structured planning are considered to be sufficient to confront this limitation.

2.8. Summary & Sub-conclusions

This chapter is occupied with the creation of a research framework, able to guide and guarantee the conduction of a state-of-the-art research. In this respect, the type of research and the research methodology is defined and it is shown how much compatible it is with the nature of this research. Furthermore, the research strategy is described and the selection of case study along with the case study approach is illustrated in order to justify this selection. Moreover, the research methods used in the adopted triangulation scheme are depicted. Subsequently, extra attention is placed on the scientific credibility and the testing of research design. The chapter is completed with an analysis of the limitations characterizing this research and the recognition of the corresponding mitigators. This chapter finalizes the exploratory phase of the research. The next chapter is the initiation of the theoretical findings regarding the research domain which goes on until *chapter 5*. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

Topic	Description
Type of Research	The type of this research is clearly explorative, with a general research question beginning with a “How” and with a corresponding research aim to produce advisory guidelines, over an unclear and not well-established theory.
Research Methodology	Triangulation method proposes a multiple confrontation of the researched topic, so as to enhance the ability and effort of the researcher to establish credibility and trustworthiness on the qualitative results. Triangulation method will be used to answer the main research question.
Research Strategy	The chosen case study is an exploratory single case study of a real construction project and more specifically the case regards the construction of the new Delft train station and City Hall.
Research Methods	1) Unstructured interviews with experts involved with the construction of the new Delft train station and City Hall, aiming to collect expert knowledge on the application of Construction Logistics 2) Semi-structured interviews with logistics experts, aiming to collect theoretical knowledge on Construction Logistics 3) Archived data from the literature, aiming to collect scientific input and theoretical knowledge on and peripherally to Construction Logistics
Research Evaluation	It mainly relies on the experience of a construction logistics expert, as well as on the integrity of the research framework.
Research Limitations and Mitigators	1) Unpredictable nature of qualitative research, mitigated by systematic and constructive research approach 2) The way to evaluate the final results of this research, mitigated by the point of view of the company that is being involved with this research through the provision of an external supervisor for this research 3) Thesis research constraints, mitigated by dedicated work, well-structured planning, and careful selection of current and future research boundaries.

Table 2-5: Summarizing Key Elements of the Chapter

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3. CHARACTERISTICS OF CONSTRUCTION INDUSTRY

Following the finalization of the exploratory phase, this chapter is the commencement of the literature findings and introduces the reader to the domain of construction logistics by answering the following research sub-question: *"What is the domain into which construction logistics are applied?"*. In order to answer the above question the economic situation of the industry is presented in *section 3.1* and the main reasons that cause project inefficiencies due to increased cost of failures are presented in *section 3.2*. By this the attention of the construction industry towards methods and solutions that will enhance project efficiency is justified. Subsequently, *section 3.3* presents an introduction to construction project management and sets the foundation for the relation between project management and construction logistics. Afterwards, a presentation of the construction industry's peculiarities is depicted *in section 3.4* so that the reader can understand the different environment that construction logistics are applied in comparison with the application of logistics in other industries such as retail and manufacturing. The chapter is completed with a presentation of the different forms of procurement procedures in construction in *section 3.5*.

3.1. Economic Situation

In 2007 the civil engineering market had a production volume of €13.1 billion with a growth expectation of 2.5% for 2008 (Verster, 2009). Until then the construction market was growing in a moderate rate, before starting decreasing in 2009 and 2010 due to the financial and economic crisis. The government budgets however mainly determine the investments in the civil engineering sector. In this way, the investments are less sensitive to changes than investments in residential construction. In the long term an annual increase of around 2% is expected.

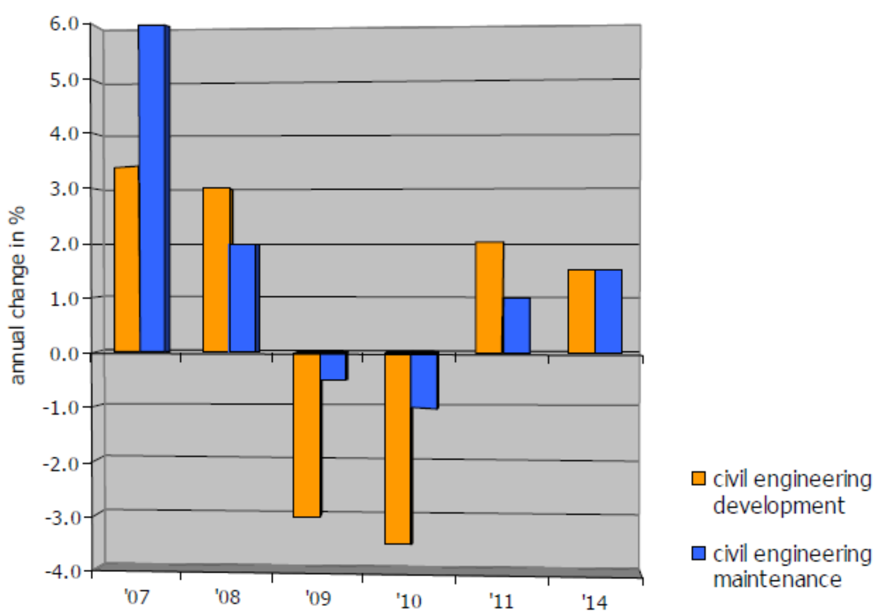


Figure 3-1: Expected production volume in Dutch Construction Market (Verster, 2009)

The three basic segments of the construction industry are building contractors, also known as *general contractors*, who construct residential, commercial, industrial, and institutional buildings; *heavy and civil-engineering contractors*, who build roads, highways, bridges, tunnels, and other similar projects; and *specialty contractors*, more familiarly known as subcontractors, who perform specific trade work such as carpentry, roofing, electrical, plumbing, heating-ventilating-air-conditioning (HVAC) work, and a host of other tasks. The 2002 U.S. Census Bureau statistics revealed that the construction industry had a total of 8.9 million wage and salary employees (Levy, 2010).

In *figure 3.2* the profit margins in the construction industry are presented. As it can be seen, the profit margins in the construction industry are traditionally low at around 3%, when in the first half of 2008 the mean profit margin of the AEX-companies was an annual 7.7%. This happens because of the capital intensive nature of construction and the high level of price competition in the civil engineering market which puts enormous pressure on prices. In construction industry firms are dependent on orders to secure the continuity of the business because they cannot supply from stock. Therefore, contractor companies regularly have to lower their price under the cost level to secure turnover so that labor force and auxiliaries at least generate some money (Verster, 2009).

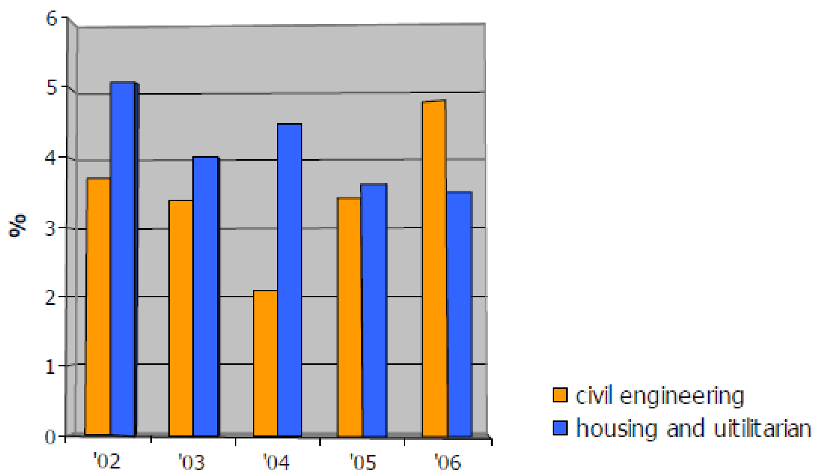


Figure 3-2: Profit margins in Construction Industry

3.2. COST OF FAILURE IN CONSTRUCTION

Dutch construction industry is facing severe problems with failure costs of projects (Rijt, Hompes, & Santema, 2009). Failure costs are quality costs that are associated with products or services that have been found not to conform to requirements, as well as all related costs. These quality costs can be classified as either costs of conformance which include training, indoctrination, verification, validation, testing inspection, maintenance and audits, or non-conformance costs which include rework, material waste and warranty repairs. In construction however, the traditional prevention-appraisal-failure (PAF) model is the most widely accepted method so as to determine quality costs. The PAF model classifies costs as follows (Love & Irani, 2003):

Prevention: money spent or invested in order to prevent or reduce defects or errors

Appraisal: the recognition of defects or errors by measuring conformity to the required level of quality through issued architectural and structural drawings, work in progress, and incoming and completed material inspection

Internal failures: caused by scrapping or reworking malfunctioning products or compensation for delays in delivery

External failures: caused after the delivery of a product to the customer and include cost of repairs, returns, dealing with complaints, and compensation

There is a growing awareness that the old methods used in the industry needs to be replaced by new innovative and effective methods that will restore trust and bilateral relationships between constructors, their suppliers and their clients, especially after the events of 2002 of the Dutch construction collusion. In 2001, the cost of failure rate was 7.7% of the total turnover, before increasing to 10.3% in 2005 (USP, 2007). USP Marketing Consultancy states that this percentage has risen to 11.4% in 2008 (USP, 2008). Several reasons for the cost of failure are presented in *table 3.1* (USP, 2007).

	Total	Architect & Engineering	Contractors (General & Sub)	Clients
Lack of communication and information transfer	21%	20%	26%	12%
During design phase inadequate attention for feasibility	20%	19%	22%	19%
Delivering quality to end user is not the highest priority	10%	15%	5%	14%
Requirements list unsatisfactory: lot of changes needed	9%	13%	7%	9%
No application of experience previous projects	6%	4%	7%	7%
Tender model not aimed at integral process procedure	5%	6%	4%	6%
Appointments not followed	5%	3%	6%	6%
Information behind on schedule	4%	4%	6%	2%
No synchronization between architecture & installation	4%	6%	3%	3%
Licenses not on time	4%	3%	2%	7%
Contract unclear and incomplete	2%	0%	2%	2%
Lack of logistic communication during realization	1%	1%	1%	2%
Other, namely	3%	3%	3%	2%
Don't know	7%	5%	7%	10%

Table 3-1: Reasons for cost of failure in construction (USP, 2007)

The three main reasons for the costs of failure are the lack of communication and information transfer, inadequate attention for feasibility during design phase and the delivery of quality to end user as not being the highest priority. Lack of communication and information transfer between the project participants may result on high costs of internal and external failures, insufficient consideration for feasibility during the design phase may result on high prevention and appraisal costs, while the lack of attention towards the quality that will be delivered to the end user may result on high compensation fees and complaints. To sum up, all these reasons highlight the current state in constructions, where the actors involved are not working together for the benefit of mutual gain to finish projects on time and within budget for a reasonable price (Rijt, Hompes, & Santema, 2009).

3.3.Introduction to Construction Project Management

Project management is the application of knowledge, skills, tools and techniques so as the project activities to meet the project requirements. A project is a "*temporary endeavor undertaken to create a unique product, service, or result*" (PMI, 2004). Project management is accomplished through the application and integration of the project management processes of initiating, planning, executing, monitoring and controlling, and closing. It includes the identification of requirements, establishment of clear and achievable objective, balancing the competing demands for quality, scope, time and cost, and adapting the specifications, plans, and approach to the different concerns and expectations of the various stakeholders.

The theory of project management cannot be bounded into a unified theoretical basis due to its multidisciplinary nature. Even though it has formed as a distinct research field, there is no universal generally accepted definition of project management. Several disciplines where Project Management is being applied and developed have been identified. These disciplines include such areas as Operation Management, Organizational Behavior, Information Technology, Engineering and Construction, Strategy/Integration, Project Finance and Accounting, and Quality and Management (Filippov & Mooi, 2009). Project Management principles are not analyzed further as they are out of the scope of this research. The following paragraphs illustrate some points of concern regarding project management in construction. Construction project management and logistics are two areas that are dependent on each other for the proper execution of a construction project and its principles are guiding the whole research.

As it can be noticed, construction is an area where the principles of project management apply. Following from the definition of project management, it can be stated that construction project management is "*the application of knowledge, skills, tools and techniques so as the construction project activities to meet the project requirements*". In construction terms this means that the project should be completed on time, within the specified budget and with the quality level expected achieved. Moreover, it can be added that the construction project should be met without any conflicts arising between the stakeholders of the project but also the actors involved in the local environment such as citizens, organizations, etc.

The Project Management Institute (PMI, 2004)recognizes several project management processes such as project scope management, time management, risk management, etc. that apply throughout the whole life cycle of a project. Moreover it recognizes the understanding of the project environment as an important area of expertise in the pursuit of the proper execution of the project. All projects are planned and implemented in a social, economical and environmental context and have intended and unintended positive or negative impacts. The connection between project management and logistics analysis is starting to become more and more obvious and will become more explicit in the following chapters of this report. Logistics processes as project management processes are applied throughout the whole life cycle of the project and are directly influenced by or influence the local environment.

Finally, Logistics and Supply Chain disciplines are considered necessary knowledge in order to be able to demonstrate the project management principles. After a brief introduction of the construction project management field, which is discussed quite often in this report, the following section gets deeper into construction related special characteristics and peculiarities that differentiate the construction industry in comparison with others.

3.4. CONSTRUCTION INDUSTRY PECULIARITIES

Construction is a specific type of project industry compared to other industries, with certain peculiarities[1] that influence the characteristics of the constructed products, ways of production and the industry itself (Vrijhoef & Koskela, 2005). Because of its peculiarities, the construction industry is often seen in a class of its own, different from manufacturing. These peculiarities are often presented as reasons when well-established and useful procedures from manufacturing are not implemented in construction. According to Koskela (1992) construction peculiarities refer especially to following features: One-of-a-kind nature of projects, site production, temporary organizations and regulatory intervention as primary peculiarities and complexity and uncertainty as secondary. These among others are the focus of the following paragraphs.

3.4.1. One-of-a-kind Projects

The one-of-a-kind nature of each building or facility is caused by differing needs and priorities of the client, by differing sites and surroundings, and by differing views of designers on the best design solutions. The materials, components and skills needed are usually the same or similar. According to Koskela (1992), from the point of view of contractors and design offices, there is often continuity and repetition; roughly similar projects and tasks recur. However, the construction supply chain is a typical engineer-to-order supply chain, with every project creating a new product or prototype. The industry can be characterized as almost pure customized, as the client initiates the entire supply chain from the concept (design) to production (realization).

In construction (especially large infrastructure) no product development takes place, except for small specialist innovations or innovations of building methods. Every project is a prototype according to the client’s wishes. One common known feature of a prototype is that it contains errors or suboptimal functioning. In construction there is usually no collection, catalogue or ‘shop window’ where clients can choose their product and suppliers do not develop product families. Finally, as construction projects are unique and not repetitive there is little marketing and branding involved.

3.4.2. Site Production

Construction is characterized by site production, a feature shared by a few other industries like mining and agriculture. Typical features that are the consequence of site production are the following:

[1] The term “peculiarities” follows from Vrijhoef & Koskela (2005). In this report, the term “peculiarities” is used, rather than terms such as constraints or problems, because peculiarities refer to characteristics that may but do not necessarily lead to constraints or problems.

- Site as a (input) resource
- Lack of shelter
- Local resources (materials, labor) and conditions (geology, environment)
- On site production infrastructure (machines, manpower)
- Space needed by production (mobile workstations)

The organization of production and the supply chains is strongly aimed at the convergence of logistics to one site, and delivery of the one-off, and often highly customized and capital intensive product to a single end customer.

3.4.3. Temporary Organization

A construction project organization is usually a temporary organization specifically designed and assembled for the purpose of the particular project. It is made up by different companies and practices, which have not necessarily worked together before, and which are tied to the project by means of varying contractual arrangements. Its temporary nature extends to the work force, which may be employed for a particular project, rather than permanently. However, these characteristics are often not caused by objective conditions, but rather are a result of managerial policy aimed at sequential execution and shopping out the various parts of the building at apparently lowest cost. The nature of relationships is very short term and the intensity of cooperation is not high (fragmented tasks, responsibilities and specialties). Sometimes hundreds of contractors, suppliers and specialists may work on the same construction site, with no one being responsible for the whole, which leads to low learning and innovation (product development). Although problem-solving takes place on project level and on-site, due to the fact of the dispersed involvement of different firms, it cannot be learned or managed in firm level. Innovations are mostly implemented on project level but not on firm level. Finally, there is no incentive for continuous improvement, as a new network of supplying parties is formed for every project and projects are directed towards cost reduction and efficiency.

3.4.4. Regulatory Intervention

The definite and detailed design solution and many work phases in a construction project are subject to checking and approval by regulatory authorities. This intervention causes uncertainty and constraints to the building process. Getting an approval for a design solution is often unpredictable. Checking by authorities during construction process can cause delays.

3.4.5. Complexity

Construction differs to production in complexity. One of the factors increasing the complexity is the number of participants in the supply chain. Picchi (2000) identified a number of actors that have influence on a construction project. These are:

- Users
- Owner
- Developer
- Real Estate companies
- Financial Agent
- City Agencies
- Designers
- Management and control company
- General Contractor
- Sub-contractors
- Materials Suppliers
- Equipment Suppliers

Additionally, the completion of construction activities is enormously interconnected in erecting a building thus making construction projects significantly complex. Bertelsen (2003) also qualify construction projects as complex and dynamic systems. This is because projects must rely on an initial design that engages a number of subassemblies with different variable specifications. Being an on-site production, the installation of those subassemblies is constrained by the interacting and overlapping activities of different contractors, making it more difficult to meet a fixed schedule. In order to meet the deadlines, the project's actors face pressures and constraints appear which cause additional costs and/or increase technical difficulties. On the contrary, manufacturing can easily manage the components because suppliers are chosen ahead of time in the design phase. Specialized facilities with suitable technology and layout ensure the reliable flow of the product. Ultimately, the supply network becomes manageable and optimized thanks to repetition (Salem, Solomon, & Genaidy, 2006).

3.4.6. Uncertainty

Construction projects are characterized by uncertainty as a direct consequence of on-site and complex production. Great uncertainties exist throughout the project and might not be avoidable, such as weather conditions, soil conditions, owner changes and exceptions erupting from the interface of multiple operations. Exceptions and planned activities are critical to the project and will both establish the project cost outcome. By comparison the manufacturing process nature allows the reduction of uncertainty thanks to the possibility to take control over the process. It is advantageous to reach a steady state as efficiency can be increased through repetition (Salem, Solomon, & Genaidy, 2006).

3.4.7. Fragmented Construction Industry

In construction, demand and supply are not synchronized. Clients specify their demand in terms of requirements and ask consulting engineers to make complete designs. Consequently, the artifact is fixed in terms of quality, planning (time) and budget (costs). Next, the brief with design specification is put out to tender. The private party who promises to execute the work with the lowest price usually gets the contract awarded. This private party, the main or general contractor, will employ its own subcontractors as well as other subcontractors named or nominated by the client.

Large infrastructure projects are complex, multi-disciplinary and with many subcontractors involved. Subcontracting is like outsourcing; the two parties are not on the same scale level in the supply chain. Every subcontractor is responsible for a subset of the specifications and the outsourcing contractor tries to pass the risks of this part of the work as much as possible to the subcontractor. Ultimately, parts of the project are subcontracted until the level of raw materials and standardized component suppliers. All subcontractors in the supply chain are squeezed out in order to lower the costs and make profit as a result of main contractors' only incentive, cost reduction. The Dutch construction industry and in a larger view the European construction sector can therefore be characterized as being fragmented or disintegrated.

The construction industry is not only fragmented in terms of the numbers of different sizes of construction firms, but also in terms of market segments, actors involved and professionalisms (specialty niches). Housing (residential), commercial (non-residential) and civil construction are the main segments that can be distinguished with limited overlap (Kok, 2007). Construction is a fragmented industry where competitive rivalry is intense and the risk of 'bad competitors' driving out 'good competitors' is high (Porter, 1985). Because of low entry barriers in fragmented industries, profits are easily competed away by low-cost suppliers undermining quality standards. One way to increase entry barriers is supply chain collaboration and partnerships. New entrants trying to enter the market are not competitive enough when they lack a network of partners, shared knowledge and synergies.

3.5. Forms of Procurement Procedures

This section elaborates on different forms of procurement procedures in construction projects. It is important to provide an overview of different forms of procurement procedures in construction because it determines the relationship between the parties involved and liabilities and responsibilities on the construction process. The term procurement procedure is frequently used and confused with different types of integrated contracts. For instance, public-private partnership (PPP) is a form of collaboration, not a type of contract. The next paragraphs will describe the kind of contracts that are used, different forms of project organization and liabilities and the most important forms of procurement.

3.5.1. Spectrum of construction contracts

For many years, the traditional form of procurement procedure, the bid & build model, dominated the relation between client and contractor. In this form of procurement the client provides the design details and the contractor builds the works in accordance with the client's design. The responsibility for the design lies with the client and the responsibility for construction lies with the contractor. The recent years the construction industry, in an attempt to deal with the problem of the separation of tasks, developed integrated forms of contract. In this kind of contracts the client is contracting more tasks to the contractor. *Figure 3.3* presents the spectrum of possible integrated contracts. In Design & Build contract form, the contractor can still be selected on lowest price but also on other criteria like duration, date of completion, traffic hindrance and quality. This selection based on more factors than only price is the basic difference from the traditional form of procurement. The responsibility of the contractor is expanded with design and possibly with the tasks of maintenance, operation and finance.

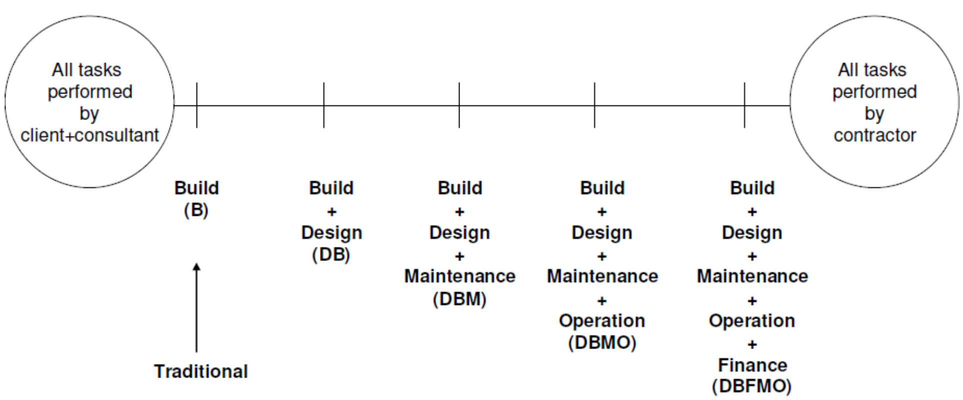


Figure 3-3: Spectrum of integrated contracts, adapted from De Ridder (2006)

3.5.2. Spectrum of liabilities

The most common types of contracts can be clustered into five categories according to the level of liabilities (ONRI, 2005). The three most important criteria recognized in order to differentiate these clusters are: the financer, the level of acceptance of responsibilities and liabilities of design/realization and the result based obligation or effort-based obligation.

The following five clusters are identified:

1. *Integrated contracts including finance*: Two party organization between the client and the full-service provider including finance, design, realization, maintenance and exploitation (BOT, DBFM, etc.)
2. *Integrated contracts for contractors*: A two party organization between client and main contractor where design and realization are integrated (DB, EPC/turnkey, etc.)
3. *Traditional contracts*: Traditional roles and responsibilities where the design and realization stages are divided (design – bid – build)
4. *Integrated engineering contracts*: Consulting engineers are being involved in more phases of the construction process. This is also known as backward integration of consulting engineers involvement (construction management)
5. *Management contracts*: Specialist consultants, consulting engineers or manager are involved in different tasks of the construction process. Disintegrated types of contracts like design management, project management, etc.

Accordingly, a ladder of liabilities is demonstrated in *figure 3.4*. Traditionally supply chains were geared towards the realization only. As it can be seen by clusters 1 and 2, supply chains have been extended by creating stronger links to design (in DB), to financing and operation (in BOT/DBFO) and to maintenance (in DBM).

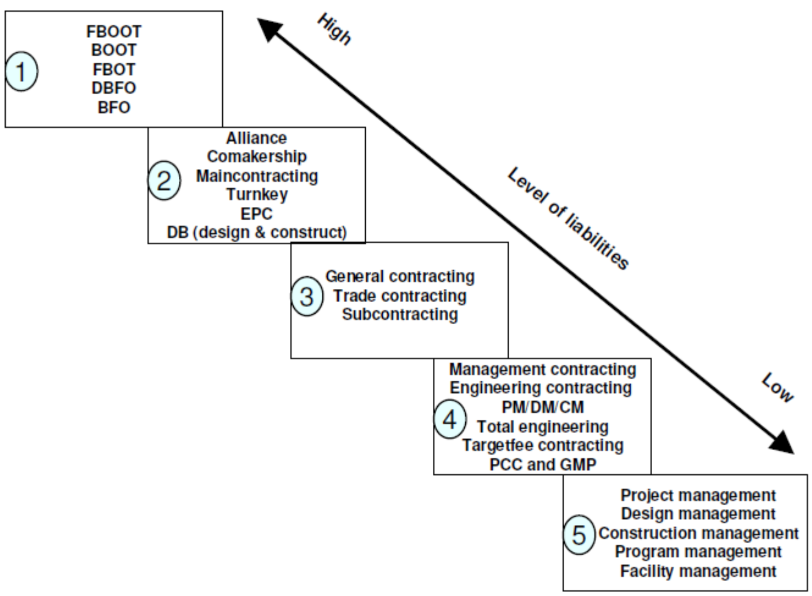


Figure 3-4: Ladder of liabilities, adapted from ONRI (2005)

Liabilities for the contractor in the traditional design-bid-build contracts (cluster 3) involve only the physical construction and construction quality control/assurance. From the third cluster to the first cluster, risks and responsibilities are increasingly transferred to the contractor. There risks and responsibilities can be shared between the client and the contractor, but can also be transferred to the contractor. These risks or responsibilities can be approvals or permits, co-ordination of works with other agencies, ground/soil conditions or changes in legal systems (Palaneeswaran, Kumaraswamy, & Zhang, 2001).

3.6. SUMMARY & SUB-CONCLUSIONS

This chapter elaborated the environment into which construction logistics are applied and answered the first research sub-question. In this respect the economic situation of the construction industry was presented, followed by an introduction on the main reasons for failure costs in construction. Furthermore the main characteristics of project management in constructions have been introduced, as project management is interrelated quite often with logistics processes. Subsequently, the construction industry peculiarities were analyzed. The chapter is completed with a rough presentation of the forms of procurement procedures in construction project and the liabilities and responsibilities that arise according to different procurement forms. Having identified the domain of the application of construction logistics, the next chapter establishes the concept of construction logistics, which is the core element of this research. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

Topic	Description
Economic situation of construction industry	• The economic situation of the construction industry plus the low profit margins in comparison with other industries gives incentives for improving the construction project efficiency through the application of construction logistics
Cost of failure in construction projects	• Dutch construction industry is facing severe problems with failure costs of construction projects • The main reasons for the costs of failure are: ➢ the lack of communication and information transfer ➢ inadequate attention for feasibility during design phase ➢ the delivery of quality to end user as not being the highest priority
Construction Project Management	• A project is a "*temporary endeavor undertaken to create a unique product, service, or result*" • Construction project management is "*the application of knowledge, skills, tools and techniques so as the construction project activities to meet the project requirements*".
Construction industry peculiarities	• Construction industry peculiarities are important in order to understand the different environment of construction for the application of logistics • Construction industry peculiarities include: ➢ One-of-a-kind projects ➢ Site production ➢ Temporary organization ➢ Regulatory intervention ➢ Complexity ➢ Uncertainty ➢ Fragmented construction industry
Forms of procurement procedures	• Different forms of procurement for construction projects influence construction logistics as it determines the relationship between the parties involved and liabilities and responsibilities on the construction process

Table 3-2: Summarizing Key Elements of the Chapter

4. LOGISTICS OF CONSTRUCTION PROJECTS

After the identification of the domain into which construction logistics are applied, this chapter describes the origins and the development of logistics as a specific discipline in the construction industry by answering the following research sub-question: *"What are the most important characteristics of logistics on building construction projects that are connected with the direction of this research?".* Moreover, this chapter fulfills the target of defining all the concepts that are involved in the research domain with the presentation of the influence logistics can have on the efficiency of a construction project and on the negative external effects in the local environment of a project. In order to answer the above question the origin and the concepts of supply chain management and logistics are being introduced in *section 4.1*, before presenting the supply chain model in construction and the conceptualization of the construction supply chain as a "make-to-order demand-and-supply chain" in *section 4.2*. Subsequently, in *section 4.3* the definition of construction logistics and the general characteristics are discussed, seminal industry reviews and reports on the construction industry are reviewed in order to present the influence construction logistics can have on a project through the proper or improper application of a logistics analysis, and the influence that the actors involved in the project can have in order to ensure the proper consideration of logistic issues during a construction project is debated. The chapter is completed with a presentation of the construction related external effects that are influenced by construction logistics in *section 4.4*.

4.1. SUPPLY CHAIN MANAGEMENT & LOGISTICS

4.1.1. Origin of Supply Chain Management

SCM is a concept that has originated and flourished in the manufacturing industry. The first signs of SCM were observable in the Just in Time (JIT) delivery system as part of the Toyota Production System (Shingo, 1988). This system aimed to regulate supplies to the Toyota motor factory just in the right - small - amount, just on the right time. The main goal was to decrease inventory significantly, and to regulate the suppliers' interaction with the production line more successfully. SCM is combining particular features from concepts including Total Quality Management (TQM), Business Process Redesign (BPR), Just in Time (JIT) and Efficient Consumer Response (ECR) (Van der Veen & Robben, 1997).

4.1.2. Concept of Supply Chain

The supply chain can be defined as "*the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer*" (Christopher, 1992).

In its broadest sense, a supply chain includes the entire sequence of firms and activities from the extraction of raw materials at the initial source (supplier's suppliers) until the delivery of the end product to the ultimate consumer in the marketplace (customer's customers). A supply chain includes flows of products and information up and down the chain including the associated managerial and operational activities. *Figure 4.1* presents a simplified linear example of a hypothetical supply chain.

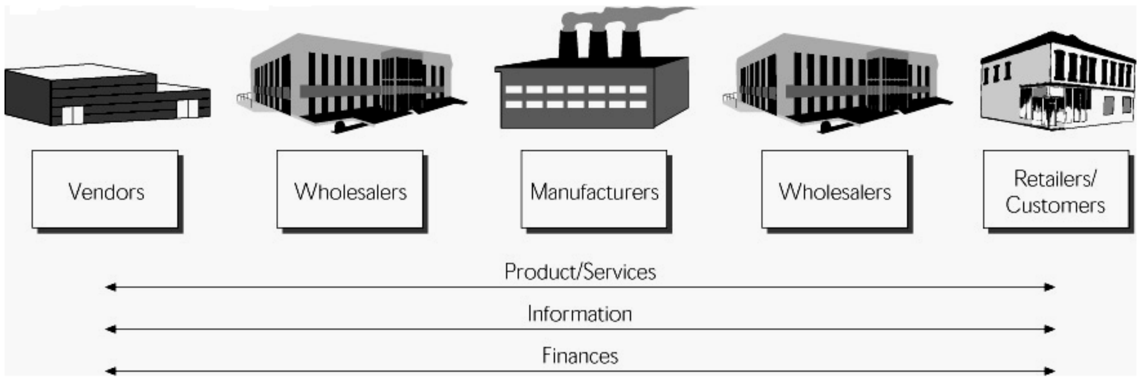


Figure 4-1: Integrated Supply Chain, based on: (Coyle, Bardi, & Langley Jr., 2003)

4.1.3. Concept of Supply Chain Management

Supply chain management can be viewed as a pipeline or conduit for the efficient and effective flow of products/materials, services, information, and financials from the supplier's suppliers through the various intermediate organizations/companies out to the customer's customers or the system of connected logistics networks between the original vendors and the ultimate final customer (Coyle, Bardi, & Langley Jr., 2003).

Supply chain management has been defined in various ways, many of which define the same issue in different words. Supply Chain Management is broadly defined as:

"*The management of all the processes that is required to deliver a service or a product for a customer through a network of organizations with minimum waste and maximum value*" (Elfving, 2003).

4.1.4. Concept of Logistics

Logistics is a critical part of supply chain management. The coordination and integration of the logistics systems of all the organizations in a supply chain are necessary requirements for successful management of the supply chain. Logistics, like supply chain management, has a number of different definitions because of the broad-based interest in its activities and the recognition of its importance. The Council of Logistics Management (CLM) defines it as:

"*the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point origin to point of consumption (including inbound, internal, and external movements) for the purpose of conforming to customer requirements*".

Another way to look at logistics is from the commercial point of view; "The Seven R's of Logistics"; delivering the Right product in the Right quantity and the Right condition, at the Right place, at the Right time, for the Right customer at the Right cost. Activities related with Logistics include: Traffic and transportation, warehousing and storage, materials handling, inventory control, order fulfillment, production planning, return goods handling, purchasing and customer service levels.

4.2. Supply Chain models for construction

Construction industry is a typical one-of-a-kind industry working in projects. It is often the end user, i.e. final customer, who takes initiative to begin a construction project, and therefore, construction is mostly customer driven. The recognition that construction is in fact a customer driven one-of-a-kind production process leads to the conceptualization of the construction supply chain as a "make-to-order demand-and-supply chain" explicitly starting and ending with the end user (Vrijhoef, 1998).

The construction supply chain refers to the goods, information and money flow for a particular project. The customer demands a build project i.e. a house, and sometimes he is represented by a principal or directly by the construction manager who takes care that the customer's requirements will be met. Several actors are involved in the construction process like the architect, electrical, mechanical and structural engineer and the contractor who will carry out the actual construction through subcontractors. Goods flow from the building products manufacturer or the raw material supplier to the end customer and money flow the opposite direction. Money is distributed as a function of the value-added services provided and the amount of risk taken by each trade through contractual agreements. Information flows in all directions as pointed out between all the stakeholders of the project. *Figure 4.2* represents an example of construction supply chain (Vaidyanathan, 2009), and illustrates the boundaries of this research which includes the members of the supply chain involved with the design project phase.

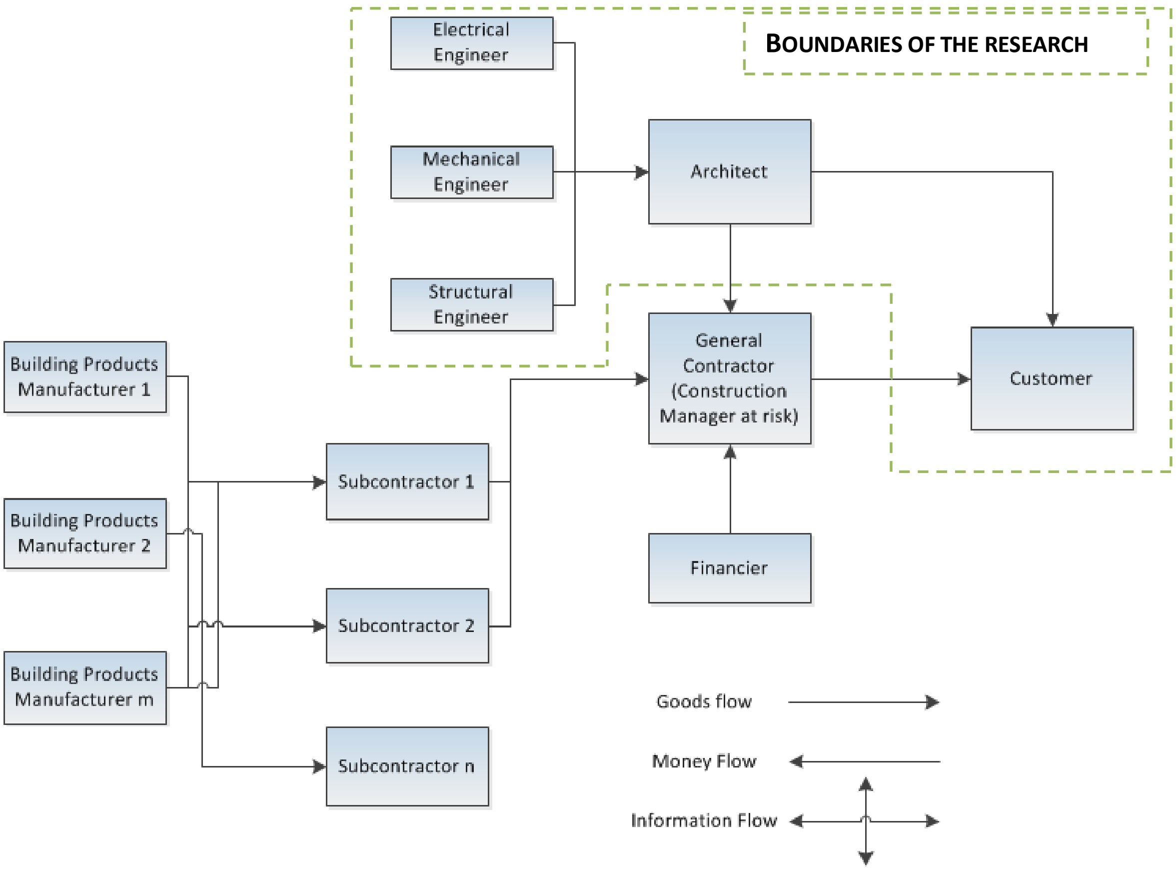


Figure 4-2: Construction Supply Chain, by Vaidyanathan (2009)adapted by the author

In contrast with the manufacturing supply chain in *figure 4.1*, in the construction supply chain the value added services are provided by several parties like the architect, engineer, trade contractors, construction managers, financiers, etc. Comparable parties are involved in a manufacturing supply chain but in construction they have a more active role in the process. The short term and the unique nature of construction projects suggests that the designers and engineers will play a major role in the construction supply chain.

The exchange of information is often through phone, fax and printed drawings exchanged through mail. Information may recreate several times between the various trades, for example the architect sends the drawing to the engineer who adds engineering information to the CAD drawings. Each architect, engineer and construction manager is an enterprise of its own and usually there are no economic incentives in order to share the effort for creating and sharing information. Sharing or lack of sharing information is a major source of delays, errors, and duplication on projects as every time information passes from one party to another there is a loss of time and productivity which leads to increased costs and inefficiency (Vaidyanathan, 2009).

4.3. Construction Logistics

4.3.1. Introduction

Construction logistics according to Serra and Oliveira (2003) is "*a multidisciplinary process applied to a given construction to ensure the supply, storage, processing and availability of material resources on the construction site, to dimension the production teams and to manage the physical flows of production*". Silva and Cardoso (1998) state that the main support of this process, which occurs through planning, organization, management and control activities, is the flow of information prior to and during the productive process. Moreover, they define logistics in construction terms, which can be understood as a multidisciplinary process that strives to guarantee at right time, cost and quality the:

- material supply, storage, processing and handling
- manpower supply
- schedule control
- site infrastructure and equipment location
- site physical flow management
- management of information related to all physical and services flow

The abovementioned can be achieved through planning, organizational, directing and controlling activities before and during the construction works. In addition the influence the construction design has on logistics is very important, as there are many things that can be done during the design process to prevent logistical problems (Maas, 2010). Following the above mentioned, a construction logistics analysis is defined for this research as *"a multidisciplinary process applied to a given construction design in order to find logistics areas of improvement based on the material supply, storage, processing and availability, the dimension of production teams and the management of the physical flows of production"*.

A company, being a member of a larger supply chain of suppliers and customers, has its own system of internal logistics also in the form of supply chains as it is shown in *figure 4.3*. Construction logistics may be considered in a number of aspects (Serra & Oliveira, 2003):

- the building site as a production system and a member of many logistic chains, where complex processes are executed within time, space and budget constraints –whole project logistics
- supply chains delivering products from external sources to the building site (supply logistics)
- co-ordination of material flows on the building site (on-site logistics)
- participants of the construction project as separate entities participating in other projects at the same time

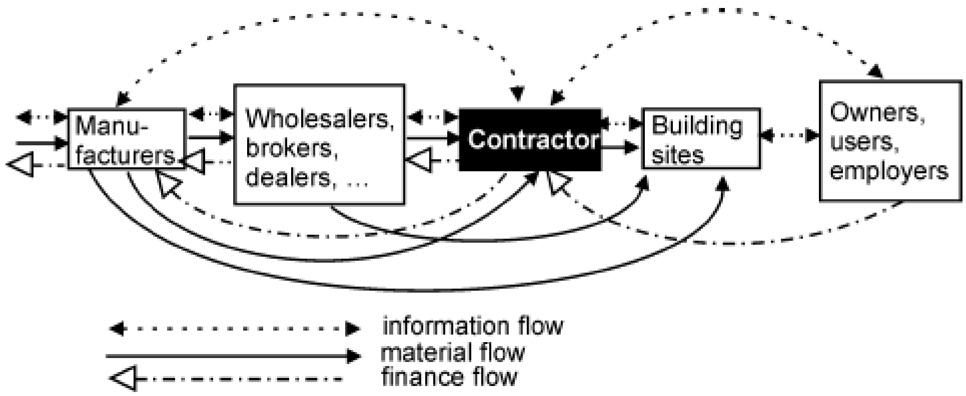


Figure 4-3: A building contractor within a construction supply chain, adapted by Sobotka et. al. (2005)

At this point, it has to be noted that the scope of this research as it has been defined in *section 1.4* is towards supply and on-site logistics.

Supply Logistics

Supply logistics regards provision of the material and human resources required for the building production. Among the most important activities are planning and purchasing of procured items, supplier management, transportation of resources on site, and maintenance of the material resources foreseen in the planning. Wegelius-Lehtonen (2001) presents two tools developed to measure the improvement potential of deliveries process. The tools measure costs and time of delivery chains. The first step is to identify all the activities from the supplier's production line to the final assembly of product on construction site. The second step is to calculate costs of each activity and finally to present the results in an informative way. Luiten (2010) mentions that the most important phase for construction logistics is the first phase of construction process where you have a lot of prefabricated elements and you need just in time deliveries. Van Moolen (2010) indicates that the construction elements that cause the biggest logistical problems are the construction materials that have the biggest volume like steel or concrete, but he also stresses the fact that from a logistic point of view there are many possibilities for improvement in smaller materials handling processes.

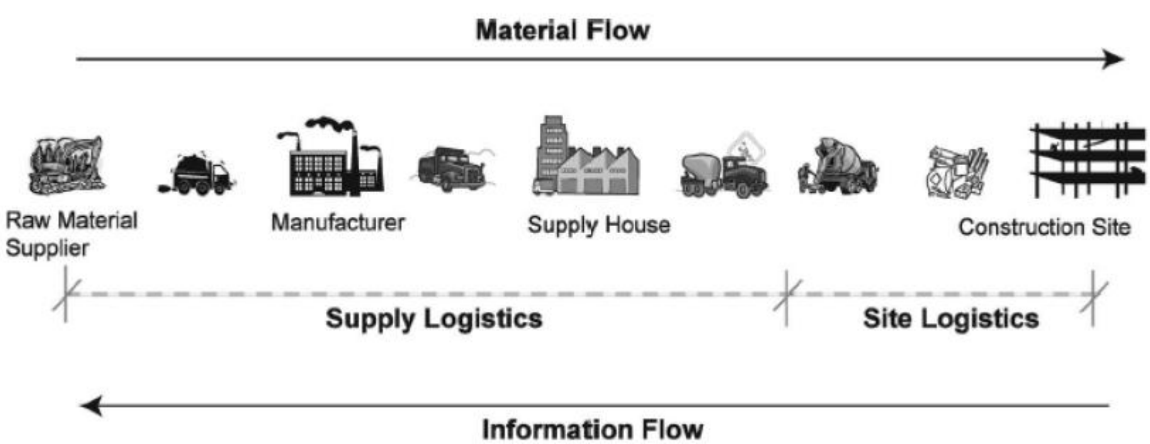


Figure 4-4: Construction logistics tasks

On-site logistics

On site logistics involves the management of the physical flows and information flows associated with on-site activities, the most important activities are: *management of the physical flows involved in the execution* (detailed planning of the service flow and its control mechanisms), *interface management between agents interacting in the construction process* (information and interposition among the services), and *physical management of the construction site* (establishment of the site, internal movements, storage and prefabrication areas, and work safety requirements).

Figure 4.4 illustrates the construction logistics tasks. Moreover, functions such as security, material handling and delivery, waste management, traffic management, temporary works, welfare, emergency services liaison, catering and housekeeping are essential functions included in the range of site-based logistical support. Although these functions can be considered as non-core construction activities, ineffective planning and unsuccessful implementation of these functions can diminish the overall project performance (Sullivan, Barthorpe, & Robbins, 2010). The importance of construction logistics is increasing even more due to the effects it can have on the construction project performance and especially in the efficiency in terms of time.

Type of Activity	Percent of total work time
Main work	**30.9**
Logistic affected processes	**29.9**
Ways	14.1
Transport, hauling	8.9
Rearrangements	5.8
Material search	1.1
Miscellaneous	**39.2**
Absence	19.8
Personal-based interruption	10.3
Failure-based interruption	3.5
Others	5.6

Table 4-1: Time slices of total work time (Guntermann, 1997)

Several studies of outfitting processes on German construction sites pointed out that a lot of time is spent on non-productive actions (Guntermann, 1997). Approximately one third of the total execution time is consumed by logistic processes (see *table 4.1*).

Following the introduction of logistics in construction projects the reader can notice similarities between some specific aspects of project management and construction logistics. The next paragraph illustrates this argument.

From logistics to project management

As it has been mentioned in *section 3.3* construction project management has the task to make sure that the project will be completed on time, within the specified budget and with the expected quality level achieved. Construction projects require superior planning, managing of a fixed scope over a long time, procurement and human and material resource management. The disciplines of logistics and project management overlaps in such a way that it is not always possible, or even necessary to tell them apart (Poppendieck, 2000). This can be noticed in the definition of construction logistics by Silva and Cardoso, where manpower supply and schedule control, processes always related with project management, are attached with construction logistics processes.

Moreover, except from the overlapping of the two concepts there are parts between them that are heavily attached. One of this is the dependence between the project scheduling and construction site logistics. The project scheduling determines the logistics on site while on the other hand the schedule cannot proceed in case of poor logistics organization. This relationship is quite important for the project realization, as any change in project scheduling will result to different logistics on and to site. This connection between project management and logistics is becoming even clearer in *chapter 5* where logistics tasks per each project phase are recognized.

As a final point it has to be mentioned that the site environment is very important for both project management and logistics. As it will be illustrated further in *chapter 6*, in a large construction area with multiple different projects running in parallel, the scheduling of each one of them can heavily influence the logistics of the whole area and the main logistical problems are identified in the interface between different projects. The case of Delft will provide a thorough understanding of this argument and is a good example about logistical problems that result in the interface of different construction projects and how these problems can be treated with project management and logistic strategies.

4.3.2. General Characteristics of Construction Logistics

Construction logistics have different characteristics comparing to logistics in other industries. According to Vrijhoef and Koskela (2005) the construction supply chain has three elements different from ordinary supply chains which include:

- ***Converging supply chain:*** The flow of the materials is towards the construction site where they are assembled into a new building or infrastructure project. The construction site can be characterized as a temporary construction factory which is only producing a single product and except from waste no products are further distributed.
- ***Temporary supply chain:*** It is common that the construction site is set-up to build just one object. Nevertheless, each construction site can be viewed as a set of processes and organizations that are reorganized and adjusted to a specific project and although the projects might differ to a great extent, the processes are not.
- ***Make-to-Order supply chain:*** Due to the unique nature of each project, highly specialized parts and materials are needed so as a result repetition only occasionally occurs. Due to this fact, delays may occur because of items that will have to be re-ordered due to damage or production errors, as factories usually have limited stock level for the highly specialized parts or materials.

Another difference regards the proportion of the logistic cost in the total construction project costs. Several attempts in the past have been carried out in order to structure the costs of a construction project. Logistiek.nl states that the logistics costs as a share of total project costs have increased during the last years from 8% to 15% although sometimes logistics costs can even be considered 20% of the total project costs (EVO, 2007). Even though there are differences on the precise estimation of the logistics costs, it is clear that construction logistics costs have a larger share than logistics in other industries. Some reasons for this, mentioned by Lange (2009), include:

- Lack of return freight
- Need for specialized equipment
- Large share of raw materials with high volume/weight ratio
- Less consolidation

Supply chain management can be a measure in order to control the logistics costs, although supply chain management traditionally plays a limited role in the construction industry due to the relatively low product value and the involvement of many and changing parties (Lange, 2009). Other indicators that can be used to describe construction logistics according to TNO are listed in *table 4.2*. The construction projects comprise from a number of stages from its conception to commissioning. Each stage involves logistic processes. It has been clear at this point the significance of construction logistics to critical site performance factors such as cost, speed of construction and plan reliability, and industry performance indicators such as accident statistics and contribution to landfill.

Indicator	
Costs vs. quality	Costs
Average product value	Relatively low, because the portion of raw materials is high
Turnover / Turnaround	Relatively long, because products are durable
Product range	Increasing, driven by customers demand and technical feasibility
Frequency of delivery	High, partly due to lack of coordination and many parties involved
Reliability of deliveries	Moderate, due to dependence on traffic disturbances
Level of customer service	Relatively high, because parties can be traced and supplier is responsible for arranging transport
Equipment used	Barges for raw materials, but in general mainly trucks (horizontal transport) and cranes (vertical transport)

Table 4-2: Characteristics of Construction Logistics (TNO, 2008)

Resulting from the analysis of the concept of construction logistics, it might be expected that substantial attention would be paid to logistics when developing a construction strategy. However, in reality construction-specific logistics is an area that has not been addressed properly by the construction industry so far. Seminal reports on the UK construction industry (Latham, 1994; Egan, 1998; Bourn, 2001; SFC, 2002) highlighted the inefficiencies and waste of the industry due to the poor logistical performance.

The "*Improving Construction Logistics*" report published by the Strategic Forum for Construction Logistics Group (2005) argues that the application of proper logistics in the construction industry has been slower than other industries and that there is a lot of opportunity for change towards this direction. In the following sections, *4.3.3 - 4.3.5*, some of the points made by the Strategic Forum for Construction Logistics will be discussed and analyzed.

4.3.3. What points to Logistics being poor in the Construction Industry?

Some of the reasons that Logistics are not being addressed properly in the construction industry can be found in the construction industry peculiarities that have been discussed in *chapter 3*. Even though the *"Rethinking Construction"* report (Egan, 1998) recommends that the construction industry should be inspired by the manufacturing industries so as to improve its working practice, it is impossible to replicate a methodology due to fundamental environmental, cultural and operational differences between the two industries. An interpretation of deliveries to the point of use, Just-in-time and the use of work packs can provide the foundation of a comparison between the two industries based on the factors that determine the success of a logistics activity – time, location, quantity and quality (Sullivan, Barthorpe, & Robbins, 2010).

Deliveries to the point of use: In manufacturing, "point of use" means the location where a "fitter" installs a component in a machine, while in construction the understanding of "point of use" is often not possible. The conveyor-belt, production-line system is the key difference between a manufacturing plant and a construction site, as it provides a static point of use for the workers in a plant. This increases the level of certainty when planning as the environment is controlled, the precise time needed for a worker to fulfill a task can be calculated, and the requirements for the completion of a task and other operations can be structured accordingly.

Just-in-Time deliveries: While in the manufacturing industry, the term Just-in-Time is quite literal meaning that materials are "picked" from the stores, taken to the line and used within minutes, construction's planning process is affected by external influences like weather conditions, environmental factors and site location restrictions, so it does not offer the same level of certainty.

Work Packs: Industries like furniture retail have made predominantly first-class use of flat-pack units. This method makes it easier for the purchaser to assembly the product on the point of his interest, guarantees the compatibility of the used components and reduces the build time by reducing the time needed for the purchaser to find the right tools and components. In construction, the designer needs to consider the construction process in great detail in order to deliver a complete pack, and the process involves greater upstream logistical participation as fittings, structural components and fixtures need to be included off-site.

The "*Improving Construction Logistics*" report published by the Strategic Forum for Construction Logistics Group (2005) recognizes the following reasons for the inefficiencies of logistics in construction:

- A high proportion of motor trucks in the construction industry move around the road network either empty or with part-loads, whereas the retail sector and wider manufacturing industry are persistently working to consolidate delivery loads in order to maximize vehicle fill and reduce transportation costs.
- Many motor trucks that arrive to construction sites have to wait to gain access or be unloaded, whereas retail and other sectors designate time slots for supplier deliveries. Suppliers are charged with a penalty fee in case of late or early deliveries that are sent away.

- In construction, skilled craftsmen are often using their skills for less than 50% of their time on site. Unloading motor trucks and moving products around site are some of the non-skilled tasks. In other industrial and retail sectors special equipment and selected trained teams are used to unload motor trucks and to deal with material handling activities.
- Construction products are often stored on site for long periods of time and have to be moved to other parts of the site when they are finally needed. Retailers and those in other industries are persistently trying to diminish inventories and at least ensure they are held in the most appropriate location and they put effort on delivering the right quantities at the right time.
- Specialist contractors sometimes arrive on the construction site when they are not expected or when the job is not ready for them. Right information flows about work progress is ensured by good manufacturers in order to prevent this never happens.

In summary, other industry sectors, especially manufacturing and retail, have made huge advances in improving logistics, whereas the construction industry does not seem to be taking advantage of these opportunities.

4.3.4. What are the consequences of poor Logistics?

Several points that show that Logistics has not been addressed in a proper manner by the construction industry have been previously presented. In this section, the consequences of this approach are discussed. The consequences of poor Logistics are mainly divided into the following categories:

Unnecessary cost in the system

All the evidence highlighted above points to there being additional cost in the system that could be saved if the process operated more efficiently as a result of improved logistics. Waiting for materials, or collecting materials, tools, and equipment may lead to reduced labor productivity on site. Given that site operations account for about 30% of construction costs (SFCLG, 2005), this would suggest that this inefficiency alone is adding additional costs to the total cost of construction.

Transportation and environmental issues

Motor trucks parked in an inconsiderate way outside construction sites in the middle of the day, whilst waiting to unload can cause major traffic problems. Vehicles driving around empty or with part-loads result to increased emissions in the environment. None of this seems consistent with the growing attention that companies are expected to pay to corporate social responsibility.

According to the Building Research Establishment (2003), an estimated of 10 to 20% of all construction costs are transport-related, and approximately one in every five vehicles on UK roads is on construction related business. This makes the inconsiderate way of thinking about transportation of construction material a big inefficiency for a construction project.

Poor quality construction

Working in a disorganized environment will inevitably make the production of quality construction more difficult. Work interrupted whilst materials are sort from elsewhere on site, or delayed whilst products are delivered, will have an adverse effect on quality. Secondary working of products on site is also less likely to provide the same quality of product that could be manufactured in a factory environment.

Increased project time

Most of the features of construction projects that point to poor logistics will add to the time of construction projects. Delays whilst product is unloaded, subsequent movement of products around site and secondary workings of product all add unnecessary time that would be eliminated in a well-organized project.

Added risks to health and safety

Unnecessary products stored on site inevitably bring with them additional potential hazards. Additional manual handling (either because product is in the wrong part of the site or because the right equipment is not available) adds to the health risks to those on site. Secondary working of material also brings risks and research has shown that a number of accidents on site occur as a result of workers tripping over discarded material arising from secondary working.

In conclusion, *figure 4.5* classify many of the problems associated with the traditional approach to construction logistics, under four headings: uncontrolled, inconsiderate, disruptive, and wasteful.

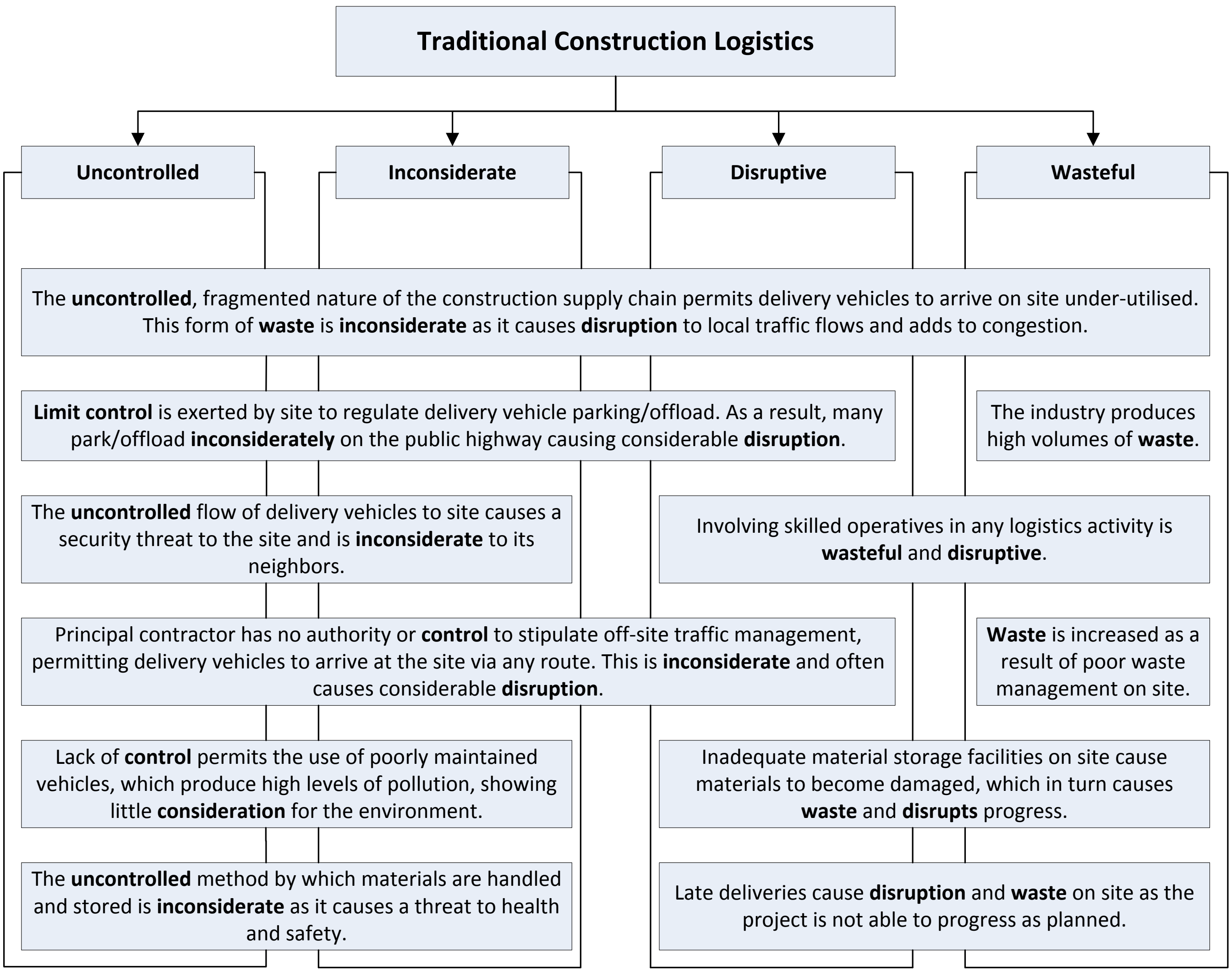


Figure 4-5: Traditional Construction Logistics (Sullivan, Barthorpe, & Robbins, 2010)

4.3.5. What is preventing the industry from addressing Logistics?

Case studies have a part to play in helping to demonstrate the benefits that arise from improved logistics, but the particular circumstances of a project limit the extent to which lessons are transferable. Nevertheless, it is hard to disagree that reduction in transport movements, less money tied up in stock, less waste, and the more efficient use of skilled craftsmen, will reduce the costs of projects, reduce construction time, improve quality, reduce risks to health and safety of those who operate on them, and generally improve the image of the industry. The challenge is to produce the information that convinces all parts of the industry that things need to be done differently in order to improve logistics.

The "*Improving Construction Logistics*" report published by the Strategic Forum for Construction Logistics Group (2005) identifies the following factors preventing the construction industry from properly addressing Logistics:

- There is no real incentive to tackle this because it is difficult to identify who benefits. There is no "Problem Owner". Those who may be required to do things differently do not necessarily benefit
- Construction projects are seen as a one-off and therefore it is difficult to optimize logistics in the way that is possible in a manufacturing or retail environment
- The fragmented nature of the construction industry with contractual arrangements that get in the way of a holistic approach to things like logistics and the lack of direct employment
- Inadequate advance planning of projects and short lead times
- The lack of cost transparency throughout the construction process. The way costs are recorded does not help identify the potential savings from improved logistics
- Inadequate information flow
- The lack of trust, confidence and understanding of the constraints of the supply chain
- Clients (and others) believe that project cost already allows for appropriate resources to be committed to logistics on the project

The report argues that logistics will not be adequately addressed until the construction industry works in a more integrated way with all the members of the supply chain. During the last years, there is some movement towards this direction. According to Fairs (2002) global logistics professionals and firms like UPS and Exel are targeting the construction industry, as they claim that contractors can reduce their materials and labor costs up to 15% by introducing Just-in-Time deliveries to site. Moreover, they state that this would also decrease damages to materials, save on storage costs and free up skilled workers for more productive work.

4.3.6. Actors involved in construction projects

The labor-intensive construction operation is characterized by decentralization. A prime contractor may self-perform a portion of the work as other specialty subcontractors move in and out of the project as their sections of work are ready. Over time, the jobsite is transformed from a temporary production facility with materials and heavy equipment to the actual completed project. Projects are typically located near the project owner who is either hands-on or represented by an architect or construction manager. There is little or no coordination and collaboration between the design professionals, prime contractors, subcontractors, and suppliers involved during the life-cycle aspects of the project. Information generated by various sources, at many levels of abstraction and detail, contributes to the fragmentation. Traditionally, the project information exchanged between architects/engineers and a prime contractor is compliant and has been mainly based on paper documents. These documents come in the form of architectural and engineering drawings, specifications, bills of quantities and materials, and change orders. This lack of communication and implementation leads to significant negative impacts—low productivity, cost and time overruns, change orders, inadequate design specifications, liability claims, and, generally, conflicts and disputes—which directly impact the customer by increasing project completion time and cost (Benton & McHenry, 2010).

The main actors involved in the construction process are categorized into four main categories: clients, design professionals, main contractors and specialist contractors, and manufacturers, suppliers and distributors. Each actor has a special interest regarding the logistic process during the project but as mentioned before there is no real incentive from anyone to intensely address the logistics problem. The following paragraphs address some of the reasons why this happens by describing the different actors' point of view towards the construction project and its logistic processes (SFCLG, 2005).

Clients

Clients have every reason to expect the supply side to deliver their projects efficiently and with minimal negative external effects and to ensure that proper attention is given to logistics so that the benefits referred to earlier are delivered. Clients can help in this by making clear to those they appoint that they expect them to prepare a Logistics Plan at an early stage in their projects, and that all the key players in the supply chain have signed up to this plan.

Design Professionals

Design Professionals need to be more aware of the part they play in ensuring good logistics, particularly at the scheme design stage. Logistics are greatly helped if the design professionals draw up a Process Map at an early stage in the design. In addition as part of the Logistics Plan for the project, a Bill of Materials should be prepared. This should look at, for example, the flow of materials needed on a project and ways of minimizing stockholding. Which of the professional members of the supply chain should be responsible for this, needs to be discussed, but the quantity surveyors with their background in measurement and costing might have the appropriate skills for this; alternatively it could require the input of logistics specialists. Manufacturers, suppliers and distributors clearly need to make an input to this Plan.

Main Contractors and specialist contractors

Many see the construction manager as the key player in coordinating the logistics on a construction project, but there is a need of cooperation between the different actors of the construction supply chain for a successful logistics plan. Irrespective of who carries it out, the responsibility for project logistics must rest with the main contractors, and it is essential they draw up a Logistics Plan in consultation with the rest of the supply chain at the outset of a project. The Bill of Materials will be an important input to this and the specialist contractors should each prepare that sub-set of the Logistics Plan relevant to their specialist input including how they will be making optimum use of the skilled labor on site.

Manufacturers, Suppliers, and Distributors

A key part of logistics for a construction project is to ensure that the products and materials arrive on site at the time and in the quantities that are required. This does not just depend on the efficiency of the supply network, but it also relies on the pre-planning of those on the construction site, as well as the quality of the communication between those planning the project and those supplying the products and materials.

Manufacturers and suppliers can make a significant contribution to the efficiency of the logistics on a project if they are involved early enough in the process and, in particular, if they can make an input to the Logistics Plan through the preparation of the Bill of Materials.

In conclusion, following the analysis of what construction logistics is, their characteristics and the influence they may have on a construction project, it can be stated that the scope of construction logistics is to mitigate risks and reduce costs by increasing certainty, productivity and predictability within the project schedule.

4.4. External factors influenced by construction logistics

Social costs[2] related with the local environment of a construction site are creating growing awareness among the public and the local government agencies. All these attention towards the significance of the social costs is leading to growing pressure towards their minimization. On the other hand, economic losses that are caused by construction related activities are not taken into account in traditional contractual and bid evaluations. This is happening, to some degree, because owners and contractors do not have to justify their choices of construction methods and practices based on any estimation that takes into account the social costs carried by the local environment. The responsibility of the contractor is to realize the project objectives in accordance with the construction contract, drawings and specifications, and project schedule and budget. Within these boundaries, his goal is to build the project for the lowest cost, within the tightest time limits, and at the highest profit. As a result, a contractor will take into account the social costs only if it is required in the construction contract or if it is economically favorable for him to do so.

The selection of arrangements and construction methods in proposals for large urban construction projects are being influenced by an organized and well-funded resistance which is growing lately. Some reasons for this transformation include (Gilchrist & Allouche, 2005):

- the growing traffic congestion in and around major urban centers
- the boost in the construction activities in urban areas due to the telecommunication revolution and large-scale programs for the renewal of water distribution and waste water collection systems, and highway rehabilitation and reconstruction programs
- growing beliefs that construction activities will not diminish one's quality of life and an increased awareness of alternative construction methods and technologies

4.4.1. Potential adverse external effects on natural and urban environments

A wide range of external effects on the local environment can occur from construction activities. An analysis of potential impacts and social cost indicators associated with construction activities is presented in *figure 4.6*. A social cost indicator can be defined as a *'measurable cost that can be quantified in monetary terms and is a result of one or more construction-related adverse impacts on the environment surrounding a construction site'* (Gilchrist & Allouche, 2005). The construction related external effects are classified under four categories: traffic, economic activities, pollution and ecological/social/health related impacts.

[2] The term "social costs" refer to costs that cannot be classified as either direct or indirect costs by the parties engaged in a contractual agreement and are incurred due to the execution of a construction project (Gilchrist & Allouche, 2005).

Traffic

Construction activities in or near a city center strongly affect roads and cause traffic congestion and lane closures. Traffic is delayed due to reduced speed through the construction zone, lane closures and adjustments of traffic distribution patterns. The movement of heavy trucks in and out the construction site creates further barriers to movement around the construction sites and can change the established traffic patterns. The traffic disruption creates adverse impact such as prolonged closure of road space, detours, and utility cuts. Construction activities require space to position and move machinery, develop the project itself and provide entry and exit passages. In many construction projects this space comes from existing road lanes, causing increased traffic congestion, loss of parking spaces and changes in recognized traffic configurations that can produce increased travel times and distances as well as an increase in car accident rates. A study conducted in France places the number of deaths resulting from traffic accidents blamed on construction projects at about 200 for the 10-year period ending in 2000 (Diab, 2002). Redirection of traffic to secondary roads because of changes in the normal traffic patterns may also lead to considerable damage of the road surface of the detour.

Economic Activities

Urban areas can be socially and economically benefited by construction projects as a result of higher land prices and the development of new commercial, cultural and recreational activities after the completion of the projects. On the other hand, economic activities around a construction site can be affected negatively during the construction. Negative impacts include: *loss of income* due to reduced accessibility to the local business, detours and construction related disturbances (i.e. noise and dust), *productivity reduction* due to traffic delays and construction related annoyances that adversely affect the ability of people to perform their work, *reduction in tax revenue* due to the loss of income of the local business and *property damage* due to landslide produced by equipment vibration or dewatering operations.

Pollution

In the context of this report, the term pollution does not only refer to environmental pollution (air, water and soil pollution) but it also refers to noise pollution, urban congestion pollution and visual pollution. Schexnayder and Ernzen (1999) define noise as any audible sound that has the potential to annoy or disturb humans, or to cause an adverse psychological or physiological effect on humans. Construction activities are a common source of noise in an urban environment, as a result of heavy earth moving and paving equipment, vehicle back-up alarms, pneumatic equipment and demolition activities (Gilchrist & Allouche, 2005). Thus, real estate values can go down, social, mental and physical health can be affected and tiredness, irritation and stress can be caused which may lead to loss of productivity. Finally, construction machinery produces air emissions that contain carbon and nitrogen oxides, toxic substances, dust, heavy metals as well as chlorofluorocarbons and other emissions that increase the 'greenhouse effect'. These pollutants are emitted from engines, fuel supply systems and material supply transportation equipment like trucks.

Ecological/Social/Health

Nowadays, the ecological damage due to urban construction projects is limited as after years of urbanization there has not been much left to affect. Nevertheless, there is one important exception, which is really important for the Netherlands, which include the ecological impact on the bodies of surface water and the groundwater table. A water flow that is intercepted by a construction project may affect the flow volume, velocity and sedimentation rate and can result in erosion, flooding, alterations of the normal course of rivers, canals and streams, and damage the aquaculture. Moreover, lowering of the water table caused by dewatering operations may result in deterioration of green life, reduction of water for agricultural use and landslide of structures (Gilchrist & Allouche, 2005). The quality of life of nearby residents that live within a construction project's radius of influence can be reduced due to pollution associated impacts. Pollution associated impacts can affect negatively human health and rest periods, while traffic related impacts increase human stress levels that may affect people's behavior and mental health. The most common health problems associated with these impacts are respiratory illnesses, cardiovascular diseases, allergies, anxiety and annoyance. These problems may lead to increased consumption of the local health services and loss of productivity due to absence from the workplace.

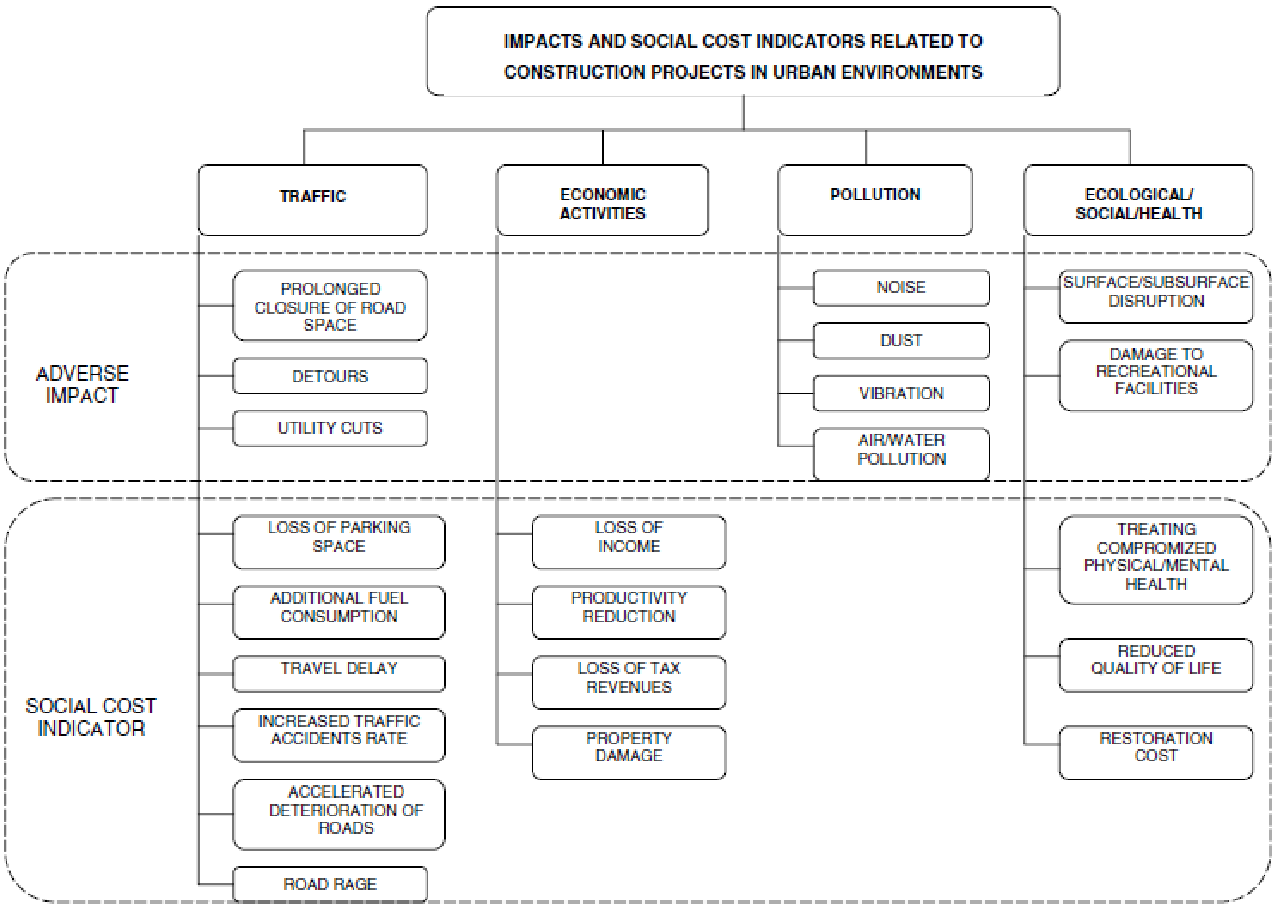


Figure 4-6: Breakdown of construction related impacts and cost indicators (Gilchrist & Allouche, 2005)

4.5. Summary & Sub-conclusions

This chapter introduces the logistics in construction projects and gives an answer to the second research sub-question. Initially, a short introduction of Supply Chain Management and Logistics which includes the origin and the concept of Supply Chain, the concept of Supply Chain Management and the concept of Logistics creates the foundation upon which the construction logistics are being applied. Furthermore, the Supply Chain model for construction is analyzed. Subsequently, construction logistics which is the core of this research are analyzed, starting with the definition and the general characteristics of the concept, the points that show the inadequacy of logistics in construction and the consequences of this fact to the efficiency of construction projects, the reasons why logistics are not being addressed properly by the industry and the actors involved in construction projects. The chapter is completed with a presentation of external factors that are influenced by construction logistics considering the adverse effects on natural and urban environment. Having identified the elements of the research domain in this chapter, the practical application of construction logistics is presented in the following chapter, which finalizes the theoretical findings and creates the foundation of proceeding to the empirical research of the case that will be studied. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

Topic	Description
Supply Chain Model for construction	• Construction Supply Chain is a "make-to-order demand and supply chain" • Designers and engineers play a major role in a construction Supply Chain • Information or lack of information sharing is a source for loss of time and productivity within the boundaries of the Supply Chain which leads to increased costs and inefficiencies
Construction Logistics	• Construction logistics is an application of Logistics in construction environment • Construction Logistics is a multidisciplinary process applied to a given construction in order to: ➢ to ensure the supply, storage, processing and availability of material resources on the construction site ➢ to dimension the production teams ➢ to manage the physical flows of production • Construction logistics tasks can be divided into supply logistics and site logistics • The importance of construction logistics is increasing due to the influence they have in project efficiency, mainly in terms of time • Characteristics of construction logistics: ➢ Converging Supply Chain ➢ Temporary Supply Chain ➢ Make-to-Order Supply Chain • Inadequacies of construction logistics: ➢ Lack of consolidation loads ➢ No designated time slots for supplier deliveries ➢ Lack of specialized equipment for efficient material handling ➢ Long term storage of materials on site ➢ Lack of proper information flows about work progress on site • Consequences of poor construction logistics on project efficiency: ➢ Unnecessary cost in the system ➢ Transportation and environmental issues ➢ Poor quality in construction ➢ Increased project time ➢ Added risks to health and safety

	• Factors that prevent industry from addressing the problems: ➢ No real problem owner ➢ Construction projects seen as "one-off" ➢ Fragmented nature of industry prevents a holistic approach of logistics ➢ Lack of transparency in costs throughout construction process makes it hard to identify savings from improved logistics ➢ Information in construction is generally an "estimation" ➢ Lack of understanding of supply chain constraints ➢ Clients consider that project cost already allows for appropriate resources to be committed to logistics on the project
External Factors influenced by Logistics	• The construction related external effects are classified under four categories: ➢ *Traffic*: Delays and congestion due to reduced speed through construction zone, lane closures, adjustments of traffic distribution patters ➢ *Economic activities*: Loss of income and productivity reduction due to reduced accessibility to the local business, detours and construction related disturbances and traffic delays ➢ *Pollution*: Real estate values decrease, social, mental and physical health affection and "greenhouse effect" increase due to noise, dust and air/water pollution ➢ *Ecological/Social/Health:* Deterioration of green life, reduction of water for agricultural use and landslide of structures due to ecologic impact on the bodies of the surface water and the groundwater table

Table 4-3: Summarizing Key Elements of the Chapter

5. CONSTRUCTION LOGISTICS IN PRACTICE

So far, the domain of construction logistics have been identified in *chapter 3* and the definition of the concept of construction logistics along with its characteristics have been presented in *chapter 4*. The next step, so as to finalize the theoretical findings and to develop a framework that will support the construction logistics analysis of the new Delft train station and City Hall, is to describe the application of construction logistics in practice.

This chapter describes the diverse range of support service applications of construction specific dedicated logistics management, by answering the following research sub-question: *"What is the field of construction logistics that needs to be taken into account for a building construction site in a residential area?"*. The chapter is written mostly from a professional practitioner's perspective- through the interviews with logistic experts-, while taking into account the findings from the literature. In order to answer the above question, a demonstration of the basic logistic tasks according to the project phase and a description about what is included on a logistic plan for a construction site is presented in *section 5.1* and *5.2*. Subsequently, a range of strategies that can be applied in order to improve the logistics of a construction project are illustrated in *section 5.3*, with an increased attention on Construction Consolidation Centers which are considered the future of construction logistics. Afterwards, the extent of the interrelations between the project efficiency and the negative external effects, for each technique are analyzed in *section 5.4,* while a discussion about the most important processes from a logistics perspective which include the construction material transportation, storage and handling takes place in *section 5.5*. The chapter is completed with a reflection on literature findings in *section 5.6*. This chapter completes the theoretical findings and provides a practical guidance on implementing successful logistics on building construction sites.

5.1. PLANNING CONSTRUCTION PROJECT LOGISTICS

Logistics, like many other aspects on a construction project, have to be planned out in detail at the beginning of a project in order to run effectively and efficiently. In a logistic plan, the logistics manager needs to formulate a strategy on how to approach the construction work at each stage of its development. The drawings and sketches of the design are vital for the development of the logistic plan, together with information about the perimeters, construction site access points, footprints, and vehicle movements which need to be considered carefully (Sullivan, Barthorpe, & Robbins, 2010).

Construction Logistics deals with many technical, organizational and environmental issues affecting the project cost, time and quality of execution (Sobotka, Czarnigowska, & Stefaniak, 2005). Traditionally, each contractor manages his own supply chains but in the case of larger projects which involve a number of contractors, serious interferences in material and information flows may occur due to the incompatibility of logistics concepts and lack of co-ordination. According to modern management ideas, centralization of logistic functions and management allow many actors of a construction project to reach the synergetic effect of their efforts. These efforts may involve a logistics center which may be specifically effective in larger construction projects located in city centers with confined space and limited transport possibilities and where massive amounts of materials have to be managed. The main task of an integrated logistic system is to provide just in time deliveries when needed to eliminate most of materials handling and storage on site, to shorten the time of the project completion by eliminating reasons of work stoppage and to minimize the local negative external effects.

There are important tasks and processes that occur at every stage of a construction project. These basic logistic tasks are listed according to the project phase in *table 5.1*.

Project Phase	Logistic tasks
Initiation / Programming	➢ Checking the concept from the point of logistics ➢ Preparation of logistic guidelines for site planning ➢ Preparation of logistic strategy for project management
Design	*Preparation of:* ➢ Logistic guidelines for the design ➢ Analysis of alternative structural designs and materials utilization ➢ Material requirement specification ➢ Feasibility study of logistic concepts ➢ Execution design ➢ Logistic guidelines for tender preparation ➢ Quality system of logistic services
Planning	*Preparation of:* ➢ Schedules and charts of labor and equipment utilization, subcontractors work and material consumption ➢ Logistic concept of the building site ➢ Design of site installation and disassembly ➢ Guidelines for purchase or lease of machinery ➢ Selection of suppliers ➢ Plans of logistic processes (models and methods of control) ➢ Assessment of logistic service efficiency and impact on environment ➢ Planning and placing orders, scheduling deliveries ➢ Waste management planning ➢ Planning information flows management and methods
Execution	➢ Work progress monitoring ➢ Schedules and plans updating ➢ Adjusting orders to current demand for resources (workforce, materials, plant, subcontractors) ➢ Creating operation centers to serve contractors ➢ Planning and coordinating horizontal and vertical transport on site ➢ Planning and coordinating deliveries, loading, unloading, and warehousing, distributing deliveries to contractors ➢ Implementing logistic service quality standards ➢ Recording feedback information on the effects of implementing integrated logistics systems ➢ Managing waste ➢ Managing information flows, documentation, implementation and maintenance of information system
Commissioning	➢ Dismantling of site installation ➢ Managing information flows, documentation

Table 5-1: Basic logistic tasks according to the project phase (Sobotka & Czarnigowska, 2005)

The analysis of the whole project's life cycle indicates that there are as many logistic tasks at initial stages of programming, designing and planning as in the execution phase. Experience prompts that careful consideration and well developed logistic concepts allow effective execution of projects and reduction of total project outlay and/or quality improvement (Sobotka & Czarnigowska, 2005). The identification of logistics tasks according to the project phase is another sign of the close relationship between project management and construction logistics. The logistics tasks follow the project life cycle and are based on the project planning and control which are the main responsibilities of project management.

The above mentioned logistics tasks should be integrated in a generic strategy on how to approach the construction work at each phase. The management of the construction logistics tasks per each project phase is possible through the development of a constructions logistics plan. Several logistics strategies for constructions can be used so as to optimize the logistics plan. The process for the development of a logistics plan and an overview of logistics strategies that can be used are presented in *section 5.2* and *5.3* respectively.

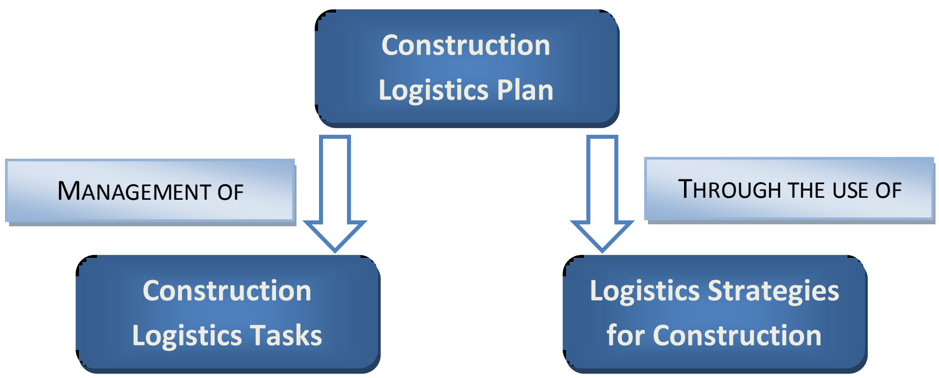


Figure 5-1: Construction logistics plan framework

5.2. DEVELOPMENT OF A LOGISTIC PLAN

This section will illustrate the steps needed for the development of a logistics plan as it has been described in the book "Managing Construction Logistics" by Sullivan, Barthorpe and Robbins (2010).

The process of the development of a logistics plan is sequential starting from the general overview of the problem (step 1) which gives a broad view about the construction area and potential problems that may arise. Subsequently, the building which is the core element of the logistics analysis is being assessed (step 2) to provide the data required for the potential solutions. Afterwards, several solutions and scenarios are being checked on their viability in practice (step 3) and finally the plan is being brought down to the smallest pieces that can affect it (step 4). The side effects are taken into account and an optimized solution can be proposed at the end. The process for the development of a logistics plan is illustrated in *figure 5.2*.

Step 1- The general overview

Initially, the context is everything when it comes to construction logistics. The local area of the construction project needs to be understood thoroughly. Issues like the requirements for access and noise control, the operation of the local road/water/rail network, the attitude of the neighbors towards the project and the traffic levels should be investigated. The local and logistics constraints need to be identified and understood in order to have a clear picture about anything likely to affect the project over the near area of the construction site.

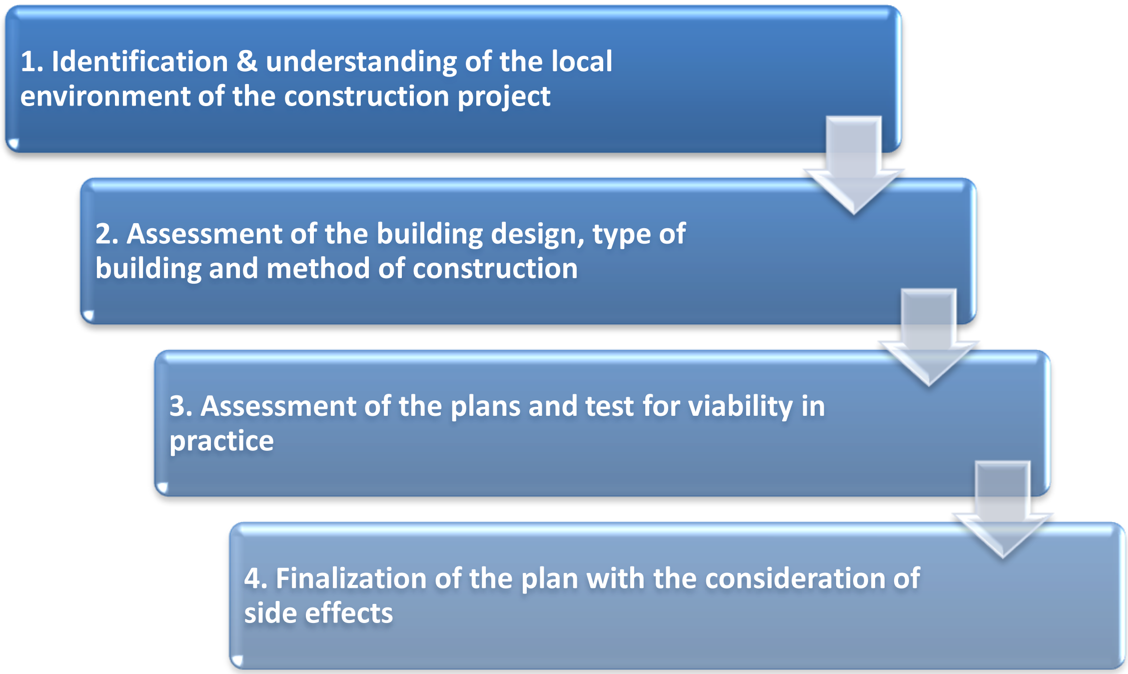


Figure 5-2: The process for the development of a logistics plan

Step 2 – Looking into the problem

Then, the design of the building should be assessed and understood. The type of the building and the method of construction should be comprehended through a methodical and extensive data capture. At this point, it is very important to realize the impacts of any constraints, the risks that may occur during construction, which may include the amount of hours which can be worked, or difficulties presented by materials, construction techniques or staffing levels. Labor histograms or capacity analysis can be used in order to visualize the workforce levels, and to establish estimations about productivity levels, while taking into consideration the number and location of unloading points, cranes and hoists, etc. Mistakes such as the need of a large piece of steel to be delivered on the construction site, while there is not enough capacity on the construction site for an articulated motor truck to deliver it, should be avoided.

Step 3 – Coming up with solutions

Afterwards, the plans should be assessed and tested for their viability in practice. Consideration of what type of vehicles, cranes, hoists and manual-handling equipment will be needed for unloading deliveries should be considered. The effectiveness of the logistics management is connected with the thorough understanding of the construction program and good preparation of the construction site in order to be able to allow the proper flow of resources. The productivity on site can only proceed at the pace of the material deliveries. Also, the consideration of the volume and flow of materials and the capacity to unload them in the time available is very important when planning for unloading procedures.

Step 4 - Optimize solutions

Finally, the logistic plan should be completed by taking into account the probable effect the weather may have on timing and logistics. A plan can always be affected by unpredictable forces of nature. Also, there can be extensive damage to many elements of a building until it is wind and water proof.

Note: *The focus of this research and the case that is going to be analyzed in the next chapters is towards the design phase and more specifically on the tasks of logistic guidelines for the design, analysis of alternative structural designs and materials utilization, material requirement specification, feasibility study of logistics concepts and logistic guidelines for tender preparation.*

For the optimization of the logistics plan several strategies can be used. In the next paragraph, an overview of logistic strategies that can be used in construction projects is presented. The presented strategies have been gathered through the literature review and have been validated through the semi-structured interviews with logistics experts. The semi-structured interview framework that has been used for this research is presented in *Appendix I*.

5.3. Logistics strategies for construction projects

There are a range of strategies that can be used to improve the logistics of a construction project. Some of these strategies can be implemented at the very beginning of the project as it regards the designers only. Some strategies can be implemented after the tendering process of a project as it is regards the contractors only and some of them can be implemented through the collaboration of the designers and contractors. The logistics strategies are mainly involved with aspects such as material management, information management, mobilization of resources, and health and safety. A brief overview of these strategies is presented in the following paragraphs:

5.3.1. Consideration of logistic issues in design

The consideration of logistic issues in design at the early phases is a very important logistical aspect. Architects and designers make logistics decisions which will influence the execution of the project. The structural design of a building influences a lot construction logistics and accordingly the efficiency of the project through the use of prefabricated elements in the initial phase of the project (Maas, 2010; Luiten, 2010). The design can also influence the traffic that arrives at the construction, the size of the construction elements and the layout of the construction site. In order to prevent logistic problems it is really important to have enough preparation time for the design. The main logistics problems are caused by the construction materials that have the biggest volume like steel and concrete. An analysis of the risks that may occur when examining the preliminary design of the architect and the construction site gives input for further consideration of logistic issues in design. The most important phase for construction logistics is the first phase of construction where a lot of prefabricated elements are being delivered on site and just in time deliveries are needed.

5.3.2. Just in time

Just in Time is a service of frequent deliveries in work packs or task loads, 'pulled' just in time for the trade to perform the next task without incurring any delays. While the general meaning of the concept needs no explanation, in the context of construction and waste reduction, the main purpose is to tackle that core problem of too much material on site. Staged deliveries and only a couple of days' worth of materials at the workplace make for a cleaner and more efficient workplace and lower the wastage rates. This strategy may of course have the adverse effect of increasing transport and handling, which is why it is most successfully employed in combination with logistics centers, often called Construction Consolidation Centers (CCC). JIT not only improves the site logistics but also reduces the risk of damage or loss of materials stored on-site as well as reducing congestion and the associated risks such as safety accidents. Just in Time is essential at the first construction phase where there is the supply of the large construction elements (van Moolen, 2010). Just in Time can be more effective with the use of logistics specialists on site. This comprises a separate team on site responsible for all materials handling traffic management, off-loading, temporary storage, and bringing materials to the work areas. When a specialist contractor is appointed for this work it is often combined with responsibility for security, Health and Safety, cleaning and other site services.

5.3.3. Logistics Centers - Construction Consolidation Centers (CCC)

A construction consolidation center (CCC) is a warehousing and consolidation operation that can serve one or several sites. Deliveries from suppliers are received and held at the CCC, typically no more than one or two weeks' usage – ideal volumes to make efficient use of the inbound transport. Contractors at the site request materials for the next one or two days and the center pick materials, makes up consolidated loads and delivers them to site. If the loads are already consolidated before the consolidation center they can be transferred directly on site. Transport from the center can serve one site or make a "milk round" to several sites. Return journeys can be used for waste bin removals. The CCC allows the implementation of JIT while at the same time drastically reducing the transport volumes and carbon emissions. It is particularly powerful in big city areas and in London projects have achieved 70% reductions in emissions from site traffic (TfL, 2008). Typically, a CCC operates in combination with on-site logistics specialists.

A CCC can provide several functions in a construction supply chain and is considered the future of construction logistics. A brief description follows of each function and its possible use in a construction supply chain. Further research is required to explore the full capability and benefits of these configurations. The functions of a CCC include (Hamzeh, Tommelein, Ballard, & Kaminsky, 2007):

Storage: storage at a logistics center can reduce supply chain costs due to reduction in inventory costs and possible economies of scale in purchasing. Variations in demand across different projects are combined into one pool of inventory resulting in lower levels of safety stock required to compensate for variations. Thus total inventory is lowered due to pooling or aggregation.

Transport: Depending on the location and function of a logistics center, transportation costs can be lower or higher depending on the trade-off between inbound and outbound transportation costs. A shorter lead time is also possible but is related to location and other factors.

Distribution: Various distribution methods can be applied such as direct shipment or milk runs. Materials stored at a logistics center can be supplied just in time (JIT) due to possible proximity to projects.

Assembly and kitting: Logistics centers can have assembly capability to supply made-to-order products with a short lead time. Made-to-stock products can be kitted at logistics centers with engineered-to-order products to form assembly packages. In addition, logistics centers can be used to adjust assemblies facing design changes thus, reducing the adverse impact of changes that are ubiquitous in construction.

Consolidation, sorting, and breaking bulk: On one hand, material ordered in bulk at possibly a discounted rate can be separated at the logistics center, sorted, and then shipped to the designated project. On the other hand, material coming from different suppliers can be consolidated and then shipped to a certain project.

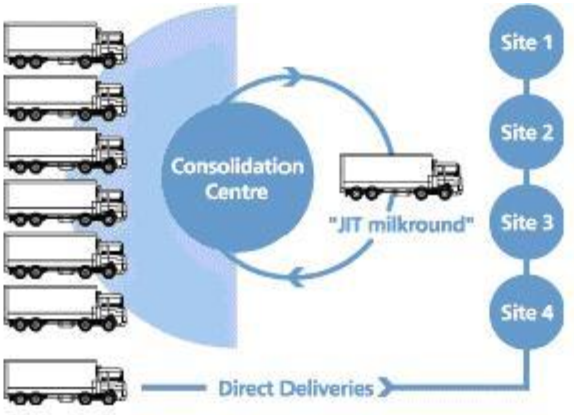


Figure 5-3: Construction site supply with the use of consolidation center

Distribution network management/vehicle routing: A logistics center can be designed to handle and optimize material distribution by assigning material packages to vehicles and choosing the best route. Vehicle routes can use milk runs or direct shipment based on project needs.

Delivery and package tracking: Using information systems (e.g., radio frequency identification or RFID), a logistics center can track the status of material and vehicles throughout the supply chain. This can increase delivery reliability when it comes to correct material orders and timely deliveries.

E-commerce services: E-commerce adds value by replacing physical paper-handling practices such as ordering with electronic ones, thus reducing cost and time. When equipped with the necessary information systems, a logistics center can apply e-commerce services such as vendor managed inventory to reduce lead times and costs while increasing supply chain reliability.

5.3.4. Prefabrication & Off Site Manufacturing (OSM)

This is an extremely effective strategy from a waste reduction perspective. For many material categories waste can be almost eliminated and waste rates reduced from 10 – 20% down to around or below 1% (TLB, 2010). OSM comes in many shapes and forms; we tend to associate it with complete bathroom pods or wall sections complete with windows, insulation wiring etc. but there are some very interesting examples of OSM in unexpected areas; in M&E installations for example. Hospitals for instance have many services and the installation of these in the ceiling of a hospital corridor is a very labor intensive task that also generates a lot of waste. By pre- fitting in-frame sections two to three meters long for all services – pipe work, water, waste, power, signal wiring – and then simply lifting them into place and connecting them up with their neighbor, enormous efficiency gains are made and waste on site virtually eliminated. Prefabrication also contains other elements like structural elements, concrete walls and floors and panels for facades.

5.3.5. Delivery management systems and other IT support

Compared to many industries the construction sector is not generally in the forefront when it comes to the use of IT. A delivery management system is a web-enabled scheduling, booking and logging system for all transport activities inbound and outbound from the site. It can also be used to book resources such as cranes, lifts and forklifts on the site. Today, systems like these act as collaborative planning tools and provide access to delivery information to all contractors in any location. ICT systems are used to tag and track materials through manufacture, distribution, assembly and installation. Commonly referred to as Tag systems they help to manage material flows by using various forms of information technology. Radio frequency identification allows a rapid and accurate reading of tags on the site. This can be done from a distance and through many materials without a direct line of sight being required. The Tag system allows the tracking of materials to the point of use and can provide considerable detail about what actually happens on-site. Suitable IT systems are relatively low cost and are becoming more widespread on construction sites (TLB, 2010).

5.3.6. Traffic Management

Effective traffic management is the key for the safe access and egress of vehicles on any construction project. This is instrumental to ensure the safety of, and minimizing disruption to, the general public, project personnel and drivers alike. Moreover, so as to fully enjoy the benefits of JIT approach, traffic management is essential (van Moolen, 2010). Poorly managed vehicle and pedestrian traffic can have serious consequences for anyone working in or around a project and also have a considerable effect on productivity. Clearly defined segregation of both types of vehicular and pedestrian traffic must be installed and constantly reviewed and adapted to minimize this risk as the project develops. Early stage pre-planning is crucial and consideration of traffic issues must addressed to ensure an effective and safe plan is developed prior to starting any project.

Usually the traffic management plans are prepared as part of the health and safety plan. Failure to safely plan vehicle and pedestrian movements on site can result in accidents, prosecutions, heavy fines and a damaged reputation. The processes involved with traffic management involve the establishment of safe vehicle and pedestrian routes ensuring that both flows of traffic can move freely and safely, identification and installation of loading and storage areas and project specific delivery management plans designed and implemented to suit the nature, location and restrictions of the construction project.

5.3.7. Early constructor involvement

Architects are aware of the logistics involved with their project but the amount of issues that demand their attention due to the increasing complexity of buildings and codes is enormous. A way to get logistics considered at the design stage is by involving constructors early in design. This requires a gradually transfer from the Design-Bid-Build procurement to more collaborative forms that enable the logistics plan to emerge with the design (Mossman, 2007).

5.3.8. Building Information Modeling

Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle. BIM uses three-dimensional, real time, dynamic building modeling software to increase productivity in building design and construction. BIM can be a tool of great value for construction logistics in the future but it is not broadly adapted in the industry yet (van Moolen, 2010). N-Dimensional design (BIM) will support the management of building data process when time becomes one of the dimensions, while nD CAD packages assist the design and construction team with the organization and management of both the construction sequence and the site before construction starts.

According to Lachmi Khemlani, founder and editor of AEC Bytes (2005):
"The current 2D mode only creates an adversarial relationship between the architect and the contractor, whereas the use of BIM will allow for more collaborative, integrated design construction teams. BIM is a revolutionary, not an evolutionary technology, which requires a complete rethinking of how we practice architecture."

Moreover, nD design support logistics as it makes the calculation of materials easier and more accurate thus reducing logistics as well as materials costs. An example from the UK illustrates this remark. A house builder at Westbury discover after the installation of BIM that they had been paying bricklayers for $10m^2$ more external brickwork that was needed to build one of their more popular house types (Mossman, 2007).

5.4. Interrelations between construction project efficiency and negative external effects

All the strategies that were discussed in the previous section are practical applications of construction logistics. At this point, an analysis will be provided in order to gain insight about how the project efficiency and the negative external effects are being influenced by this application of construction logistics and how these two concepts are interrelated. Every logistic strategy that was presented will be analyzed independently, although in reality most of them can be applied in combination so as to get the best out of this application.

5.4.1. Consideration of logistic issues in design

Project efficiency: The use of prefabricated elements speeds up the construction process, while at the same time improving the quality of the building as fewer quality failures arise due to the manufacturing of the elements in a controlled environment such as the factory.

Negative External Effects: Early consideration of logistic issues in design may lead to more balanced or even reduced traffic on and to site. Decisions about the size of structural elements, may affect the modality of transportation to construction site which consequently may reduce the local negative external effect.

5.4.2. Just in time

Project Efficiency: Construction is schedule driven, so if everyone stays on their part of the schedule then the work flows smoothly and maximum performance is achieved. Just in Time deliveries also tackle the problem of accumulating inventory on site. This has several consequences on project efficiency, as it lowers the wastage rates, improves the productivity of the workers which are not influenced by the large amount of inventory on site, and reduces the risk of damage or loss of materials stored on-site as well as reducing congestion on site and associated risks with site congestion such as safety accidents.

Negative External Effects: On the other hand, JIT deliveries may cause the adverse effect of increasing transportation and handling due to the frequency of deliveries. This may lead to increased disturbance of the surrounding environment of the construction site due to increased traffic and noise. It may also result to negative effect to economic activities around the construction site which involves loss of income due to reduced accessibility to the local business and productivity reduction due to traffic delays which influence the ability of people to perform their work.

5.4.3. Logistics Centers - Construction Consolidation Centers (CCC)

Project Efficiency: With the use of a logistics center, supply chain costs can be reduced due to reduction in inventory costs and possible economies of scale in purchasing. Thus the total inventory is lowered which improves the total project efficiency. On the other hand, transportation costs can be lower or higher depending on the trade-off between inbound and outbound transportation costs and also the investment required for a logistics center may not justified by the benefits it will bring to the project. The LCCC demonstration (pilot) project (TfL, 2008) has shown some benefits regarding project efficiency of using consolidation centers in the construction sector.

These benefits have included:

- Improvements in delivery reliability to construction sites
- Time savings for drivers delivering to the consolidation center (rather than having to deliver to the construction site)
- Time savings for trade contractors working at the construction site in collecting or waiting for delivery of materials

Negative External Effects: With the use of a logistics center, the traffic towards the construction site is being managed more efficiently and this has a positive influence on the minimization of negative external effects. The distribution network management and the vehicle routing can optimize material distribution and reduce the negative effects related to the disturbance of the local environment around site with consolidated loads transportation during night for example. The LCCC demonstration (pilot) project (TfL, 2008) has shown the benefits of using consolidation centers regarding the negative external effects in the construction sector. These benefits have included:

- Reduction in total goods vehicle journeys to construction sites
- Elimination of deliveries by articulated goods vehicles, significantly reduced deliveries by vans, and far greater use of rigid goods vehicles for deliveries to construction sites when using a consolidation center
- Associated reductions in CO_2 and noise emissions, and traffic casualties
- Increasing network capacity by reducing curbside activity
- Smoothing traffic, by reducing deliveries in the congested peaks
- Scope for the consolidation center to provide packaging, waste and material return collection services for construction sites

5.4.4. Prefabrication & Off Site Manufacturing (OSM)

Project Efficiency: Prefabrication is the most effective strategy from a waste reduction point of view, but also for the enhancement of the project efficiency in terms of time as the construction process speeds up with the use of prefabricated elements. Still though, OSM is considered more expensive, with high initial capital outlay, higher design, and cranage and transport costs. Although cost seems greater with OSM there appears to be a lack of awareness of the possible cost savings over the whole life of OSM products. Production efficiencies, given sufficient volumes, together with reduced on-site activities can enhance the total project efficiency by decreasing overall cost (Blismas & Wakefield, 2009). OSM also improves the integration between the manufacturing sequence in the factory and the assembly sequence at the building site. The design choice of using prefabricated elements result in decentralization and decreasing of inventories, shorter distances for transport through local-for-local production, more efficient material handling and improved service to the contractor due to increased flexibility (Voordijk, 2000). On the other hand, problems may arise when the higher quality and precision of factory products is fitted onto less imprecise components on site.

Negative External Effects: The use of prefabrication and OSM results to waste reduction and to reduced impact of construction activities on site such as noise, minimal ground disturbance, and vehicle movements. Moreover, OSM seems to reduce on-site risks through lower time on-site, lower hazard exposure, fewer trades and fewer people on-site. On the other hand, OSM necessitates the use of larger and heavier components that increase the consequences of any accidents. Also the need for mobile cranes with OSM has specific safety risks associated with large loads that need to be considered. Finally, prefabricated elements may need specific transport arrangements that may create congestion around the site.

5.4.5. Delivery management systems and other IT support

Project Efficiency: Information flow is very important for the construction supply chain and logistics. An efficient ICT system may act as a collaborative planning tool that will provide access to delivery information to all contractors involved with a construction project. By this the project's efficiency is enhanced through the reduction of incompetencies regarding inbound and outbound transportation of materials, labor programming, resources planning, etc.

Negative External Effects: A delivery management system which will be supported by an efficient IT system will provide considerable details about what actually happens on a construction site. This will enable a better programming of the required logistic activities which may result to reduced transportation of materials, reduced waste and a smooth operation of the construction site which will help to minimize the negative external effects.

5.4.6. Traffic Management

Project Efficiency: Effective traffic management with clearly defined segregation of both types of vehicular and pedestrian traffic will minimize the risks regarding transportation on and to site and reduce the possibilities for heavy fines and damaged reputation for the construction company.

Negative External Effects: Poor traffic management may lead to major disrupt of the general public, the project personnel and drivers in a similar way. Major congestion, public transport disruptions, traffic accidents, traffic rearrangements and damage to infrastructure are some of the risks related with negative external effects which are influenced by the traffic management.

5.4.7. Early constructor involvement

Project Efficiency: Early involvement of constructors at the design stage is a way to enable logistics plan to emerge with the design. This may enable the use of set-based design, a process that keep open the design space in order to evaluate different design options against both design and constructability criteria and allows more time to develop off-site prefabrication solutions which can lead to reduced cost and faster construction (Parrish, Wong, Tommelein, & Stojadinovic, 2007).

Negative External Effects: As it has been discussed before, early constructor involvement gives more time to evaluate different design decisions and develop off-site prefabrication solutions which can lead to safer construction and reduced waste.

5.4.8. Building Information Modeling

Project Efficiency: Building Information Modeling and n-Dimensional design can enable the design and construction team to look at the organization and management of both the construction sequence and the site before the actual start of the construction. BIM enables all project members to share the same up-to-date information. Moreover logistic benefits result from moving to BIM, as the 3-D representation of the project helps the client realize earlier any changes he may want. Some of these changes can be made at the design stage with less cost and less waste, which will improve the total project efficiency.

Negative External Effects: Information about the construction sequence and the construction site that arise with the use of BIM is really important in order to manage the construction logistics processes on and to site. By this, transportation of materials on site may be reduced and less waste which will lead to environmental pollution may be generated.

> **Note:** *The overview of the logistics strategies has been considered important so as to create a broad perspective about potential applications of logistics in construction projects. From the above mentioned strategies, consideration of logistics issues in design, just-in-time, prefabrication and off-site manufacturing, and traffic management are applied in the current phase of the Delft project and will be described in the following chapters.*

5.5. Material transportation, storage and handling

The most important stage from a logistics perspective is the execution phase of a construction project where the transportation of materials takes place. The execution phase can be separated in three sub-phases: *site preparation for the building* (phase 1), *structure construction* (phase 2), and the *completion of the building* (phase 3). Different types of traffic need to be considered according to each phase. The first phase requires specialized companies, for example in pile driving heavy and outsized materials will be supplied. During the last phase the installation sector (electric installations, heaters) and the finishing sector (painters, plasterers) will provide materials in smaller vans and the traffic considered is more relating to persons going to the site (Oostrum, 2003).

The most important materials transported in phase 1 and 2 are steel, concrete and concrete products, bricks, asphalt and wood. The materials can be grouped with respect to granular (concrete, asphalt) or shaped in a certain form which includes large loads (concrete elements, steel structures) or small loads (isolation materials, bricks, window frames) that can be consolidated in one payload. According to van Moolen (2010) during the first phase of the construction truck loads are generally full, mostly because of the transportation of specialized prefabricated large elements, while at the last phase there are only small deliveries. At the beginning there are few trucks but fully loaded and at the end there are a lot of trucks with small deliveries and this creates opportunities for consolidation of loads.

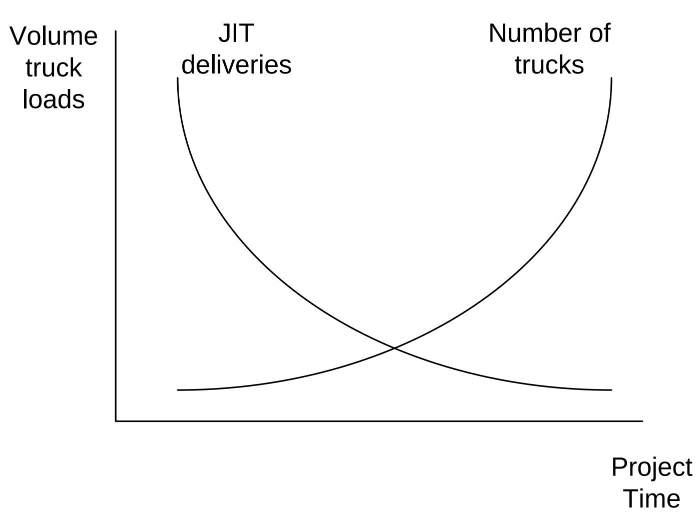


Figure 5-4: Volume of truck loads according to the progress of project (van Moolen, 2010)

Moreover, van Moolen (2010) declares that there is not one solution for logistics in construction; logistics have to grow with the construction itself. He illustrates this argument with *figure 5.4*, which shows the volume of truck loads according to the progress of the project. JIT deliveries of full truck loads are the point of attention in the beginning of the project, while consolidation of loads is more important during the last phase of the project. A completed building comprises a wide range of materials and components that require specific attention to ensure that they are not wasted. *Table 5.2* shows suggested categorizations of materials to demonstrate different handling and storage issues.

March (2009) presents a list with issues concerned with storage and handling in order to reduce waste:

- When unloading certain materials the proper equipment is needed to ensure safe and secure lifting, such as using lifting beams so vertical lifting can be assured without structurally damaging the component
- Appropriate transportation methods should be used when transporting materials in order to ensure that no damage will occur
- Storage areas should be clean and level enough to permit proper storage
- Appropriate designed support structures, racking and spacers should be provided
- All goods sensitive to damage from different climatic conditions should be protected by covers or stored in a secure cabin
- Certain goods, such as cement, have limited shelf life and need to be stored in such a way as to permit the earliest delivered material to be used first
- Certain materials are delivered in bulk, so adequate and appropriate storage has to be provided. This can mean silos, in case of cement, or constructing bays to segregate the different aggregates to stop cross pollution
- Consideration should also be given to combating theft and vandalism

	Examples
Valuable (small items)	Door and window furniture
Consumables	Nails, tie wire, brushes, nuts and bolts, fixings
Short shelf life	Cement
Medium shelf life	Paint, untreated timber, reinforcement steel
Bulk	Bricks, blocks, aggregates, sand, structural steel
Environmental hazards	Fuel, oils
Easily damaged	Plasterboard, polystyrene
Components	Windows, doors, cladding panels

Table 5-2: Materials categories (March, 2009)

In the construction industry it is common that the unloading and movement of materials, both to storage areas and finally to the workforce, are a responsibility of the trade contractor that has procured them. This adds even more to the complexity of the construction supply chain and can be a source of inefficiency for the construction site. The options that can be used for material handling in order to lift materials off a truck include a forklift, a crane, a beam winch, or as a last - but quite often used - resort muscle power. In case there is no possibility to build an unloading platform at truck height which will allow the unload of materials directly into a hoist, the options can be either crane to access platform, beam winch or gantry crane to a level one gantry, or forklift to ground floor hoist. These options are mainly applied on handling materials transported by truck. Different modes of transportation such as water or rail transportation involve more specialized handling options.

Figure 5-5: Different kind of material handling options

During the last years, a big discussion is going on about the benefits and the importance of the alternative modes of transportation that can be used for a more sustainable future of the construction industry. Although this is a praiseworthy ambition, the construction reality dictates that for most projects it is hard to translate this ambition into practice. The main reason for this is that in case of absence of proper infrastructure that can support water or rail transportation the investment needed in order to make alternative transportation a reality will probably not be justified by the benefits that this investment will bring.

Moreover, the rail network is already congested by the passenger trains, which are the priority, and in case of a delay due to track repairs or accidents freight often has to wait for a new time slot for transportation. Also, water transportation is slow, not suitable for moving small items due to the extra material handling processes and is suitable mostly for short distances.

Nevertheless, a good logistics manager has to consider all the options available and in case that a project is located near a river or a railway, these options should certainly be considered. Rail and water transportation are much more sustainable means of transportation that road transportation. One train can transport the equivalent of almost 75 motor truck loads, while a barge can replace 8.5 motor trucks and can create substantial reductions in CO_2 emissions (Sullivan, Barthorpe, & Robbins, 2010).

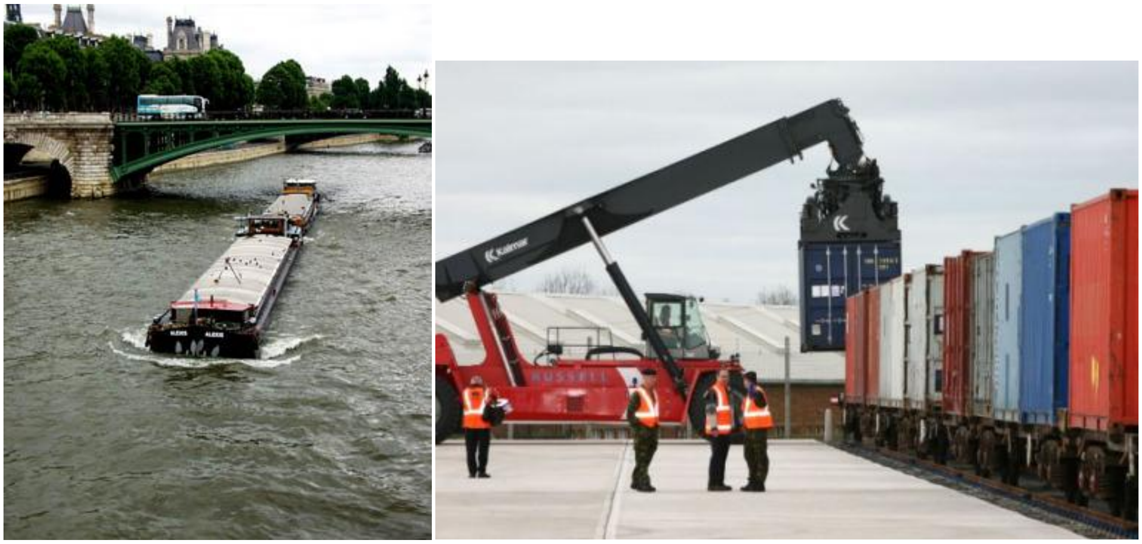


Figure 5-6: Different modes of transportation for construction materials

5.6. Reflection on literature findings

This chapter completes the theoretical background that will support the empirical research as it has been described in the research design section in *chapter 1*. The application of construction logistics in real life becomes more apparent through the description of important logistic tasks and processes that occur during a construction project life cycle according to the interpretation of Sobotka & Czarnigowska (2005). In addition, the identification of the steps needed in order to develop a logistics plan for a construction project by Sullivan, Barthorpe & Robbins (2010) gives a proper level of detailing about the process that has to be followed so as to gather the information needed and to identify the restrictions and opportunities for the proper deployment of a logistics plan. Areas of consideration such as material handling, transportation, traffic on and around site, site organization, etc. are implemented into the way of thinking about delivering better logistics in construction projects. While the theory has been clearly identified as regards the concept of construction logistics, its practical applicability should be confirmed and justified by practical examples and experience. Semi structured interviews have been conducted with three experts from TNO, an independent research organization, who have been involved with the topic of construction logistics in several construction projects. The semi-structure interview analysis and framework are presented in detail in *Appendix I*. Moreover, the interviews validated the construction logistics strategies that are being used currently or are considered to be used in the near future.

Finally, the industry practice of construction logistics needed to be identified so as to understand what kind of processes are considered as important in a real construction project. A number of websites of companies that are active in the field of construction logistics have been assessed (CSB Logistics, 2010; Amalga, 2010; Alandale Logistics, 2010; Streif Baulogistik, 2010; Munnelly Support Services, 2010).

The services that these firms are offering regarding construction logistics include: *Movement & Management of Materials, Security Services, Cleaning Services, Waste Management, Site set up and welfare provision, Traffic Management, Delivery Management, Health & Safety, Fire Management and Equipment Handling.* These services have been offered either as parts of an integrated construction logistics solution or as separate tasks that could be handled by the companies.

Logistics Element	Literature				Interview		
	Silva & Cardoso (1998)	Sobotka & Czarnigowska (2005)	Mossman (2007)	Sullivan, Barthorpe & Robbins (2010)	Luiten (2010)	Maas (2010)	Van Moolen (2010)
Materials Management	✓	✓	✓	✓	✓	✓	✓
Site infrastructure	✓	✓	✓	✓	✓		
Mobilization of construction site	✓	✓	✓	✓		✓	
Schedule control	✓	✓			✓		
Information Management	✓	✓	✓		✓		✓
Traffic Management			✓	✓		✓	✓
Critical Risks Management				✓		✓	✓
Site Security			✓	✓			
Health & Safety Management			✓	✓			
Waste Management		✓	✓	✓			

Table 5-3: Assembly of literature review and interviews analysis

Table 5.3 is the assembly of the literature review and interview analysis regarding the most important elements of construction logistics. As it has been expected, materials management is the most prevalent aspect of construction logistics. Processes like materials delivery and handling have been an important part of logistics since its existence. When it comes to construction logistics, it can also be noticed the importance of the site infrastructure, information management and traffic management that can facilitate the proper flows of resources on site. *Table 5.3* recognizes the most important elements of construction logistics that can be taken into account for the development of a construction logistics plan.

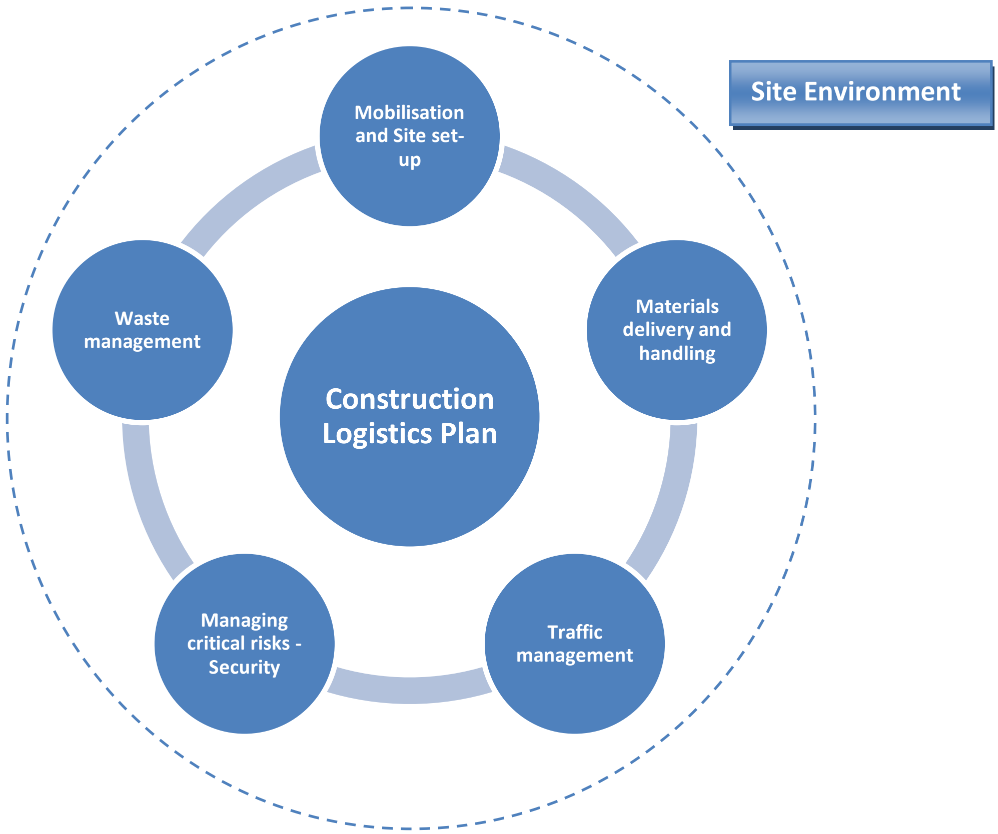


Figure 5-7: Areas of consideration for the analysis of a logistics plan

After recognizing the most important elements of construction logistics and consultation with Robert Gips, who is the responsible for the development of the logistics plan for the new Delft train station and City Hall, the areas of consideration will be used for the analysis of the case in *chapter 7* can be seen in *figure 5.7*. Of course, the initial step of the construction logistics analysis is the identification and the assessment of the construction site environment and this process is described in the next chapter.

Framework for the construction logistics analysis of the new Delft train station and City Hall

One step before the introduction of the case that is being studied for this research, it is important to establish the framework that will be followed for the conduction of the construction logistics analysis of the new Delft train station and City Hall. The framework describes the process that has been followed in order to come up with recommendations regarding the development of a logistics plan for the construction site of the Delft project. The steps for the development of a logistics plan have been identified at the beginning of the chapter. These steps are being processed and integrated with the case study approach that has been described in *section 2.5* and the areas of consideration for the analysis of the logistics plan that have been identified through the reflection of literature findings.

The framework for the construction logistics analysis of the new Delft train station and City Hall is illustrated in *figure 5.8*. It is a process that begins with the general assessment of the project environment (*step 1 – the general overview*), followed by the information gathering process (*step 2 – looking into the problem*) which gives the required input for the evaluation of the situation (*step 3 – coming up with solutions*). The analysis is finalized with the design process (*step 4 – optimize solutions*) which lead to the development of a drawing of an integrated approach for the logistics plan of the new Delft train station and City Hall construction site.

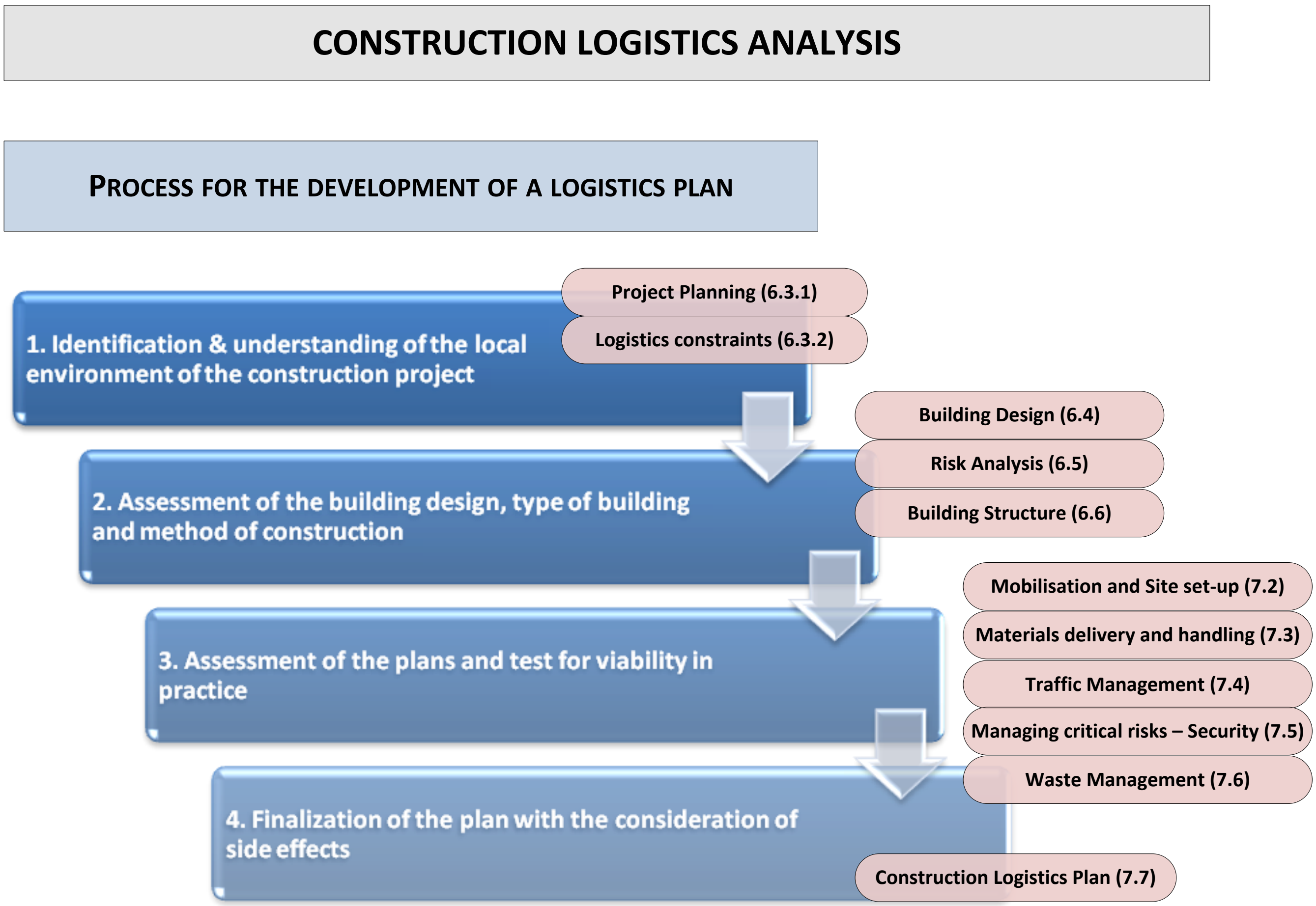


Figure 5-8: Framework for the construction logistics analysis

In conclusion, it can be stated that the above mentioned framework for the construction logistics analysis is satisfyingly covering the topic of the applicability of construction logistics in the case that will be studied as it is a synthesis of the literature findings of the previous chapters and the knowledge that has been acquired through interviews with experts on the field.

5.7. Summary & Sub-conclusions

This chapter introduced the "Construction Logistics" in practice. Initially, the planning construction project logistics are discussed which include important tasks and processes that occur at every stage of a construction project from the initiation and programming, to the design, planning, execution and commissioning. Subsequently, the steps that are needed in order to develop a logistic plan are discussed. Afterwards, a range of strategies that can be used in order to improve the logistics of a construction project and the way they influence the project efficiency and negative external effects are analyzed. The chapter is completed with a discussion about the material transportation, storage and handling which is a very important aspect from a logistics perspective.

The theoretical findings phase is finalized with this chapter. A reflection on the literature findings is discussed at the end of the chapter as a final step before proceeding to the case that will be studied. The literature findings are integrated with the case study approach in a framework for the construction logistics analysis that is followed for the case which is discussed in the next chapter. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

Topic	Description
Planning construction project logistics	• Logistics have to be planned out in detail at the beginning of the project • A logistic plan is a strategy on how to approach the construction work at each stage of its development • Construction Logistics deals with many technical, organizational and environmental issues affecting the project cost, time and quality of execution • Several logistics tasks occurs at every stage of construction project
Development of a logistics plan	• The management of the construction logistics tasks per each project phase is possible through the development of a constructions logistics plan. Several logistics strategies for constructions can be used so as to optimize the logistics plan • There are several steps in order to develop a logistics plan which include: ➢ Identification and understanding of the local environment of the construction project ➢ Assessment of the building design, the type of the building and the method of construction ➢ Assessment of the plans and testing for viability in practice ➢ Finalization of the logistic plan while taking into account side effects that may have an impact such as weather conditions
Logistics strategies	• There are a range of strategies that can be used to improve the logistics of a construction project: ➢ Consideration of logistic issues in design ➢ Just-in-Time ➢ Logistics Centers – Construction Consolidation Center (CCC) ➢ On-site logistics specialists ➢ Prefabrication and Off Site Manufacturing (OSM) ➢ Delivery management systems and other IT support ➢ Traffic Management ➢ Early constructor involvement ➢ Building Information Modeling • The use of these strategies may have a positive or negative influence on the project efficiency and the negative external effects, that’s why it should be carefully analyzed how to apply them

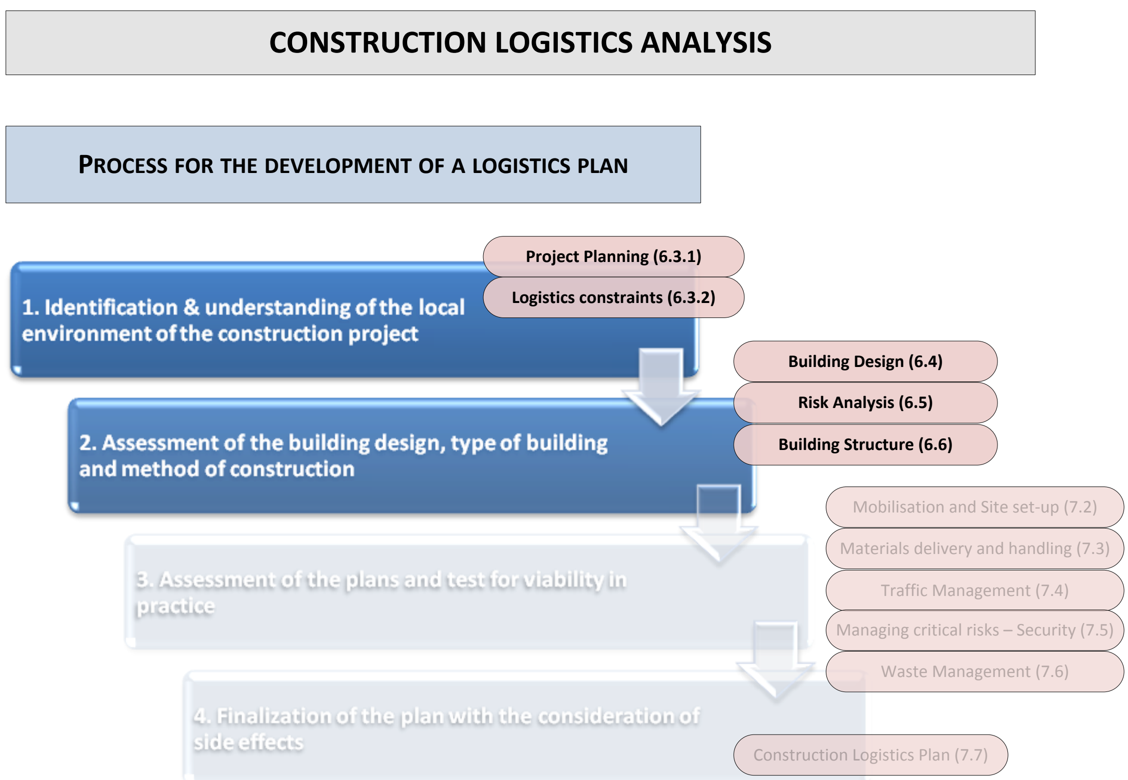
Material transportation, storage, handling	• Different type of traffic needs to be considered according to each phase of the execution of the project (site preparation for the building, structure construction, completion of the building) • The most important materials transported during the first two phases of execution are steel, concrete and concrete products, bricks, asphalt and wood • Issues concerned with storage and handling in order to reduce waste: ➢ Safe and secure material handling according to the type of material ➢ Appropriate transportation methods in order to minimize material damage ➢ Clean and adequate storage areas ➢ Provision of appropriate designed support structures, racking and spacers ➢ Special attention should be given to goods sensitive to damage from different climatic conditions ➢ Adequate and appropriate storage for bulk materials ➢ Theft and vandalism should be considered • Options for material handling include the use of forklifts, cranes, beam winches, muscle power • Rail and water transportation are alternative modes that can be used for material transportation. The advantage is that these modes are more sustainable than road transportation. The disadvantage is that usually they are impractical and expensive
Reflection on theoretical findings	• Theoretical background of construction logistics application: ➢ Description of important logistic tasks and processes that occur during a construction project life cycle ➢ Identification of the steps needed in order to develop a logistics plan for a construction project • Practical applicability of construction logistics justified by practical examples and experience: ➢ Semi structure interviews with TNO experts ➢ Industry practice of construction logistics • Comparison of literature findings and interviews analysis to define areas of consideration for the analysis • Areas of consideration that link theory with the case that will be studied include: ➢ Mobilization and Site set-up ➢ Materials delivery and handling ➢ Traffic Management ➢ Managing critical Risks - Security ➢ Waste Management

Table 5-4: Summarizing Key Elements of the Chapter

6. THE NEW DELFT TRAIN STATION AND CITY HALL

After the completion of the theoretical findings phase, the next step, as it has been demonstrated in the research design section, is the conduction of the empirical research. This chapter is the commencement of the case study and follows the model of analysis that has been described in *chapter 2*. The chapter identifies the areas where logistics can be applied in order to enhance the project efficiency while minimizing the negative external effects by answering the following research sub-question "*How can construction logistics apply to the case of the new Delft train station and City Hall, in order to enhance the project efficiency and reduce the negative external effects?*". In order to answer the above question, the project scope is identified in *section 6.1*, the project organization is illustrated in *section 6.2*, while *section 6.3* analyzes the project planning. The investigation of the case begins with the assessment of the building design in *section 6.4*, the identification and analysis of the main risks in *section 6.5* and the chapter is finalized with the assessment of the building structure in *section 6.6*.

This research follows the steps taken from ABT towards the development of the logistics plan for the project and will comprehend this process in order to investigate the relationships between the construction logistics, the project efficiency and the negative external effects in the local environment. The first two steps that are being examined in this chapter are illustrated in the following figure:



6.1. IDENTIFICATION OF PROJECT SCOPE

Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS) is the development company for the Delft station zone and was established by the municipality of Delft in 2007 in order to implement the project "Spoorzone Delft". OBS has the task to implement the agreements established with the stakeholders of the project, in the field of urban development and the hub of public transport. The case that will be investigated is the construction of the new Delft train station and City Hall.

The new Delft train station and City Hall (*stadskantoor en stationshal Delft*) is a unique project in the heart of Delft next to the current train station. A new building will be constructed which will have two functions: a recognizable and functional train station and a representative accommodation place for the municipality of Delft, with space for the public counters and workstations for about 1000 employees. The new building will be constructed on top of the new railway tunnel of Delft, in the interface between two different projects and on a small construction site in the middle of the city. This situation may cause several problems regarding building logistics, project efficiency and negative external effects in the local environment. *Figure 6.1* illustrates the design of the new building and its positioning on the top of the new railway tunnel. The new building will be constructed in two phases, the first one regards the part of the building that is built above the tunnel, and when the tunnel is in use and the old railway viaduct is demolished, the second phase will finalize the building. The new train station was originally planned to operate in 2013 and the City Hall to be completed in 2015. Due to the complexity of the project, the size of the construction site, the number of the contractors involved in the project and the uncertainties that will arise from it, OBS has assigned ABT, which is also the construction consultant for the design phase to develop a logistics plan for the construction site.

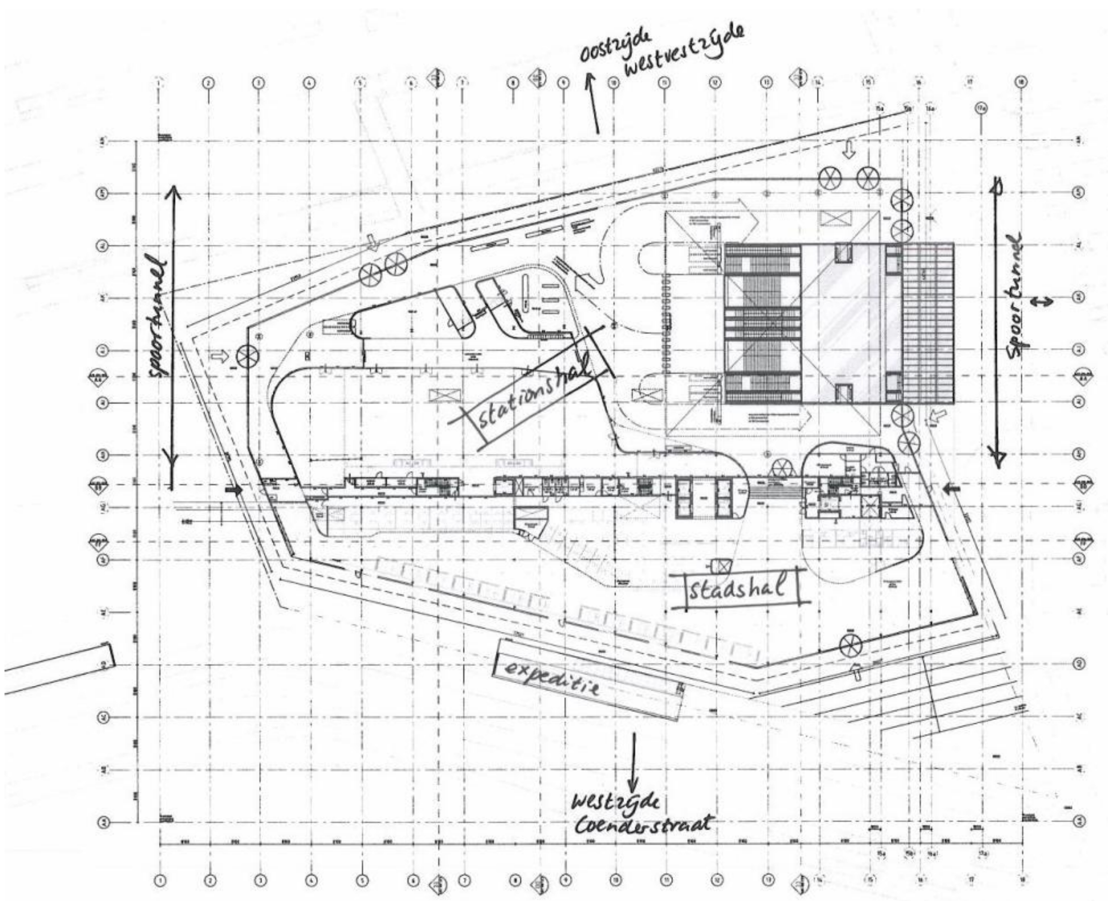


Figure 6-1: Drawing of the new Delft train station and City Hall (ABT, 2009)

6.2. Project Organization

In this paragraph the project organization at the current stage will be presented. The project organization is very important in order to understand the relationships and the responsibilities of the different actors involved in the design phase. *Figure 6.2* presents the current project organization.

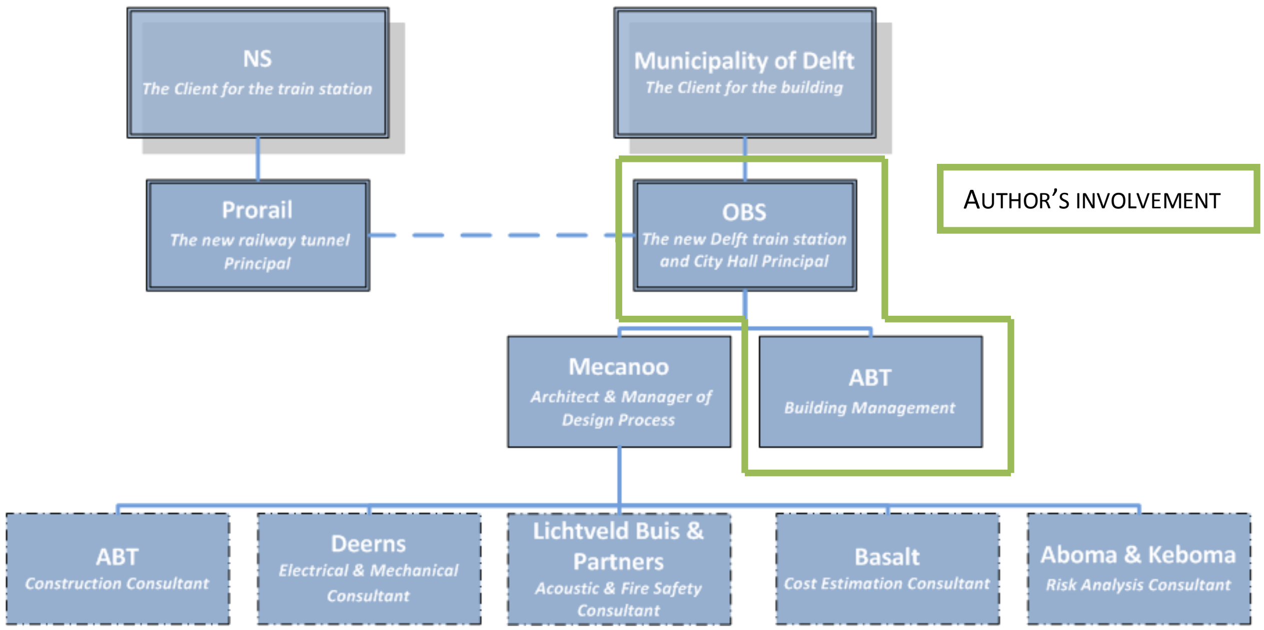


Figure 6-2: The new Delft train station and City Hall project organization

Municipality of Delft

The municipality of Delft is the client of the new Delft City Hall. It has assigned OBS as the principal of the project that is handling the relationships with the other actors involved. The municipality of Delft is also providing the funds for the project and is setting the requirements about the proper construction of the building. The interest of the municipality of Delft is that the project will be realized within budget, time and quality as it has been defined during the preliminary design phase and also has a great interest on minimizing the negative external effects in the city of Delft so that there will be minimal distortion of the everyday life of Delft citizens during the execution of the project.

NS

Nederlandse Spoorwegen (Dutch Railways) is the principal passenger railway operation company in the Netherlands. Its trains operate over the tracks of the Dutch national rail infrastructure company Prorail. NS is the client of the train station and its interest is towards the completion of the new railway so its train can operate through the new tunnel and train station of Delft.

Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS)

OBS is the principal of the new Delft City Hall and the ground floor of the station hall. OBS's role is to manage the project and is the intermediate between the design teams, the future contractor that will build the project and the interaction with the other contractors that are already working on the area. Due to the nature of the building that will be built on the top of the new tunnel, OBS has to make sure that everything will be ready to start building when the future contractor will arrive on the construction site. From this point of view they have a great interest in the logistics on site in order to make sure that everything will be ready to start the construction of the new building. Moreover, OBS is responsible for the communication between the different actors of the project. Finally, OBS directs Mecanoo and via Mecanoo, the other design teams in the design process.

Prorail
Prorail is a government task organization that takes care of the maintenance and extensions of the national railway network infrastructure of the Netherlands, of allocating rail capacity, and of traffic control. The municipality of Delft through OBS and Prorail cooperate in the project Spoorzone Delft which includes the construction of the new Delft train station and City Hall. Prorail awarded the construction of the new railway tunnel of Delft to the Combinatie CrommeLijn VOF (CCL). CCL has to construct a tunnel of 2.3 km, an underground train station, a parking garage along the Spoorsingel, the site preparation of the entire planning area and to carry out a large part of the design of the public space in the surrounding area of the project (Spoorzone, 2010).

Mecanoo
Mecanoo is a firm of architects which is based in Delft. Mecanoo is the leader of the design team, responsible for the construction engineer, the technical engineer and the costs of the building. Mecanoo is the process manager of the design with a double role, initially as the architect of the building and secondary as the responsible party for the management process of the design.

ABT
ABT is a multi-disciplinary consultancy firm. Structural engineering and building management are among other disciplines in which ABT is active. ABT is mainly responsible for the structural design of the new Delft train station and City Hall, to integrate the structure into the architectural design. In addition, ABT's building management team is involved in the construction logistics of the Delft project and is the company with whom the author is mainly involved for this research. ABT provided the drawings for the structural design of the building and is also assigned the task of developing a logistic plan which will serve as input for the future contractor of the project.

Deerns
Deerns is a consultancy firm with expertise in the field of electrical, mechanical and energy engineering solutions and building physics. Deerns is responsible for the mechanical and electrical designs of the new Delft train station and City Hall.

Lichtveld Buis & Partners
Lichtveld Buis & Partners (LBP) is an engineering consultancy in the field of building physics, environment and spatial planning. Lichtveld Buis & Partners is responsible for the acoustics and fire safety design for the new Delft train station and City Hall.

Basalt
Basalt is the building cost consultant for the new Delft train station and City Hall and is responsible for the cost estimate of the project.

Aboma & Keboma
Aboma & Keboma is a business provider and is responsible for the risk analysis for the new Delft train station and City Hall.

6.3. Analysis of Project Planning

6.3.1. Current state of the project planning

The new Delft train station and City Hall is partly located in the new tunnel trace and partly projected onto the existing rail route. Due to the requirement for continuous operation of the trains the construction of the building cannot be constructed in one phase. The construction sequence is very important for the realization of the building. The current phasing and construction of the building is as follows (Mecanoo, 2009):

1. Construction of the tunnel and the underground platforms (the shell of the building is not included during this phase)
2. After the construction of the tunnel, **construction phase A** will start where the part of the building above the tunnel will be built. This step is necessary for the operation of the new train station
3. Existing platforms dismantling and finishing of the new train station
4. After the beginning of operation of the new train station, the old part of the railway will be demolished as the train will go through the new railway tunnel
5. **Construction phase B** begins, finishing of the City Hall
6. Full implementation of the new Delft train station and City Hall

This division of phases, which is presented in *figure 6.3*, brings a number of complications with it. Due to the fact that the train station should operate during the *construction phase B* special attention should be paid to the temporary facilities that will be needed for the mechanical and electrical installations, the construction and stability throughout all phases, the preparation of construction cranes and escape routes in case of emergency.

From a construction logistics perspective there are a lot of issues of attention due to the complexity and the phasing of the project such as the access to the construction site and the availability of space on the construction site. Although there have been agreements with the tunnel contractor, Combinatie CrommeLijn VOF (CCL), which is the responsible party for the logistics in the whole area about the continuous access on the construction site during construction phases A and B, OBS still has to assess carefully the construction logistics to make sure that the building process will be realized without problems.

The milestone planning is taken from the overall planning for the Delft station zone and includes[3]:

- Tunnel construction work completed on November 2011
- Delivery of train station on May 2013
- Start of construction phase B on September 2013

Note: *At this point it needs to be mentioned that the planning and scheduling of the new Delft train station and City Hall depends heavily on the planning and phasing of the construction of the tunnel. This means that there is a high possibility of delay on the completion time and the milestone planning of the project*.

[3] The overall planning during the time of the conduction of the research has been changed to: Tunnel construction work on March 2013, Delivery of train station on January 2015 and Start of construction phase B on May 2015

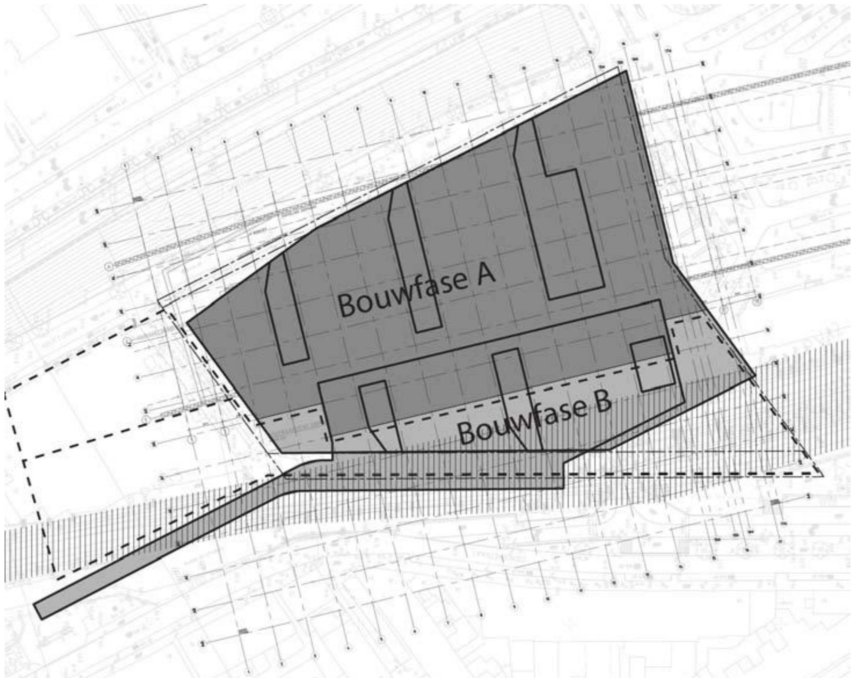


Figure 6-3: Phasing and site accessibility (Mecanoo, 2009)

6.3.2. Logistics constraints

Logistics constraints have been identified as an important element in the development of the construction logistics analysis in *chapter 5*. This section will identify the logistic constraints of the new Delft train station and City Hall project.

The physical constraints regard mostly the building location. The building location is quite inaccessible especially during the first construction phase due to the fact that the railway on the one side will be operational during construction. Materials will be difficult if not impossible to be transferred through that side. Moreover, the complexity and difficulty is increased due to the fact that the other side is bordered with a canal, while there is also a tram line running next to the canal. The access to the site is possible for big trucks only through the connection from Westvest, the road next to the tram lines, and this might create a bottleneck for the construction traffic. Moreover, the complexity of the construction site increases even more due to the fact that there will also be a temporary staircase so that the people can reach the trains and a temporary bicycle parking in the area that the new building is going to be constructed. This means that there are also going to be problems related with the traffic of people and cyclists, who should be able to reach the train platform, which need to be addressed.

Transportation of large elements through water could be an option for this congested construction site, but several factors make this possibility difficult. As it can be seen in *figure 6.4* there are two possibilities for using water transportation, the big canal De Kolk and the smaller canal Buitenwatersloot. These two waterways are blocked by bridges. Some of them are mobile and can allow the transportation of an element of big height or size, but in the Delft case there are also fixed bridges which have to be demolished in order to allow the transportation of these elements. Even though it is a decision of the client, at this case the municipality of Delft, to decide whether it is beneficial to opt for this possibility it is wise to think of different scenarios that can make the transportation of large elements feasible without so many complexities and costs. The transportation of bulk material over water can be an option that the future contractor should take into consideration.

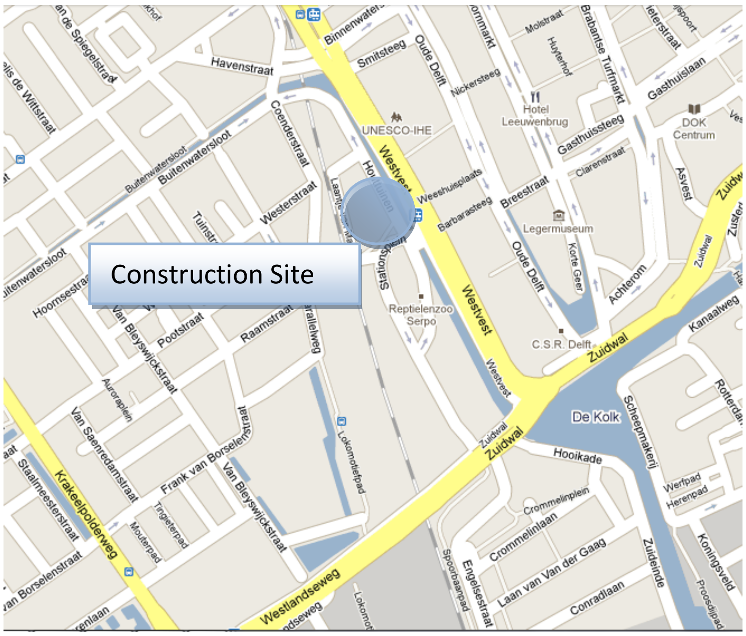


Figure 6-4: Map of the surrounding area of the new Delft train station and City Hall

Rail transportation should also be considered for the Delft case, although there are a lot of constraints with most important the fact that the scheduling of the trains in case of material transportation is a very complex process that takes a lot of thinking ahead and a lot of information needs to be available at an early phase of the project. This means that it can be considered as a possibility when the planning schedule of the project is determined in detail, which is not possible at the current stage of the project due to the uncertainties of the tunnel construction which affects the planning.

6.4. Assessment of the Building Design

The first step in order to gather the information and data needed to develop a logistic plan is to assess the building design and the construction site area so as to gain understanding of the local area, like perimeters, access points, surface area and vehicle movements which need to be considered carefully. Moreover, the design of the building needs to be considered and understood so as to comprehend the impact of any constraints that exist like difficulties presented by materials, construction techniques or staffing levels. The new Delft train station and City Hall is a universal building design and as compact as possible to fit within the construction limits of the zoning. It will contain the City Hall offices and public hall with surface of around 33,000 m² and the train station main hall with commercial space, including a mezzanine, with a surface of 3,645 m². The building ratios are (ABT, 2009):

- Building dimensions length: 124 m
- Width: 85 m
- Height: 22.5 m (floor to roof)
- Gross floor area around: 33,000 m^2
- Building volume around: 120.000 m^3

As it can be noticed, the volume of the building is quite large, especially when you compare it with other large buildings in the city of Delft. The architects came up with this design as a result of the program of the building, as it is the Delft train station and a municipality building and both have public programs. An illustration of the future shape of the building is shown in *figure 6.5*.

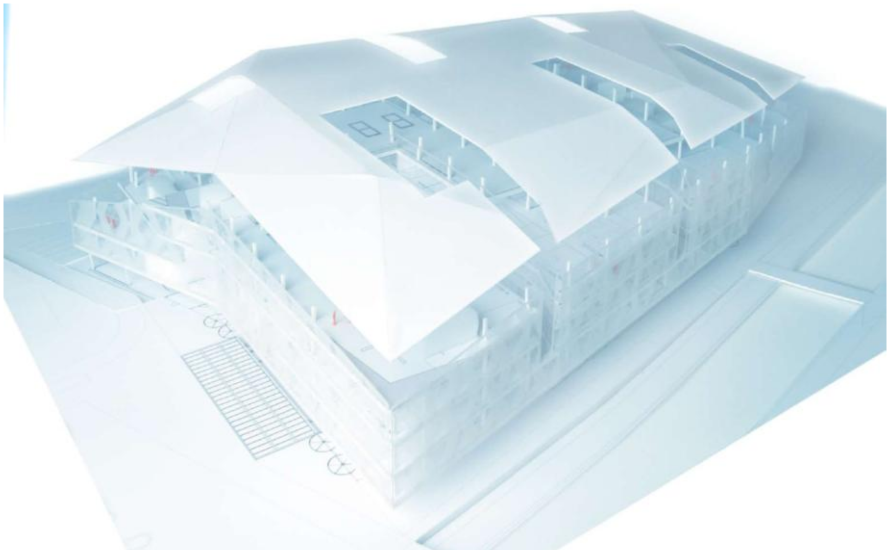


Figure 6-5: 3D-design of the new Delft train station and City Hall

The horizontal division of the building volume provides a distinction between the public and the private area through the use of a plinth of clear glass above the raised office landscape of the city hall. The ground floor is the floor where the train station meets the city hall; the two functions are subtly separated by a glass wall.

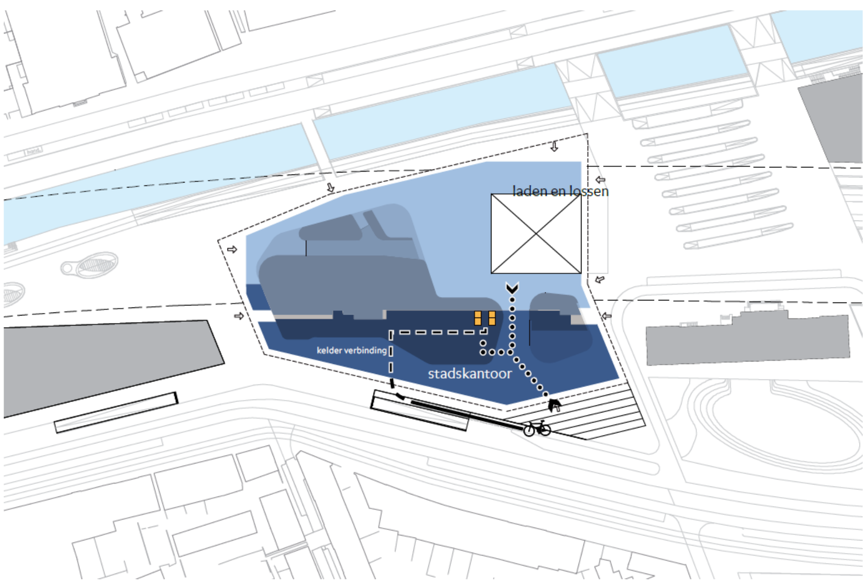


Figure 6-6: The separation of the two functions of the new Delft train station and City Hall

Figure 6.6 illustrates the separation of the two functions; the light blue represents the station and the dark blue the city hall. The ground floor includes also desks, the front office of the municipality, consulting rooms, stairways and elevators to the upper offices, commercial and sanitation facilities. On the first floor there is a multipurpose room, a restaurant, meeting rooms and the rooms for the Mayor and the city council. The floors above contain the offices for the employees of the City Hall and the fifth floor is used entirely for installations.

The building consists mainly of steel structure elements with concrete floors and the difficulty in the design is the fact that the offices above the station hall have the big trusses that are used to support the structure, running through them. The structure elements will be analyzed later on this chapter. Another difficulty for the design is the fact that the building construction can only go down on the side of the walls of the tunnel column and in the north side it can go down in the middle tunnel column. This creates the problem with the interface of the two different projects, the railway tunnel and the building, and it has quite an impact on the design.

The use of the columns of the tunnel in order to be able to construct the building on the top makes the project quite complex in the design but also in the construction and the planning. The interaction with the tunnel below is complicated as the tunnel contractor is already working on the site. According to Jasper Tonk (2010), architect and project leader at Mecanoo, the difficulty in the whole project is that the timing and scheduling of construction around the site is very complex. Spoorzone Delft is a project that includes multiple projects running. In order to understand the complexities of the construction area, *figure 6.7* presents the phasing diagram of the construction area.

There is the construction of the building (black color), the construction of the railway tunnel (blue color), the current railway which will be operational during the first phase of the construction (red lines on the bottom of the figure), the tram lines which passes in front of the two access points of the construction site (red lines in the top of the figure) and the construction of the bike parking.

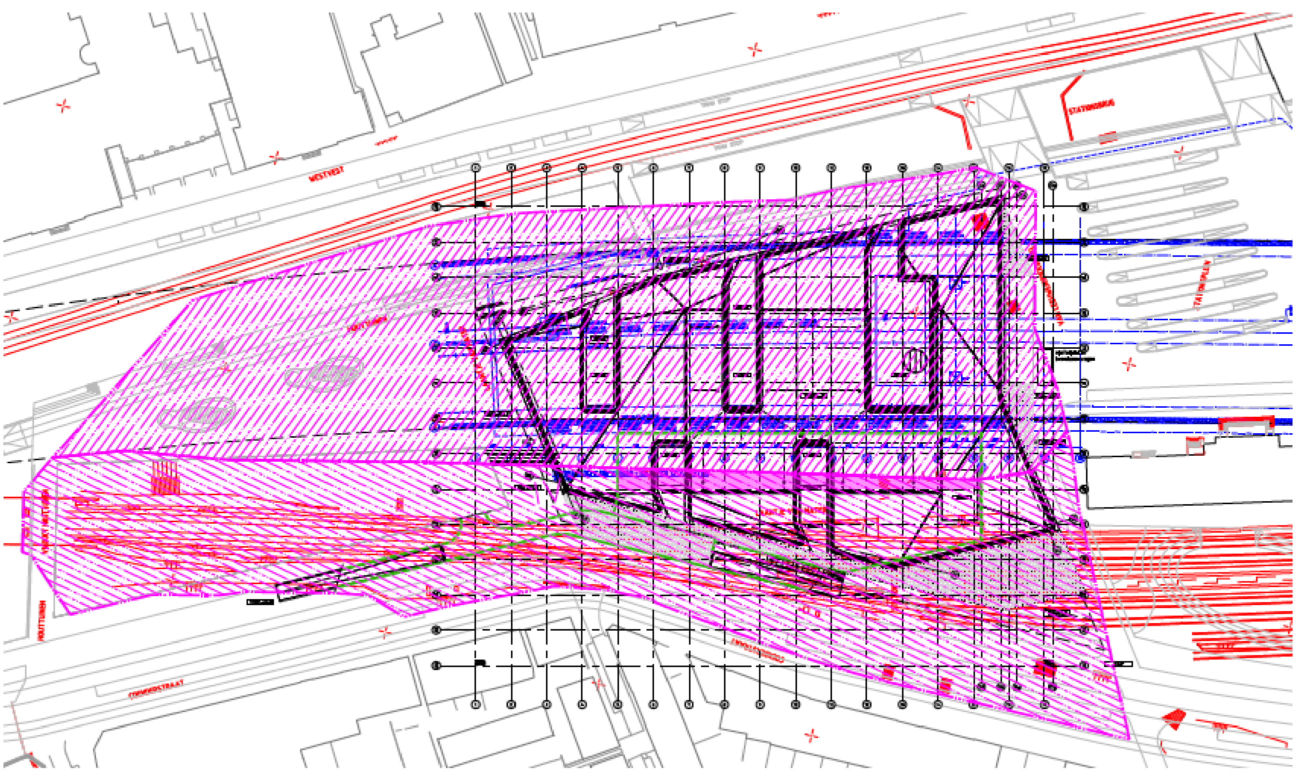


Figure 6-7: Phasing diagram of the new Delft train station and City Hall

6.4.1. Bill of Materials

The bill of materials at the current phase of the project is still under construction. *Appendix II* presents a draft version of the final bill of materials which can be used for the consideration of the volume and length of materials that will be used for the project. The most voluminous materials include the concrete foundation beams, the steel structure, the steel trusses, and the prefabricated floor and roof elements.

6.5. Analysis of the main risks

In the pursuit of improving a construction project's efficiency it is very important to identify the risks that have the potential to influence the cost, time, quality and environment of the project. The need to manage risks in construction projects is relevant to all professionals and groups in the construction industry such as client groups, design team, project management team, contractors, etc. In order to get insight in the influence which logistics can have on the risks involved in construction projects, a risk analysis about the new Delft train station and City Hall will be conducted. Several areas that may be influenced by logistics will be identified and will be used for the further analysis of the building structure that will provide the information needed for the development of a logistics plan.

Managing risk is an important part of the design and construction process. In order to manage the risks, these must be named. The risk analysis may be used for Health and Safety (H&S) plan, but also risks other than H&S aspects play a role in the project. Risk management is a critical activity for major projects as it supports the control of the effects of risks through opening up the discussion about them and by showing the major uncertainties of the project. Moreover, by determining critical activities the prioritization of actions is feasible, support to decision making can be given by choosing alternatives and assessing the go / no go decisions and estimates can be substantiated with respect to the time schedule and cost estimate. Finally, the efficiency is enhanced through the reduction of risk funds and cost of engineering or reengineering (van Beurten, 2010).

A risk analysis consists of the following steps:

- Determine focus of analysis
- Determine Risks (logical order: event, cause, consequence)
- Prioritize risks (Determination of the most critical risks)
- Add and execute control measures
- Reporting

In *Appendix III* the risk analysis for the Delft case is presented. The identification of the risks is based on the reports of the construction consultant, the architect, the risk analysis consultant and interviews with engineers and managers involved in the project (ABT, 2009; Mecanoo, 2009; Aboma+Keboma, 2009). In accordance with the research orientation, the focus of the risk analysis is towards the determination of the probability and effect of risks that are involved with the project efficiency and the negative external effects. Although different categories of risks are identified, the focus will be towards the most important risks for the design and execution phase of the project, and towards areas where construction logistics can have an influence towards the mitigation of these risks. The perspectives that have been assessed involve the: *technical risks* in the design and execution phase, *project management risks*, *social risks*, *financial risks* and *health & safety risks* with respect to the project environment. The prioritization of the risks is based on the qualitative assessment of the chance of the risk cause and the effect of the risk consequence.

GENERAL		RISK			QUALITATIVE ASSESSMENT		CONTROL	
Nr.	**ARTICLE**	**CAUSE**	**EVENT**	**CONSEQUENCE**	**likelihood**	**impact**	**MANAGEMENT ACTION**	**LOGISTICS ACTION**
1	Technical / Execution Phase	Small and congested construction site and work field layout	Lack of access on site	Resources not available, supplies delay	**High**	**High**	Consultation and agreement with CCL for construction site and work field	Logistic concept of the building site, work progress monitoring, communication system
2	Technical / Execution Phase	Transportation of large construction elements	Prolonged closure of local road lanes	Extensive traffic jam, local residents complaints	**High**	**High**	Alternative modes of transportation, split the large elements in smaller pieces	Traffic Management, vehicles, pedestrian, cyclists and workers access points, loading / unloading areas
3	Project Management	Uncertainty on the plan of the tunnel construction project	City Hall construction delay	Penalty clauses, delay on planning	**High**	**High**	Basement along with tunnel section entirely by CCL	Provide CCL with information about the logistic plan after the completion of the basement
4	Health & Safety / Environment	Combination of underground tunnel and upper ground building, the constructive possibilities are limited by the foundation and the route of the tunnel, concurrent work between the two phases	Falling objects, traffic congestion	Disturbance of the local environment, damage to the public image of the actors involved in the project	**High**	**High**	Supply and delivery routes in consultation with road authorities to be determined, public and visitors in the construction site should be banned, escape routes	Assessment of vehicle entrance points to recognize feasibility of transportation, Segregation of construction and public traffic
5	Project Management	Different contractors working on the same area	Excessive equipment and material deliveries on construction area	Construction site congestion	**High**	**Medium**	Logistic plan for the execution of the project	Mobilization and Site set-up, Materials delivery and handling, Traffic Management, Waste Management

GENERAL		RISK			QUALITATIVE ASSESSMENT		CONTROL	
Nr.	**ARTICLE**	**CAUSE**	**EVENT**	**CONSEQUENCE**	**likelihood**	**impact**	**MANAGEMENT ACTION**	**LOGISTICS ACTION**
6	Technical / Execution Phase	Small and congested construction site and work field layout	Limited opportunities for crane placement	Machinery not in right place, delays on construction	**High**	**Medium**	Procurement based on final design so that a contractor can timely contribute implementation expertise	Feasibility study for crane positioning
7	Technical / Execution Phase	Transportation of large construction elements	Traffic accident near construction area	Train, tram delays, danger for people safety	**Medium**	**High**	Transportation of the large elements during night, safety plan for transportation of materials	Planning and coordinating horizontal and vertical transportation
8	Social	Building construction on the area of the current bicycle parking	Inconsiderate bicycle parking on the area around the train station	Local citizens life disruption	**Medium**	**High**	Early consideration of the repositioning of the bicycle parking	Feasibility study for bicycle parking repositioning
9	Social	Construction works while the train station is operational	Falling objects and materials, construction vehicles overturn	Death or injuries due to struck of materials or moving vehicles	**Medium**	**High**	Health and safety plan	Guidelines for managing critical risks on the construction site
10	Health & Safety / Environment	Long term construction activity in a city center	Local traffic disruption	Local roads damage due to detours, increased traffic accidents rate	**Medium**	**High**	Traffic management, special attention to material delivery on site	Clearly defined vehicle access points and special traffic arrangements regarding the construction phase

Table 6-1: Prioritization of the main risks and logistics actions

The measurement has been based on a *low – medium – high* scale. The likelihood and the impact of the risks have been measured based on the author's personal opinion after gathering information through several discussions with relevant engineers involved in the Delft project. Also, the fact that the new Delft train station and City Hall is a public project has been taken into account, meaning that safety and environmental risks are considered quite important.

> **Note:** *The scope of the research is not to make a thorough risk analysis of the project but through the risk analysis to derive information and requirements that will be the basis for the logistics plan and recognize areas where logistics can have a positive influence for the project.*

From the analysis of the main risks, the qualitative assessment, and the management control required for their mitigation the areas where logistics can have a positive influence can be identified. *Table 6.1* presents the 10 most critical risks, the management actions need to be taken and logistics tasks that need to be done so as to assist the management actions. These logistics tasks will be considered in the analysis that will take place in the next chapter in order to develop a logistics plan which will take into consideration the risks that may occur so as to enhance the project efficiency and minimize the negative external effects on the local environment.

6.6. Assessment of the Building Structure

The final step before proceeding to the analysis of construction logistics for the new Delft train station and City Hall is to assess the building structure and the way it is going to be assembled on the construction site. The way that the building will be constructed has not been finalized yet. The designers are still into discussions with the client about the right way to construct the building. So far, two solutions have been proposed that will be described in this section. These two construction solutions are based on an old and a new planning. The old planning consists of the construction of the basement, the structure of the building and then the finishing and delivery of the train station, the demolition of the old railway and then the finishing of the City Hall, the facades placement and the installations. The new planning takes into account the assumption that the basement will be built in parallel with the completion of the tunnel, and consists of two realization phases. The first phase will deliver almost 80% of the complete building and the second phase will finalize the building after the demolition of the old railway (Gips, 2010a).

6.6.1. Old Planning

In *Appendix IV* the old planning is roughly presented. The planning assists in identifying the stages of the building construction. Initially, the excavation works and the construction pit cladding take place through the sheet pilling, the excavation, the tipping of concrete and floor, temporary braces attachment and the dumping of walls, columns and at last the basement floor. This stage occurs after the work for the tunnel construction is completed. The need to build the basement which is located next to the tunnel wall is justified by the fact that no horizontal load is allowed to be transferred to the tunnel as the structure of the tunnel will not be able to transfer those loads to the foundation. That's why the horizontal loads need to be transferred to the basement of the new building. *Figure 6.8* illustrates the part of the basement that will be built to support the horizontal loads.

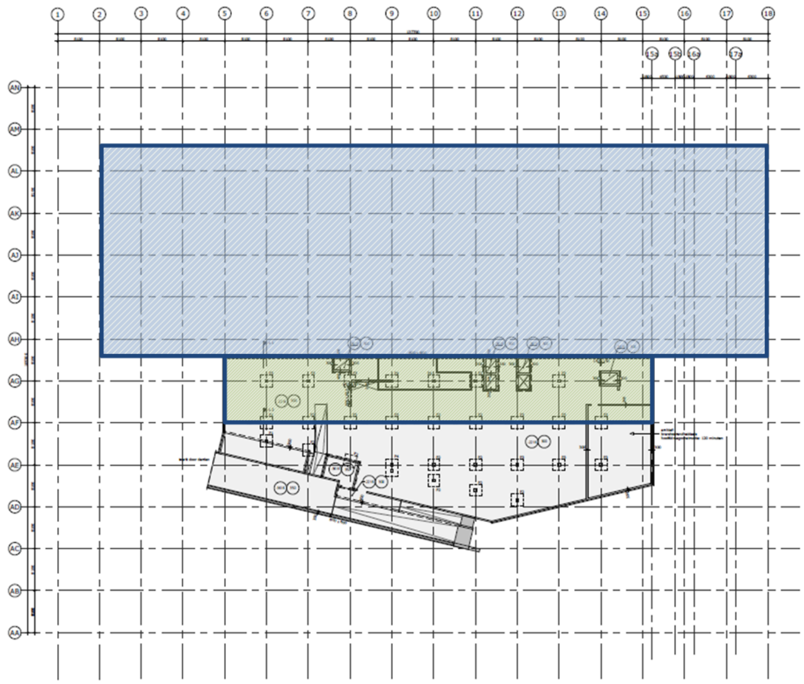


Figure 6-8: Part of the basement that will be built during the first phase of construction

Once the foundation of the building is in place, the next stage takes place which is the rising of the construction and includes the trusses, the floors and the roof set up. The structural design is based on a grid of 8.10 meters. The tunnel walls will be used to support the structure and the position of the columns of the building is illustrated on *figure 6.9*. As can be seen, on the southern part of the building only the two sides of the tunnel can be used, due to the interface between the underground train station and the entrance of the main building. As a result, the trusses that will be used to support the structure at this point will be almost 40 meters long. The long trusses will be placed on the 3rd and 4th floor on the southern side of the building, while on the north side trusses are being placed on the 1st and 2nd floor. The rest of the structure consists of columns, diagonals, beams and concrete work. *Figure 6.10* presents the trusses that will be used for the building construction. The trusses represent an important point for the construction logistics analysis as they are large, heavy, voluminous and difficult to handle.

The floor will be constructed with prefabricated hollow floor slabs. The slabs are typically 1.20 meters wide with standard thicknesses between 15cm and 50cm. The slabs are going to be cast together with a 70mm layer of in-situ concrete, and they will be connected through reinforcement bars in the concrete. For the roof, composite floor slabs will be used. Most of the parts that will be used during this phase of construction will be prefabricated and assembled on site. When the structure is in place, the temporary façade placement, the architectural finishing and the train station installations, which are possible only when the building will be wind and water proof, will follow. At this point, the train station will be ready for delivery and the old railway will be able to be demolished, so that the second phase of construction can take place.

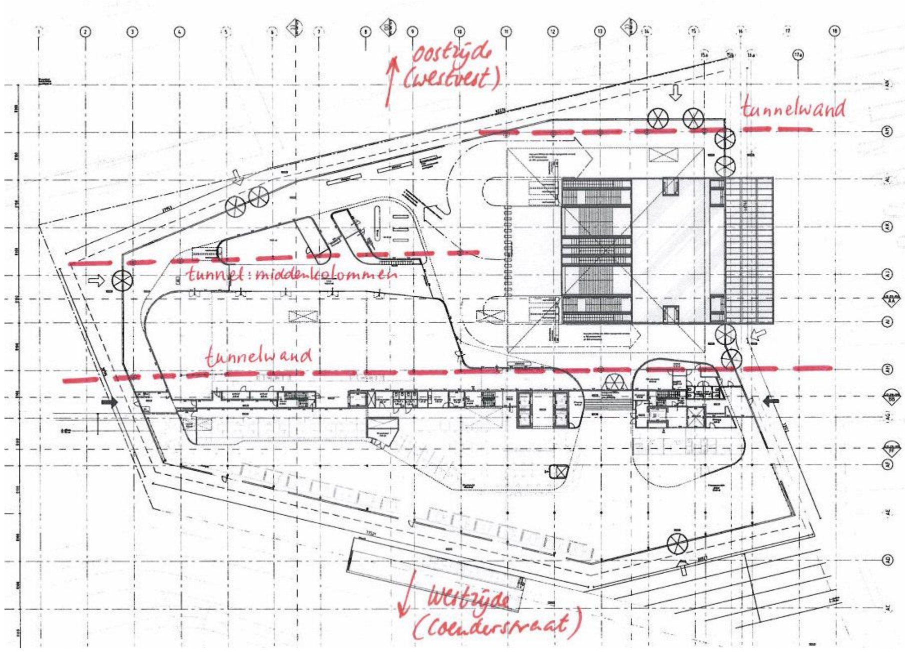


Figure 6-9: Building columns positioning

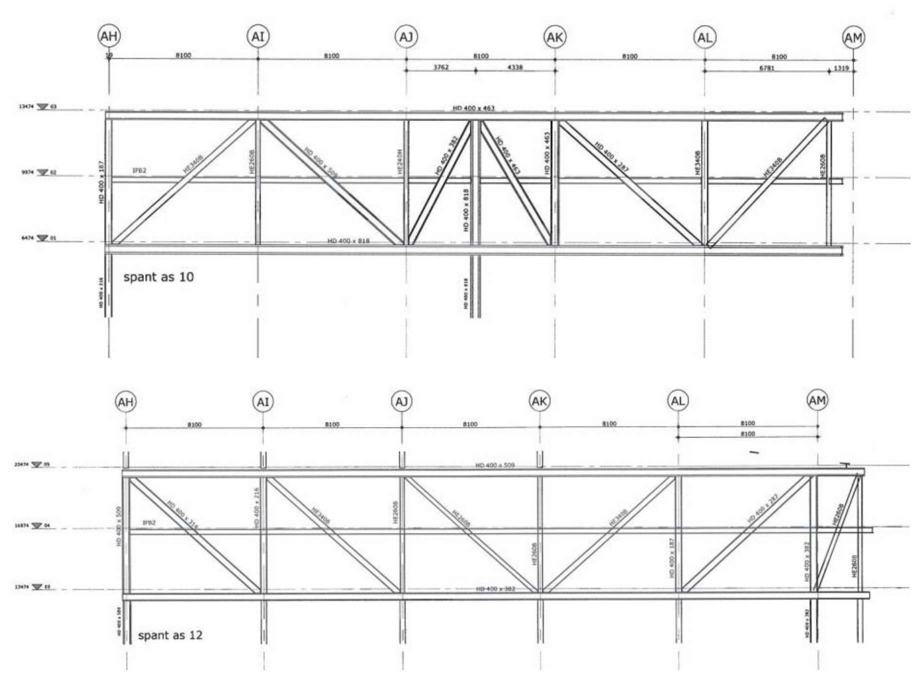


Figure 6-10: Trusses used for the new Delft train station and City Hall: a) truss with overhang on 1st/2nd floor, b) truss with wide span on 3rd/4th floor

The second phase of construction includes the finalization of the basement, the City Hall building shell, the west side façade, the architectural finishing of the east and west side of City Hall and the installations. The construction logistics analysis of the Delft train station and City Hall is focused mainly on the first phase of construction where the main logistic problems are possible to arise. During the second phase of construction and after the demolition of the old railway, another entrance for the construction site will be available which will decrease the complexity of the project during that phase. After the description of the old planning for the

Delft project and the assessment of the building structure, ***the main logistical problems*** are identified: ***a)*** on the construction of the basement next to the tunnel and ***b)*** on the transportation and assembly of the largest elements that will be used for this construction, the steel trusses. The reasons for this are explained in the following paragraphs.

Basement construction

The construction of the basement next to the underground tunnel may lead to the occurrence of several risks that have been identified in the previous section. The most important is the risk of two contractors working together on a small construction site. There is already one contractor on the site who has his own concrete mill, cranes and his own welding factory on site. This equipment will be on the site anyway and having another contractor bringing the same materials and equipment will be a considerable problem for this small construction site. Moreover, there are technical risks related to the project efficiency and there are negative external effects due to the need for new excavation next to the tunnel and the tunnel wall will need to be supported during the construction of the basement. Finally, as the planning in *Appendix IV illustrates*, with the basement construction by a different contractor there is a conflict at the project schedule. The first phase should be finished on May 2013 but the earliest it could be finished is July 2013. On May 2013 the station could be delivered partly but some works would still need to be done which would lead to safety risks.

Large trusses transportation and assembly

The trusses represent the largest construction elements that will be transported to the construction site. Special logistic attention should be given to these elements as the efficient assembly of these elements is crucial for the efficient completion of the project with a minimum of negative external effects. Decisions like the mode of transportation, the handling of these elements and the assembly process on site will be analyzed in the next chapter. Due to the complexities that were arising when making this planning, the construction consultant came up with another proposal so as to improve the project schedule and deal with some of the complexities of the project. The new planning will be described in the following section.

6.6.2. New Planning

The new planning is presented in *Appendix IV*. The goal of the new planning is to deal with important risks regarding the time and the realization of the project. The main focus is towards the independence of the second phase of construction with respect to the new railway and the tunnel construction. The main time based risks include the (Gips, 2010a):

- Preparation of the tunnel shell
- Completion of the new rail route
- Demolition of the old railway
- Penalty clauses related the above risks
- Operating losses due to late commissioning

The main realization risks include the (Gips, 2010a):

- Overlapping construction activities for surface and underground work
- Damage risks to CCL tunnel shell construction due to the boundaries of tunnel / basement
- Overlapping contractor activities to a small construction site

With the old planning, the two construction phases were dependent on the completion of the new rail route and the operation of the new train station. In case of a delay on the completion of the new rail route, the building would not be able to be used. Moreover, from a logistic perspective the congestion on the construction site due to the number of contractors is a major logistic problem. The proposed change in the new plan is the suggestion that the part of the tunnel next to the basement of the City Hall, and the basement will be constructed by the tunnel contractor. By doing so, the completion of the work for the tunnel construction and the first phase of the basement construction will be executed in parallel, which means that when the construction site will be delivered by CCL, the basement will be ready and the second phase of realization, which include the rising of the construction, the floors and the roof, can begin. Subsequently, the architectural finishing and the installations of the building will lead to the delivery of the station on July 2013. At that time, the 80% of the building will be delivered and will be ready for use by the Municipality of Delft regardless the progress of the tunnel construction and the demolition of the old railway.

Differences between the old and new planning

Apart from the obvious difference regarding the time completion of the project, there are more differences between the two project plans concerning the construction of the building which will be briefly described. The first difference is the construction of the basement and the tunnel section next to the basement by the same contractor (*figure 6.8*). The part of the basement that will be built during the first phase of construction contains the shafts that are going all the way up to the building services on the top floor of the building. This creates the possibility to use the building with all the building services installed at the end of the first phase of construction. The designers took that into consideration and after the risk assessment they proposed a new plan to deliver the building up to 80% with all the building services working so as to make it more independent of any disruptions in the tunnel construction. In case of having a different contractor building the basement the deadline of 18 months (*from the time that the tunnel shell will be finished until the operation of the new rail tracks*) cannot be met. On the other hand, having the same contractor for both construction parts will result on time savings due to the exploitation of the construction area, the machinery that will be already in place and the knowledge about the boundaries of the two constructions. Moreover, the logistic processes are becoming less complex and allow the project to save up to 7 months of the construction time.

Another difference involves the decision to use mobile cranes for the handling of the construction elements. This choice is possible only after the decomposition of the large trusses into smaller elements that could be handled by lighter and smaller cranes. *Figure 6.11* presents a drawing of the ground floor of the building along with the crane positioning. The dark green color represents the area that will be built during the first stage and the light green the area that will be built on the second stage of construction after the demolition of the old railway. The use of the building will be possible through a temporary facade that will be placed on the interface of the two stages. The little red stars represent the mobile cranes that will be used for the vertical and horizontal transportation of materials and for the erection of the structure.

Moreover, one shaft needs to be moved in order to be able to finalize the building (small circle with red arrow). The use of light cranes mitigates another important risk of the project which is the load that could be applied on the tunnel shell. The use of small and lightweight cranes is also important as they will be placed inside the building volume after the construction of the first floor and will go up with the building.

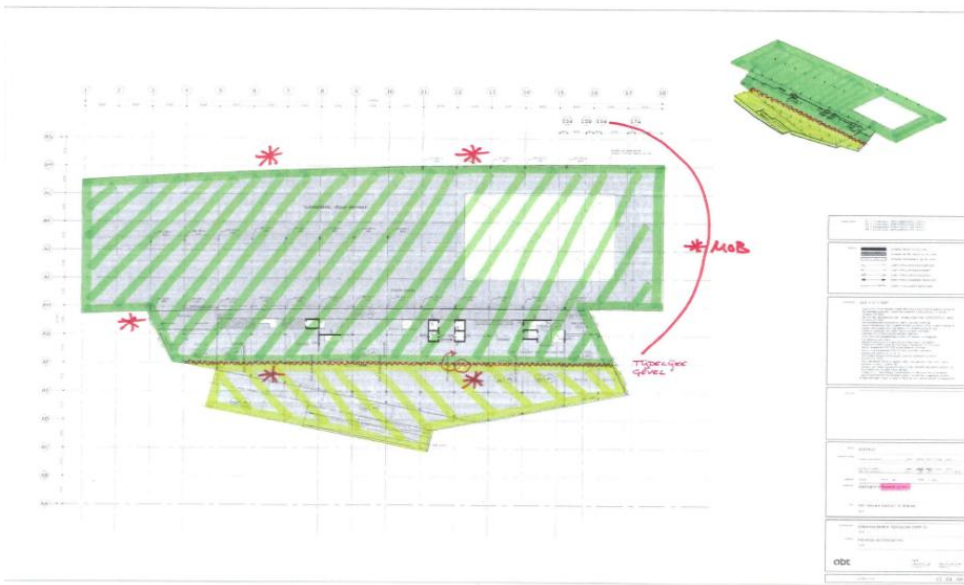


Figure 6-11: Ground floor and crane positioning for the new Delft train station and City Hall

In conclusion, the new planning offers a lot of benefits on the project management area in terms of mitigating important risks about time and realization of the project. More specifically the benefits with respect to time-related risks include:

- the simultaneous construction of the tunnel shell and the basement will save approximately 7 months until the delivery of the 80% of the building and a total of approximately 15 months until the completion of the whole project
- the realization of both the train station and the biggest part of the City Hall by the integration of the vertical shafts that will enable the building services to operate from the end of the first construction stage
- the operation of the new railway does not affect the exploitation of the building, as with the use of a temporary facade the building can be operational and the last construction stage can be realized independently
- earlier return on capital invested high degree of reduction in penalty clauses due to late delivery for the tunnel contractor

The benefits with respect to the realization risks include:

- savings in construction by only using one sheet pile construction
- the part of the basement will provide direct horizontal tunnel pressure compensation
- after the completion of the first phase, the final works on the tunnel are fully independent

On the other hand, the new planning may result on more logistical problems due to the fact that almost 80% of the building will be delivered during the first phase of construction. The need for more materials will result in more traffic flow on and to construction site, and by taking into account that during this phase there will be only one entrance to the construction site, there is a high possibility that bottlenecks may arise. This means, that logistics on site should be carefully planned to assist the smooth completion of the first construction phase. The next chapter will analyze the empirical findings of this chapter to identify areas of improvement for construction logistics and to present recommendations and guidelines for the Delft project.

As a conclusion, it can be mentioned that construction logistics can serve as a valuable assistance for the project management towards the realization of the benefits of the new planning in the pursuit for enhancing the project efficiency with the minimal negative external effects.

6.7. Summary & Sub-conclusions

This chapter introduces the case that is being studied for the conduction of this research and provides the empirical findings that will be used for the analysis of the case. Initially, the reader is familiarized with the Delft case, through the presentation of information about the project and its organization and by the identification of the project scope. Subsequently, the building design is being assessed and the main risks that may lead to project inefficiencies and to negative external effects are identified. The chapter is finalized with the assessment of the building structure which is the part where construction logistics have a big influence during the design phase. The acquisition of the required knowledge regarding the case makes possible the analysis process which takes place in the following chapter. The key points of this chapter, according to the topic that has been described, are summarized in the following table:

Topic	Description
Project Scope	• New building with two functions: Underground train station plus City Hall on the upper ground • The project is at the finalization of the design phase • Construction of the building in two phases • Due to the complexity of the project, the size of the construction site, the number of the contractors involved and the uncertainties that will arise, a logistic plan for the construction site will be developed
Project Organization	• Several actors and companies are involved in the current phase of the project • The client is the City of Delft, the principle is OBS which assigned ABT, the construction consultant, to develop a logistic plan • No existing construction supply chain as the project has not been tendered to a main contractor yet
Analysis of project planning	• Construction of the tunnel and the underground platforms • After the construction of the tunnel, **construction phase A** will start where the part of the building above the tunnel will be built. This step is necessary for the operation of the new train station • Existing platforms dismantling and finishing of the new train station • After the beginning of operation of the new train station, the old part of the railway will be demolished as the train will go through the new railway tunnel • **Construction phase B** begins, finishing of the City Hall • Full implementation of the new Delft train station and City Hall

Assessment of the Building Design	• Building ratios: ➢ Building dimensions length: 124 m ➢ Width: 85 m ➢ Height: 22.5 m (floor to roof) ➢ Gross floor area around: 33,000 m^2 ➢ Building volume around: 120.000 m^3 • Logistic constraints: ➢ Physical constraints: Building location, one entrance, temporary station platform, public traffic, tram and train lines, canals ➢ Material transportation constraints (water or rail transportation) • Bill of Materials (important categories of materials, volume, flow of materials)
Analysis of the main risks	• Identification of risks and management actions for the mitigation of these risks • *Technical risks* in the design and execution phase, *project management risks*, *social risks*, *financial risks* and *health & safety risks* with respect to the project environment • Logistic tasks according to management actions
Assessment of the Building Structure	• Assessment of the building structure based on the old and new planning • Old planning: ➢ Basement construction by OBS, tunnel construction by CCL ➢ Late delivery of the first phase of the building ➢ Less material transported during the first phase • New planning: ➢ Basement construction plus tunnel construction ➢ Benefits in time related risks and realization related risks ➢ Delivery of 80% of the building after the finish of the first construction phase ➢ More material transportation during the first phase may cause logistical problems • Construction logistics can assist the project management towards the realization of the benefits of the new planning

Table 6-2: Summarizing Key Elements of the Chapter

7. ANALYSIS OF THE NEW DELFT TRAIN STATION AND CITY HALL CASE

This chapter is analyzing the empirical findings from the case of the construction of the new Delft train station and City Hall so as to present the practical application of construction logistics analysis towards the enhancement of the project efficiency while at the same time minimizing the negative external effects by answering the following research sub-question: *"What kind of recommendations and guidelines can be given for the case of the new Delft train station and City Hall?"*. The steps needed for the developments of a logistic plan for the construction site have been discussed in *chapter 5*, while in *chapter 6* these steps were comprehended in order to provide the information needed for the logistic plan development.

This chapter analyzes the decisions taken in the design phase of the project from a logistics perspective, their influence on the project efficiency and negative external effects and at the end it provides a logistics plan for the construction site based on the data collection. An introduction to the construction logistics analysis that will be applied in the case of Delft is presented in *section 7.1*, where the areas of consideration for the analysis are presented. Following, mobilization and site set-up analysis takes place in *section 7.2*, the materials delivery and handling processes are examined in *section 7.3* and traffic management procedures are analyzed in *section 7.4*. The management of critical risks and security issues are described in *section 7.5* and the chapter is finalized with the examination of waste management in *section 7.6*. The deliverable of this chapter is a draft development of a logistics plan for the construction of the new Delft train station and City Hall which is presented in *section 7.7*.

7.1. CONSTRUCTION LOGISTICS ANALYSIS

7.1.1. Introduction

As it has been discussed in *chapter 4*, construction logistics are mainly involved with supply logistics to site and on-site logistics. There are four main resources that are competing for access and egress in the construction site: *people*, *materials*, *plant/tools* and *waste*. Supply logistics processes include the provision of materials and human resources, materials delivery, traffic management, transport and communication. On-site logistics include the physical flows involved in the execution phase of the project, establishment of the construction site, internal movements, material handling and storage, and security. While a lot of these activities are being managed during the execution of the project as a responsibility of the main contractor, a lot of things can be planned and thought ahead during the design phase, so as to ensure the proper execution of the project. The Delft case is a good example about how the decisions taken in the design phase and the early consideration of logistics with the development of an initial logistics plan have set the foundation for the proper execution of the project. Proper execution of the project comprises of the realization of the project scope in terms of time, cost, and quality and with minimal negative effects in the local environment.

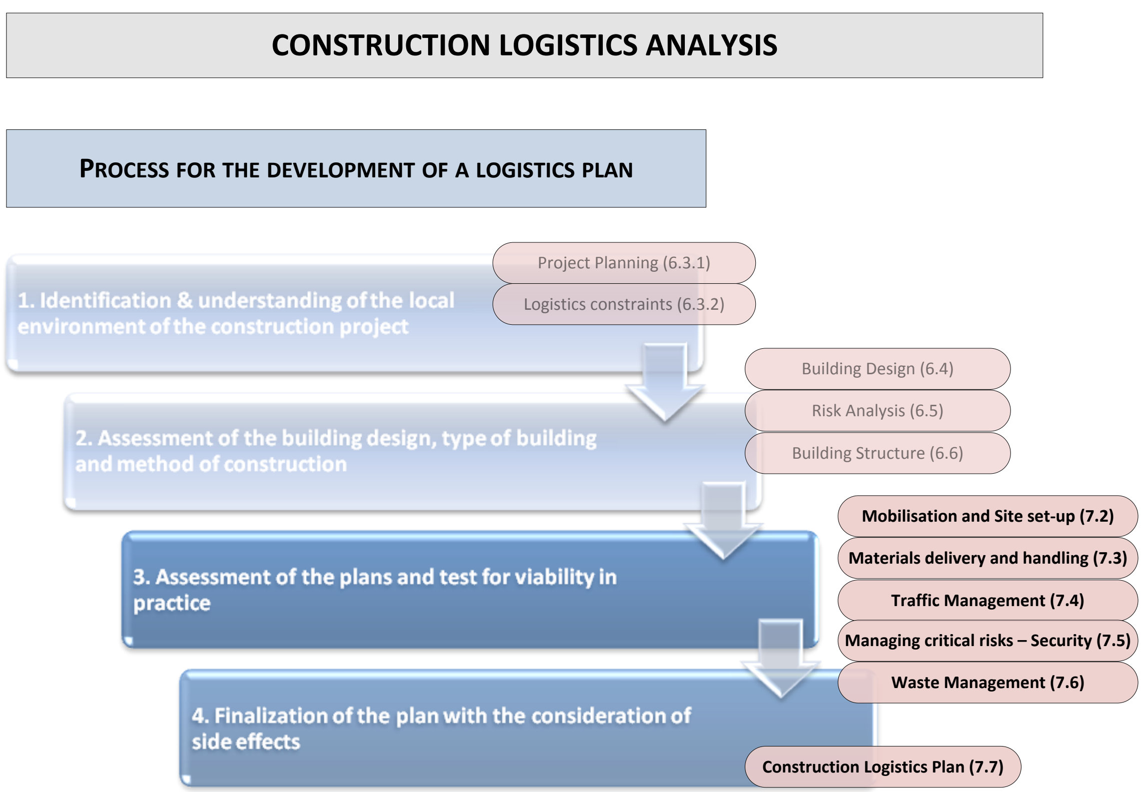
7.1.2. Areas of consideration for the logistics analysis

The construction process can be seen as the execution of a series of activities. The construction of the new Delft train station and City Hall will be realized only after the sequential execution of different construction activities. For any activity or task to be performed there are a number of conditions that must be satisfied. These conditions consist mainly of the availability of the resources needed at the time in which the activity or task is to be performed.

These conditions consist of the availability of:

- Appropriately skilled labor
- Materials
- Access to area
- Plant and equipment
- Design information
- Completed previous tasks
- Agreed method and permissions in which to operate
- Acceptable weather conditions

In case that one of the above conditions is not satisfied then the task will not be able to be performed efficiently and the construction process will be delayed or not realized properly. The coordination of resources so that they can satisfy the above conditions is essentially the process of logistics management. Of course the weather conditions are out of the hand of human, but still can be taken into account so as to consider contingency plans. *Chapter 5* illustrated the importance of early planning of logistics, with respect to the logistic tasks that occur during the stages of construction and the logistic techniques that can be used, so as to formulate a strategy on how to approach the construction work at each stage of its development. The logistic plan for the construction site is a crucial step towards the smooth realization of the construction and will be the outcome of this chapter. Based on what has been discussed in *chapter 5,* the main areas of consideration for the development of the plan have been identified. These areas of consideration will lead the assessment of the plans and the test of their viability in practice. Subsequently, with the information gathered in chapter 6 and the analysis of this chapter, the logistics plan will be finalized with the consideration of side effects. The process towards the finalization of the construction logistics analysis is presented in the following figure:



Note: *At this point it has to be mentioned that during the conduction of the research a lot of information needed for the development of the logistics plan were missing. That was due to the fact that the project is at the design phase and a lot of the decisions regarding the way of construction, materials, trade contractors, equipment, etc. are still under discussion. A number of assumptions will be used in order to deliver an end result. These assumptions will not affect the core of the research as the main objective is to present the applicability of construction logistics analysis in a real project.*

Due to the uncertainty of the future planning of the area assumptions have to be made about the progress of works in the area at the time the construction of the new Delft City Hall will begin. These assumptions are based on the planning for the projects that will be running in parallel during that period. Apart from the City Hall, the other projects that will be either completed or still under construction in the area are:

- *The construction of two new bridges on Westvest Street:* The old bridge that was leading the traffic to the current train station will be demolished and two new bridges will be constructed in the same area.
- *The construction of the tunnel on the south side of the City Hall:* The progress of construction work in the tunnel on the south side of the City Hall is quite important for the logistic plan.
- *The construction of the area in Bolwerk:* The works in Bolwerk will make the possibility of resources flow from this direction not feasible.

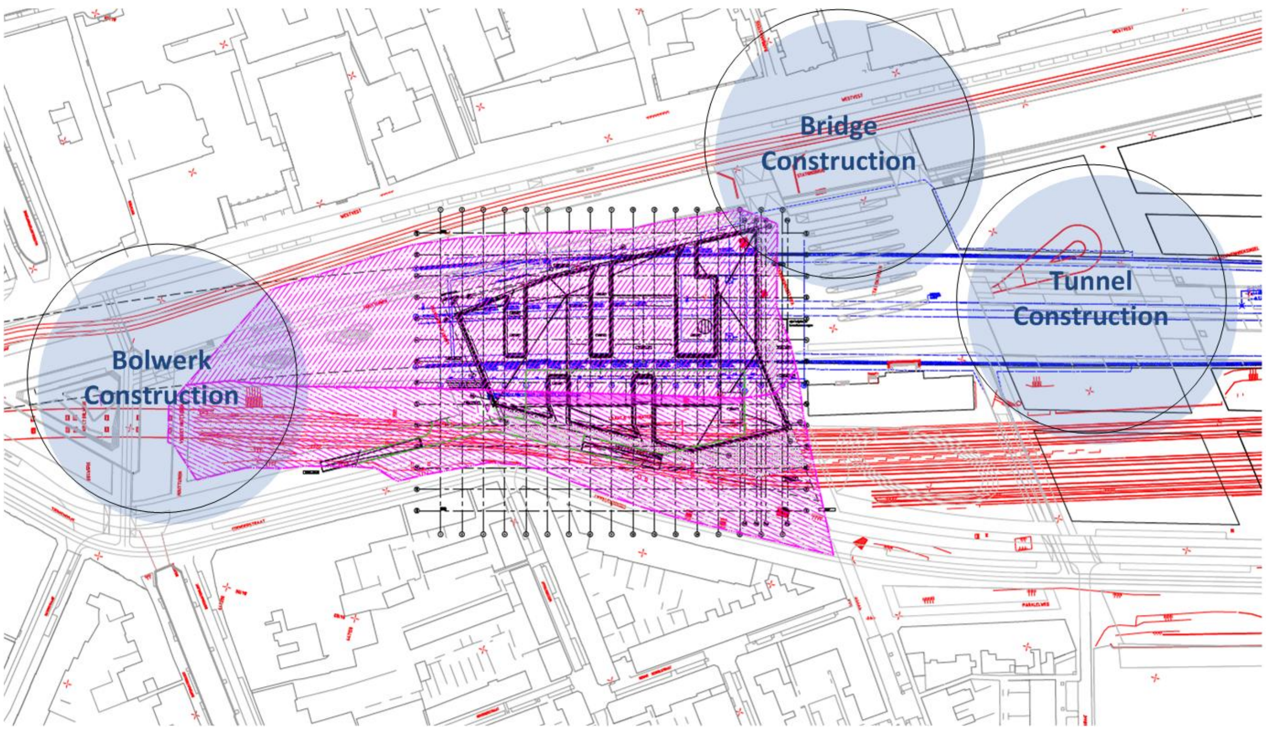


Figure 7-1: Projects in the area of the new Delft train station and City Hall

7.1.3. Future state of the surrounding area

In order to start organizing the logistics processes of the new Delft train station and City Hall, the future state of the surrounding area, the construction site environment, needs to be depicted. The construction site environment has been identified as an important factor for the logistics analysis in *chapter 5* and is the first step for the assessment of the plans and the test for viability in practice. *Figure 7.1* illustrates the area and the projects that will be either complete or still running by the time the building construction will start. The aim of the assessment of the future state of the area is to highlight the uncertainties that should be dealt early on a proposal for a logistics plan. These uncertainties have been previously discussed and mainly consist of the uncertainties regarding the scheduling of the projects in the surrounding area. The areas that will be influenced by the different future states of the surrounding area regard the processes related with construction site accessibility and the public traffic that will be guided around the construction site.

From the assessment of the current information regarding the planning of the area and consultation with the actors involved in the planning procedure, **two future states of the area** will be investigated which are taking into account the possible versions of the planning. The first future state is considered "*the realistic scenario*", and is the most probable to occur. The second future state represents "*the contingency plan*" and is considered as an undesirable situation by the construction consultant. This is because in this case there will be a lot of overlapping between construction traffic of different projects and also between construction and public traffic. In any case, the analysis that will follow will also take this possibility into consideration, but the main direction will be towards the realistic scenario.

"THE REALISTIC SCENARIO"	***Bridges construction completed before the beginning of the City Hall construction***
"THE CONTINGENCY PLAN"	***Bridges construction in parallel with the City Hall construction and tunnel works on the south side of the building completed***

The last two steps of the process for the development of a logistics plan will be comprehended in the following sections. This comprehension process is based mainly on empirical knowledge of the author and the engineers involved in it (*see table 2.2 – unstructured interviews*) and on the theoretical findings with respect to the topic. The theory provided the framework that will be followed for the construction logistics analysis but as it has been mentioned in *section 3.4*, the peculiarities of the industry and the one-of-a-kind nature of construction projects call for a case specific analysis. This point is justifying the statement that the recommendations and guidelines that will be derived are case specific and are not applicable to any construction site. At the end of the chapter, an integrated approach for the logistics plan of the new Delft train station and City Hall construction site will be presented.

7.2. MOBILIZATION AND SITE SET-UP

The mobilizations and site set-up is the step that will make the construction work feasible. Even though it is not considered core for construction, a proper organization of the construction site is crucial for the success of the project. The layout of the temporary facilities that support construction activities at a site is an important planning activity as it can affect cost, quality of work, safety and other aspects of a project. Depending on the type and size of the project, temporary facilities may include temporary offices, warehouses, batch plants, maintenance facilities, labor residence and fabrication shops. Moreover, in order to make the construction site run temporary utilities like water, plumbing, drainage, electricity and communication lines are vital for many functions on site, such as canteens, equipment cooling, managing water and floods and providing basic electrical and telecommunication functions .

7.2.1. Temporary accommodation

For the Delft case, the temporary accommodation that will be needed include the temporary offices, a canteen, welfare facilities (toilets, showers, drying room, changing room, locker room), and a reception area with a bar and a turnstile. In order to be able to dimension the temporary facilities, a visualization of the construction site and the size of construction are needed. *Chapter 6* already provided the main information needed to realize the amount of space that will be used for the construction and a first impression about the staff that will be occupied on site. But still, as long as a labor histogram is not available yet, the size of the temporary facilities will be based on assumptions. The functions of the temporary offices include:

- The supervisor's headquarters and office where the supervisor and the field management personnel like field engineers offices are located
- The contractor's place of business and the place where management meetings are taking place
- The location of posters and information for employees, and first aid information and equipment
- Computers, telephones, fax, documents archive

In order to optimize the location of the temporary buildings an assessment of the facilities that are being supported by them is needed. Relations between permanent facilities (operation area, crane radius or site entrance) and their support facilities (residence facilities, offices, parking and welfare facilities) should be developed in order to increase productivity, minimize travel time and improve the site safety. Due to the qualitative nature of the research relations such as "close to", "far from" or "next to" will be used for the allocation of the temporary facilities. *Table 7.1* presents some guidelines for the logistics design regarding the temporary facilities (Sebt, Karan, & Delavar, 2008).

The temporary offices should be next to the site entrance and close to the car entrance so that visitors do not have to travel a long distance to reach them, and far from the operation area due to safety reasons. On the other hand, a dining hall should be far from the operation area for safety reasons and close to the lavatory and washroom so that the workers do not have to waste time by walking far from their position.

Number	Temporary Buildings	Relation	Related Facility/Area
1	Residence facilities	Far from Far from Close to	Operation Area Crane's operating radius Site entrance
2	Lavatory and washroom	Within distance of	Operation area Office Residence facilities
3	Dining Hall	Far from Close to	Operation area Lavatory and washroom
4	Parking	Next to Close to Far from	Offices Car entrance Operation area
5	Offices	Next to Close to Far from	Site entrance Car entrance Access road

Table 7-1: Temporary facilities relation, adapted by Sebt, Karan & Delavar (2008)

Based on the construction site restrictions and the surrounding environment it is assumed that the temporary accommodation will be based on containers that can easily be placed on site and dismantled at the end of construction. The sanitary facilities will be approximately 1.20m x 1,20m, they must be located within 60 meters horizontally of all employees and prior to the installation of permanent sewer and water facilities most contractors use portable chemical toilets. *Table 7.2* presents the quantity of toilets required for the number of employees (Mincks & Johnston, 2004).

Number of Employees	Toilets Required
1 through 10	1
11 through 25	2
26 through 40	3
41 through 60	4
61 through 80	5
Over 80	One additional toilet for each additional 20 employees

Table 7-2: Quantity of Toilets Required for Number of Employees (Mincks & Johnston, 2004)

7.2.2. Temporary utilities

Building utilities such as water and power are not available until the construction of about the two-thirds of the building, that's why temporary utilities are needed for construction operations and therefore have to be considered for a construction logistics plan. With the current state of the project, the tunnel contractor that is working on the area has placed his facilities on his construction site and these facilities are connected with the main electricity and water lines of Delft in the Zuidwal Street. These facilities are supporting the current construction work, with one line of electricity and water running along the tunnel walls and another one supplying the temporary buildings.

Temporary power

Temporary electrics have to be flexible and agile so as to compel with the different needs of power distribution on site. Most construction tools run on 110 volts but some others like electric power compressors run on 220 volt power. Also the temporary accommodation will need to be powered. The installation of the temporary power will be handled by a specialist contractor so as to deal with all the health and safety related risks. Moreover temporary lightning is an important aspect as it is a crucial part of the safety strategy but also it facilitates construction work that will be executed in areas with insufficient light or during night.

Temporary water and plumbing

The construction site needs to be supplied with water and should be able to remove the waste water. Also careful consideration should be given to the management of rainwater and other flooding as the water is a big risk during the execution of a construction project. The temporary utilities are assumed to be connected to the already existing system on the area, as there are several projects running in this area of Delft. The positioning of the temporary accommodation facilities and utilities will be presented at the integrated logistics plan at the end of the chapter.

Following the analysis of the functionality of temporary accommodation and utilities on site, and the assessment of the construction site area the following guidelines are formulated.

7.2.3. Guidelines for mobilization and site set-up:

- Temporary offices should be placed near the main entrance to limit visitor access and to monitor worker entry and exit
- First aid facilities should be nearby and easily accessible, parking area for an ambulance should be considered
- Sanitary facilities should be in easily accessible areas, away from operating machinery
- Temporary offices can serve also as a fence for the construction site
- The size of the temporary accommodation is assumed to be **500 square meters**. The assumption is based on the size of the building, the size of the construction site and the number of employees on site and on previous projects with similar size
- The canal should be exploited and the positioning of the temporary accommodation over it should be investigated
- Temporary power should be located as centrally as possible to avoid long power cords
- Temporary power should be located in a place that will not be moved until disconnection, when permanent power will be installed
- Water and power lines should not interfere with the structure or any delivery equipment
- Power lines should be located where they will not be dug up by construction operations
- Temporary water and power lines installation according to local codes

7.3. MATERIALS DELIVERY AND HANDLING

Materials management is a quite complex activity with many aspects. Materials management is one of the core activities of construction logistics. Materials have to be transported to site, unloaded, and then either stored or moved on site in order to arrive at the right place, at the right time so that the project can progress. Almost every actor on site will be involved with materials management. Staff at every level will be involved physically, administratively or managerially, to cope with this crucial flow of resources to the site. Traditionally the unloading and movement of materials both to storage areas and to the workforce has been a responsibility of the relevant trade contractor with the coordination of the main contractor of the project.

After the assessment of the Delft case in *chapter 6*, several risks related with materials delivery and handling have been identified which need to be treated for the development of a logistics plan. The next paragraphs will analyze the problems identified regarding these areas, describe what kind of actions have been taken to tackle these problems and what is the influence of these actions to the project efficiency and negative external effects.

7.3.1. Materials delivery for the new Delft train station and City Hall

Following the assessment of the bill of materials, the areas that needed special consideration regarding the requirements for delivery on site, as it has been identified by the literature, were the large structural elements and more specifically the steel trusses that will be used. The rest of the materials that will be used during the first stage of construction such as the floor elements, beams, concrete, installations, etc. do not have any special delivery requirements, meaning that they can be transported to the construction site by common means of transportation, such as normal trucks[4]. The steel trusses on the contrary needed special consideration, mainly due to the size and the weight of the elements, which resulted to logistical problems that needed to be treated. The main characteristics that created logistic problems were:

Just-in-Time

The space restrictions of the construction site result to minimum storage area on site. In order to solve this problem, a Just-in-Time approach on material delivery should be applied. As it has been discussed in *section 5.3.2*, this approach will add more complexity on material transportation and handling on and to site. A realistic approach is needed in order to assess what kind of construction traffic will be possible to reach the site. The size of trucks that will be possible to reach the construction area can serve as a valuable input for the future contractor of the project so as to provide high quality services. Moreover, following the Just-in-Time approach the use of prefabrication becomes more than necessary and is discussed in the next paragraph.

Prefabrication

The use of prefabrication as a logistic strategy was used in order to speed up the construction process and meet the deadlines for project delivery. The characteristics and the benefits of this strategy have been discussed in *section 5.3.4*. The drawback of this decision was the fact that due to design restrictions the steel trusses have a length of 40 meters and a width of 8.5 meters.

Transportation of steel trusses

The dimension of the elements made the possibility of using common means of transportation impossible. Special arrangements about the transportation of these elements needed to be considered. Alternative modes of transportation included the rail and water transportation, or the use of specialized trucks. An analysis of the transportation process is needed in order to demonstrate how the logistics analysis assisted the decision making process.

Rail transportation: Rail transportation was not feasible due to dimension restrictions. Even though the length of the elements could be handled, the width of 8.5 meters made the transportation through the rail network that leads to Delft impossible.

Water transportation: The transportation of similar elements over water is feasible, as water transportation had been used in the construction of a school in Rotterdam next to a metro station (Scheffer, 2010). The only realistic scenario would be to bring the elements with an appropriate barge up to the point where the two big canals of Delft are meeting. Then special arrangements would be needed so as to transfer the elements to special trucks and transport them to the street next to the construction site. From there, special cranes could deliver the elements directly on site. From the analysis of the process, two inefficiencies arise that made this decision inappropriate.

Firstly, the dimension of the elements made the transportation difficult due to the capacity of the canals that leads to Delft. Several problems with turning and height would arise and some bridges would have to be demolished in order to allow this transportation.

[4] The term "normal trucks" is used to describe a motor vehicle designed to transport cargo that does not require special arrangement (special permits from the city, lane closures, etc.) for delivery on construction site.

Secondly, as it can be seen in *figure 7.2*, water transportation for materials would result into 3 handling points; the first one next to the canal for material unloading, the second one opposite the construction site through the use of trucks and the third one on the construction site for the assembly process.

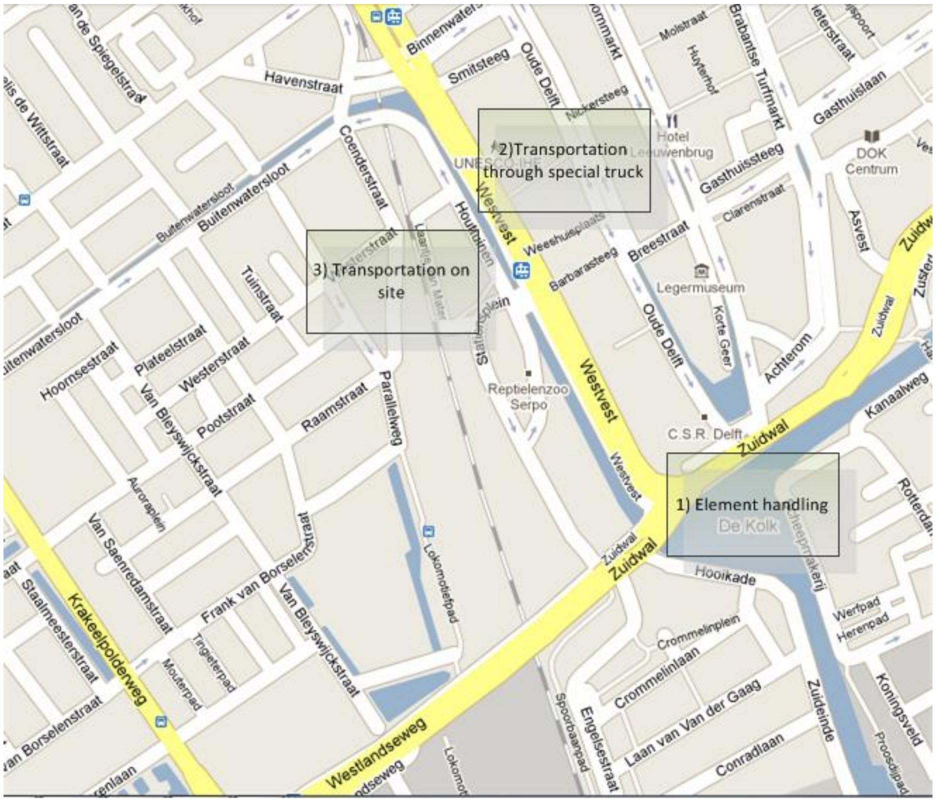


Figure 7-2: Material handling points for transportation through water

Specialized trucks transportation: Transportation with the use of special trucks could be a possibility for the large steel trusses. The main problems that would arise in this case include the fact that large negative external effects and project inefficiencies would occur. The factories that can produce such elements are located far from Delft which means that there is a distance of around 60-80 km that had to be covered. The nature of this kind of transportation is calling for special permits for road lanes closure as the width of 8.5 meters will occupy whole streets or parts of the highway and moreover Just-in-Time delivery would be difficult as transportation could only be possible during night.

This analysis assisted the decision making process for the structural engineers who came up with a solution of decomposing the large elements in 5 pieces, as it is presented in *Appendix V*. The new elements can be handled by normal heavy trucks, transported directly on site without double handling, just in time and assembled directly on the structure. The benefits of this decision are huge as the time and realization related risks regarding the structure construction are mitigated. The material delivery process is smoothed, the delays of material transportation are minimized and more flexible material handling processes are feasible. The material handling processes are being discussed in the next section.

Material unloading points

Another important aspect of materials delivery processes that has been identified through literature is the materials unloading points. In order to enhance the efficiency of the material handling processes it is important to optimize the construction worker's productivity. This is possible through the elimination of the distance of the material handling points with respect to the materials point of use. The material unloading areas for the construction site of the Delft project need to be evaluated so as to guarantee the minimum distance between these two aspects. The structural steel, the prefabricated concrete elements and the concrete trucks will have to be handled in a manner that will allow Just-in-Time delivery and assembly on site, so specific unloading areas will be presented on the logistics plan.

In order to be able to minimize the distance between the material unloading areas and the material handling areas for the Delft project, an analysis for the possibilities that can be used is needed. The normal heavy traffic will consist of trucks with a width of 2.5 meters. The length and the height will depend on the kind of materials that will be transported. For example, the delivery of the prefabricated concrete floor elements can be done with a Star type trailer, with a maximum load of 34 tons, trailer length 13.6 meters and maximum stack height of 2.27 meters (Granzier, 2010). *Figure 7.3* illustrates the process for material delivery on site, resulting from the assessment of the site specific restrictions in terms of accessibility and space available for vehicle movements. This figure will help the future contractor to realize the restrictions regarding material transportation on and to site, and lead to more efficient process regarding the programming of Just-in-Time approach.

> **Note:** *For the analysis of the vehicle turning, programs AutoCAD 2010 and CadTools[5] have been used. CadTools uses an application based on Swept Path Analysis[6] in order to calculate the vehicle turning radius for different vehicles. Blue color lines represent the vehicle sweep while magenta color lines represent the wheel sweep.*

In *figure 7.3*, three kind of construction traffic has been analyzed. Construction traffic that can be handled by a semi-trailer truck of 16 meters length (**1, 2, 3**), a normal truck of 10 meters length (**4**), and a forklift of 5 meters length (**5**). This choice is justified by the fact that no special material transportation requirements have been identified through the assessment of the building design and structure. Some important remarks arise from the analysis of the material delivery on site such as:

- Trucks with length more than 16 meters will not be able or have great difficulties to access the construction site
- The construction traffic on the bottom side of the building can only be handled by small vehicles such as forklifts, due to space restrictions that result from the proximity of the railway lines
- A mobile crane on a truck of 10 meters length will be able to cover the ¾ of the building site

After the identification of the constraints regarding the construction traffic that can be managed on this small construction site, a material delivery process can be proposed that will assist the Just-in-Time flow of materials.

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[5] http://www.glamsen.se/CadTools.htm

[6] Swept Path Analysis is the calculation and analysis of the movement and path of different parts of a vehicle when that vehicle is undertaking a turning maneuver.

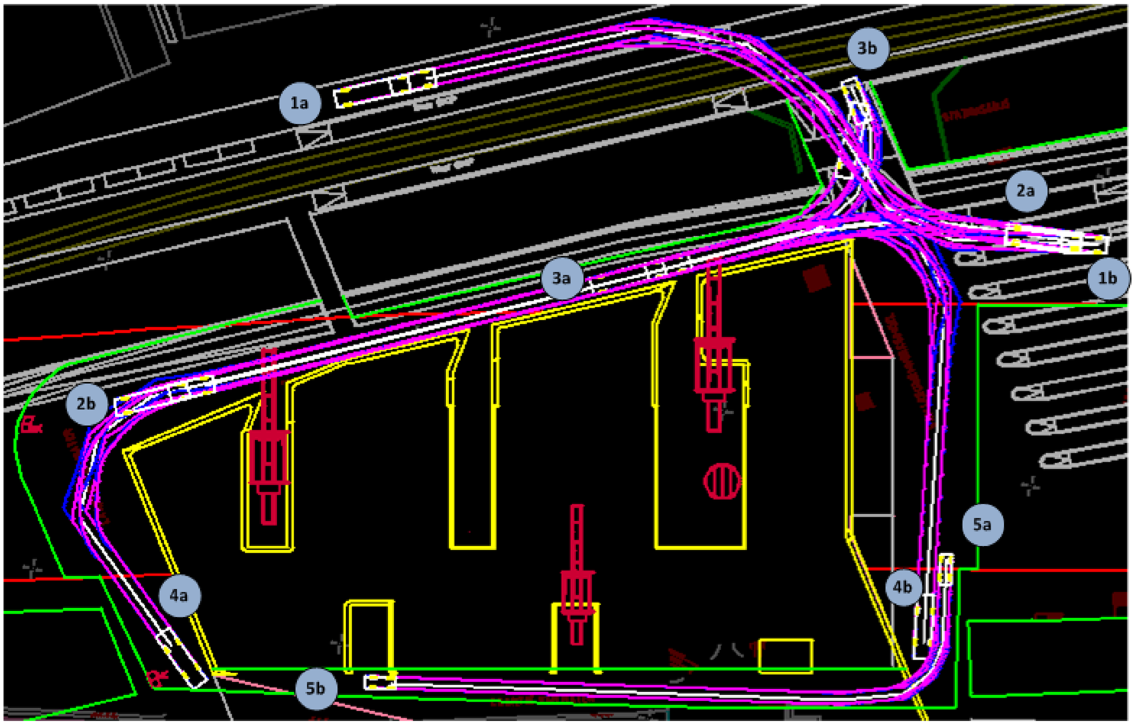


Figure 7-3: Turning circle of material delivery vehicles

As it can be seen in *figure 7.3*, a realistic and feasible approach regarding heavy construction traffic will consist of the following steps:

1. Entrance to the construction site (**1a – 1b**)
2. Make a turn on a specified area (**1b – 2a**)
3. Go backwards to the side of the construction area of the building (**2a – 2b**)
4. Deliver materials to the specified handling equipment (**2b – 3a**)
5. Go forward and leave construction site (**3a – 3b**)

Also, material delivery is possible to take place through the use of an appropriate vehicle to the two sides of the building (**4a – 4b**) and to the bottom side of the building (**5a – 5b**). The proposed material delivery process regards the "*realistic scenario*". In the "*contingency plan*", the material process is the same but the entrance to the construction site is in a different place (see the integrated plan at the end of the chapter). In the next paragraph, the material handling process demonstrates in detail the steps for material handling. The proposed material delivery process regards mostly the materials that will be used in the first phase of construction and more specifically the delivery of steel structure elements and prefabricated concrete elements and floor slabs.

7.3.2. Materials handling for the new Delft train station and City Hall

The material handling on site will take place mostly with the use of cranes and hoists (*vertical transportation*) and the use of trucks (*horizontal transportation*). The steel and prefabricated concrete elements, which will be used at the first phase of construction, will be lifted by the mobile cranes that will be in place from the delivery truck to the installation point. The decision for the decomposition of the large steel trusses had a big effect also to the material handling processes. After the decomposition, the smaller elements made the use of small, flexible and lightweight cranes a possibility. The building has 6 voids, beginning on the second floor and going up to the roof of the building, which can be exploited through the use of the lightweight cranes. The risk of having a heavy crane on site would lead to several consequences with a direct effect on the efficiency of the project. The cranes will initially be placed in the exterior of the building until the construction of the second floor and then they will be positioned on the voids by an external crane.

The choice for lightweight cranes brings the following benefits for the project:

- the risk of putting too much load on the tunnel shell is mitigated
- no extra construction work needs to be done in order to support the cranes
- the construction process speeds up, as the cranes can rise with the structure through the exploitation of the building voids
- all the vertical transportation until the completion of the first phase of construction can be handled

The Delft project is a good illustration of an early consideration of logistics in the design. After the assessment of the building design by the designers, possibilities to improve the site logistics through the exploitation of the voids of the building have been recognized. The next step was to recognize the proper dimension and capabilities of the material handling equipment that could be placed on them so as to speed up the building process. After the first evaluation of the materials needed to be handled by this equipment, the use of mobile cranes has been decided. The cranes should have a capacity of around 5 tons, and crane reach of about 25 meters so as to properly cover the construction area (Gips, 2010b). The exact amount of cranes that will be used is a decision that the future contractor will take, but an assumption for the development of the logistics plan will be made.

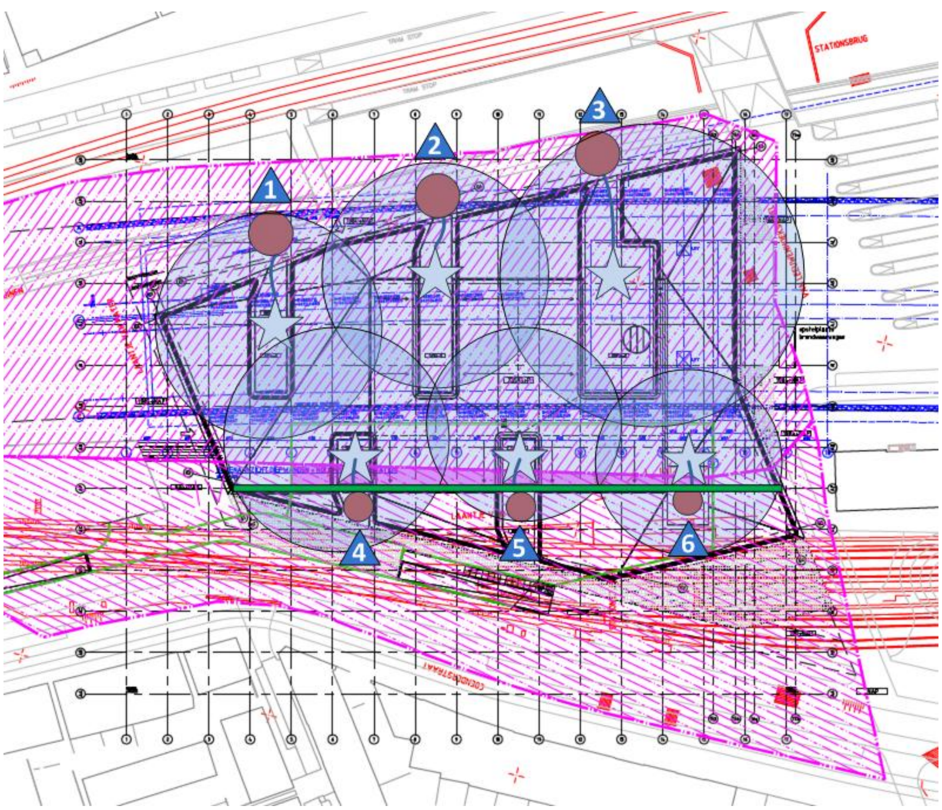


Figure 7-4: Material delivery and handling processes on site

According to March (2009) an issue concerned with material handling in order to reduce waste is the use of the proper equipment so as to ensure safe and secure vertical lifting, which will not structurally damage the lifted component. This process is accomplished with the use of cranes for the vertical transportation of materials. The crane positioning should be carefully analyzed so as to ensure that the whole construction will be covered by their reach and that the overlapping between the different cranes will be minimal.

Figure 7.4 illustrates the material delivery and handling processes in case of using one crane in each building void. The red circles stand for the material unloading points, where the trucks will deliver the supplies. The cranes will be positioned on the ground for the construction of the first two floors and afterwards they will be transferred on the voids that can be seen in the figure, which go all the way up to the top of the building. By this, the building can rise up without any conflicts regarding the crane positioning. The green straight line corresponds to the part of the building that will be built during construction phase A. An assumption about the cranes range has been made and is portrayed by the light blue circles.

As it can be seen, the whole construction area is covered by the crane reach but the overlapping between the cranes is huge. After considering different scenarios, an optimized solution is proposed in *figure 7.5*. The building voids are exploited by three cranes with a reach of around 28 meters, while the areas that are not covered by them are covered through the use of a mobile crane on ground.

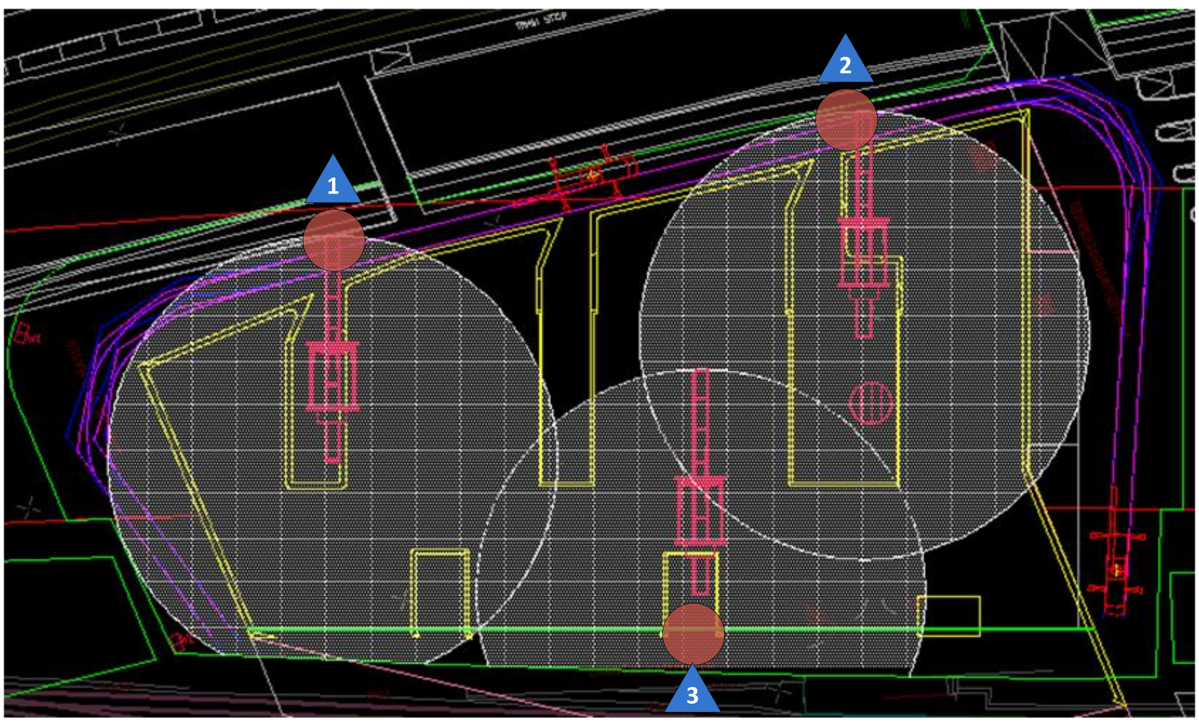


Figure 7-5: Crane positioning and radius, and material unloading areas

The last item that needs to be addressed for the material handling processes is the handling sequence. It has been mentioned already that the ultimate goal of material delivery and handling processes is to minimize the distance for material delivery and eliminate the double handling of materials. After the crane positioning and the definition of the unloading areas the first condition is satisfied as the materials will be delivered exactly at the point of handling. In order to satisfy the second condition the handling sequence is quite important. Due to the restrictions of the construction site dimensions both the truck traffic and sequence should be carefully planned in detail. The handling of the prefabricated floor slabs can serve as an example to a detailed planning process. The floor slabs and the trucks that will deliver them will be planned in detail and will be given specific numbers so as to guarantee the effectiveness of the handling process.

Following the discussion about the material handling processes, the following guidelines can be derived for the material delivery and handling for the construction of the new Delft train station and City Hall.

7.3.3. Guidelines for material delivery and handling

- A dedicated material handling team on site to manage unloading and distribution of materials
- Eliminate repeated handling of materials
- Minimize the storage of materials on site
- Minimize the distance that workers must transport materials to the point of use
- Make staging areas accessible to lifting equipment
- Make sure cranes are accessible to staging and building areas but clear of overhead power lines and other utilities
- Store materials in the order they are going to be used
- Exploit the range of cranes by utilizing the reachable areas for material delivery and handling
- A traffic light on the entrance of the construction site will help to smooth the traffic so as to make sure that the public traffic will not be disrupted due to the material deliveries
- Avoid the use of special trucks as the construction site does not have the capacity to accept lengthy vehicles

7.4. Traffic Management

Traffic management is the second most important aspect of the logistic plan, alongside with material delivery and handling. It can be considered as the keystone of the logistic plan, as it coordinates the movement of vehicles, pedestrians, workers and plant; elements that in case of failure can temporary disrupt the project. Moreover, in order to fully enjoy the benefits of Just-in-Time approach, traffic management is essential (van Moolen, 2010).

The key to creating an efficient and successful traffic plan is to know what exactly needs to be managed. The Delft project is a quite complex project but also political sensitive. It involves the construction of a public building and any kind of disturbance that may occur during construction will be highly criticized by the public. For that reason, traffic management is considered quite critical for the smooth completion of the project and will be analyzed in order to be addressed properly on the logistic plan for the construction site. After consultation with various actors involved with the design phase of the Delft project the following areas of consideration have been identified:

- *Vehicles access on site* depending on the future state of the project
- *Pedestrian routes*, through the new bridge that will be constructed and nearby the project area
- *Cyclist routes* towards the station, focus on the cyclist parking which is a big problem (2000 bicycles parking need to be relocated in the area)
- *Workers route* as there is no possibility for parking on site

The two different future states of the project that have been mentioned in *section 7.1.3* will result to different design principles regarding the vehicle access on site, the pedestrian, cyclist and workers route which will be analyzed in the next paragraphs.

7.4.1. Vehicle access on site

In *section 7.3.1* the process and the logistics benefits of the decomposition of the steel trusses have been discussed. For traffic management, the logistic benefits of this decision are huge. Initially, the decomposition of the steel trusses made possible the use of normal trucks for the transportation of these elements. By this, one of the largest risks of the project, the transportation of large elements in an already congested construction site, is being mitigated with direct influence to the project efficiency. The consequences and the benefits of this decision include:

- The impact of the extra traffic to the local community is minimized
- The vehicle access on site becomes easier and more flexible

In the case of transportation of the large trusses in one piece on site, special arrangement should have taken place. The transportation of a 40 meter long and 8.5 meter wide element could only be feasible by special trucks (as alternative modes of transportation are not feasible for the Delft case, see *sections 6.4.1* and *7.3.1*) that would occupy a large part of the highway. In that case, special arrangements with the public authorities should be made and probably the transportation could be taken place just for a restricted period during night with road lane closures. This could create huge disturbance to the local environment and the element would not be able to be delivered in a just in time basis, which would cause delay of the construction work. In addition, due to the special transportation arrangement, the access on site would have been very difficult. The special truck would not be able to access the site through the entrance as the size of the vehicle and its turning cycle would make that impossible. As a result, the only possibility would be to transfer the element over the canal and the tram line on Westvest which would add complexity and more risks for negative external effects to the project.

Another important input for the traffic management is the likely constraints on the volume of the materials needed for the construction and the degree of difficulty of deliveries which depends on the size of the vehicles used for material transportation and their turning circles. Appropriate transportation methods should be used when transporting materials in order to ensure that no damage will occur (March, 2009). The assessment of the Bill of Materials for the Delft project, which is presented in *section 6.4.2*[7]*,* confirms the flow of construction traffic without the need for special transportation arrangements.

In conclusion, material transportation which has been considered a major risk for delaying the project, due to the size and the nature of the construction site, is mitigated through the smoothing of construction traffic. This is considered very important for the development of an efficient logistic plan. Having knowledge about the construction traffic and knowing that there is no need for special arrangements of transportation decreases the complexity for the design of the vehicle access on site. The main requirements that need to be taken into account are the trucks access route to the site and the turning circle of the trucks on site.

[7] The reader should keep in mind that the argument is based on a draft version of the Bill of Materials. In case of any changes on the definite Bill of Materials, some of the mentioned approaches about traffic management may not be applicable.

"The realistic scenario"

In the realistic scenario, the vehicle access point will be positioned next to the new bridge that will be constructed on the side of Westvest Street. Westvest is a double traffic flow street which means that trucks will be possible to arrive on site from both directions. For the logistics plan it is important to assess any restrictions regarding the turning of the trucks towards the site entrance. The new bridge will be 13 meters wide which means that it can allow the turning of the vehicles that will be used for most material deliveries (see *section 7.3.1*). The bridge will be able to accept the load of the heavy traffic as it will be able to stand up to 20 KN/m^2.

"The contingency plan"

In the contingency plan, the vehicle access point will be positioned at the current vehicle access point of the tunnel contractor. This side gives also the opportunity for double traffic and can assist the flow of trucks as it has been already successfully used for the deliveries for the tunnel construction. By the time the City Hall project will begin there will be a possibility of using this entrance as the tunnel roof will be constructed, so the area will be able to support the construction traffic. The vehicle access on site depending on the future state of the surrounding area is depicted in *figure 7.6*.

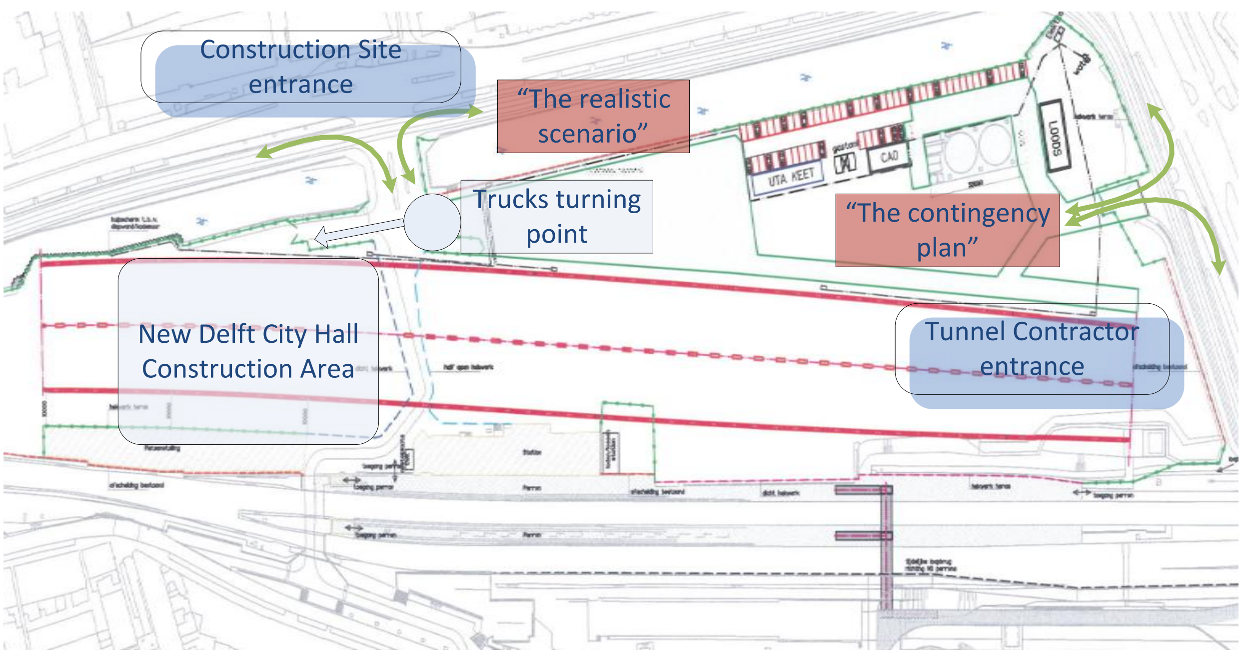


Figure 7-6: Vehicle access points for the construction of the new Delft train station & City Hall

7.4.2. Pedestrian route

The construction of the new Delft train station and City Hall interferes heavily with the public flow towards the current train station, which will be in operation in parallel with the construction of the first phase of the building, from the side of the Westvest Street. This side is considered critical as it is connecting the Delft city center with the current train station. At the current phase, the pedestrian routes (green lines) are shown in *figure 7.7*. The traffic flow from the city center is being guided to the temporary staircase that leads to platform 1 of the Delft train station and to the small tunnel located under the current railway which leads to both station platforms. There are also two more access points for the platforms, one from the opposite side of the current train station and one on the side of Zuidwal Street. From this side both platforms are accessible through another temporary staircase that has been placed which also connects the bus station on the other side of the train station.

The main problems that have to be dealt with for the logistic plan are the access to the train station for the people that will be coming from the city center and the presence of a small booth of GWK bank and the current temporary staircase very close to the future construction area. The current pedestrian route for the public traffic that is coming from the city center will not be able to be used due to the construction works at this area. Moreover, the exit of the small tunnel next to the train station that leads to the city center will have to be covered for safety reasons as there should be no public traffic so close to the construction works. Also, the current temporary staircase that is located next to the small tunnel will have to be moved as there will be no public traffic at this direction. This creates another problem which regards the use of the small booth of GWK bank that is located after the exit of the small tunnel and next to the current temporary staircase, as it will be unreachable for its customers. Guidelines about these problems will be given later in this section.

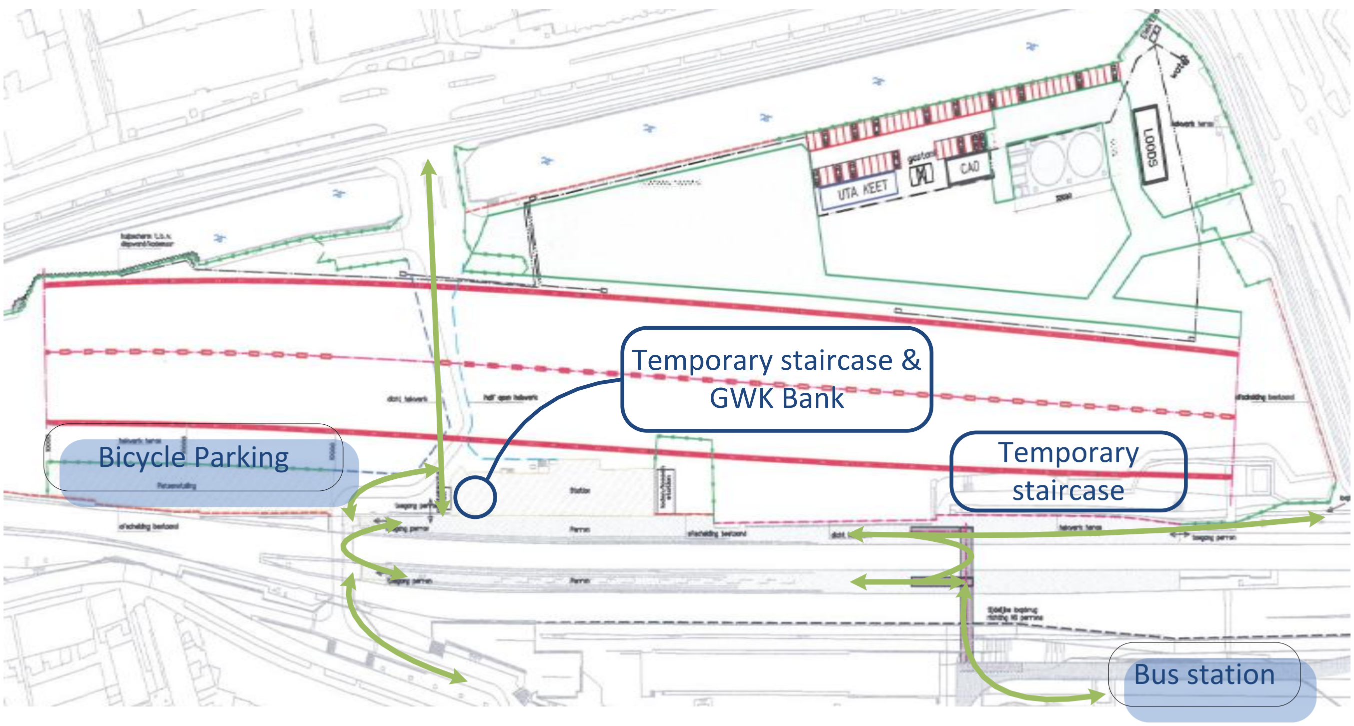


Figure 7-7: Current state of pedestrian and cyclist routes

"The realistic scenario"

In the realistic scenario the one bridge is being used as the vehicle access point on the construction site and the construction site entrance. There is also another bridge next to it that will be able to be used so as to guide public traffic towards the train station. The advantage of the use of this bridge is that the construction related traffic is totally segregated from the public traffic. The drawback is that as far as the future planning of the area is not clear yet, there might be some conflicts with the construction work that the tunnel contractor will do at this area.

"The contingency plan"

In the contingency plan the bridges are not completed yet and the construction traffic is coming from the current entrance of the tunnel contractor. The only possibility of sending the public traffic from the city center to the train station without any conflicts with the construction traffic will be the use of a temporary high bridge that will cross the construction area in a height of around 8-10 meters. By this the proper segregation of public and construction traffic is guaranteed, although a number of drawbacks will arise, with the most important to be the accessibility of the train station to disabled people. In case that this proposal will be considered too complex and expensive, there is a possibility of leading the pedestrian traffic through the ground, but with proper consideration of safety measures such as dedicated pedestrian crossings assisted by traffic lights.

In conclusion, there are possibilities that will allow public traffic to flow from the city center to the train station but this topic needs further and more detailed consideration as soon as more information regarding the future planning of the area will be available. The proposed future pedestrian routes can serve as an input for further research and are depicted in *figure 7.8*.

7.4.3. Cyclist route

According to the current state of the project, a bicycle parking with capacity of around 2000 bikes has been placed next to the current train station as it can be seen in *figure 7.7*. The current cyclist routes are following the pedestrian routes up to the point that is reachable by bike. With the new planning and the construction of a part of the City Hall basement next to the tunnel, the current bicycle parking will have to be relocated. This specific point is a logistics nightmare as so far the future planning of the area is not clear and the parking has to be moved in about 15 months.

A position for the bicycle parking will be proposed for each scenario, but as the choice is based on assumptions it cannot be concluded that the proposed positioning will solve this problem comprehensively. Still, it can be a valuable guide for the people that will look in depth into this problem in the next months and will give an idea about the future state of the project and the corresponding problems of the bicycle parking positioning. The bicycle parking that is going to be relocated needs to be around 1,150 square meters so as to assist the accommodation of almost 2000 bicycles (Neufert & Neufert, 2000).

Finally, the bicycle parking repositioning is really important for the municipality of Delft, as a careless approach to this problem may result to one important risk identified in *section 6.5,* the inconsiderate bicycle parking on the area around the train station. Cyclists are not going to accept a bicycle parking far away from the train station and this may result to a distortion of the local life of the citizens.

"The realistic scenario"

In the realistic scenario, bicycles will be possible to reach the train station but it will be useless as there will be no parking space. A parking place on the side of the city center would be the best solution, as then the pedestrian route can be used to reach the train station platforms. An interesting idea will be the use of the canal as a temporary bicycle parking area. This solution has been used in the construction project at Amsterdam Central Station where the municipality of Amsterdam had to free the entrance plaza of Central Station from the mass of bicycles. The proposed solution by the VMX Architects was a temporary bicycle storage construction with 100 meters length, 17.5 meters width and a capacity of 2500 bicycles, in the water between Lovers quay and the Ibis Hotel (VMX, 2001).

The points of consideration with respect to this proposal are:

- The availability of the space for the construction over the canal in front of Westvest
- The accessibility from the city center towards the temporary bicycle parking
- The cost of the construction with respect to its benefits

As regards, the availability for the construction over the canal in front of Westvest, there might be a possibility as the dimensions of 70 meters length and 17 meters width for example, will be able to be covered. What still remain unknown are the specific parameters with respect to the accessibility of the bicycles from the city center to the specified area of the parking that will make an idea like this feasible. The area that can be used is depicted in *figure 7.8*. The main problem for the accessibility of the bicycle parking will be the tram lines that are next to the proposed position for the parking. What is known so far is that the tram line will be diverted in the future but is still unknown is whether the line Westvest will be kept running along the whole street or not. In any case, this area has to be further researched so as to come with a comprehensive solution about this point.

"The contingency plan"

In this scenario, the construction work at the tunnel will be almost completed. After a discussion with one of the site supervisors of the tunnel construction (Ozinga, 2010), it has been mentioned that there is a possibility of using temporarily an area of the finished tunnel shell that is depicted in *figure 7.8*. The advantages of this decision will be that the traffic from the bicycle parking to the train station platforms may be able to connect with the temporary bridge that is already on the station. That will smooth the traffic and decrease a lot of the complexities regarding the public traffic management.

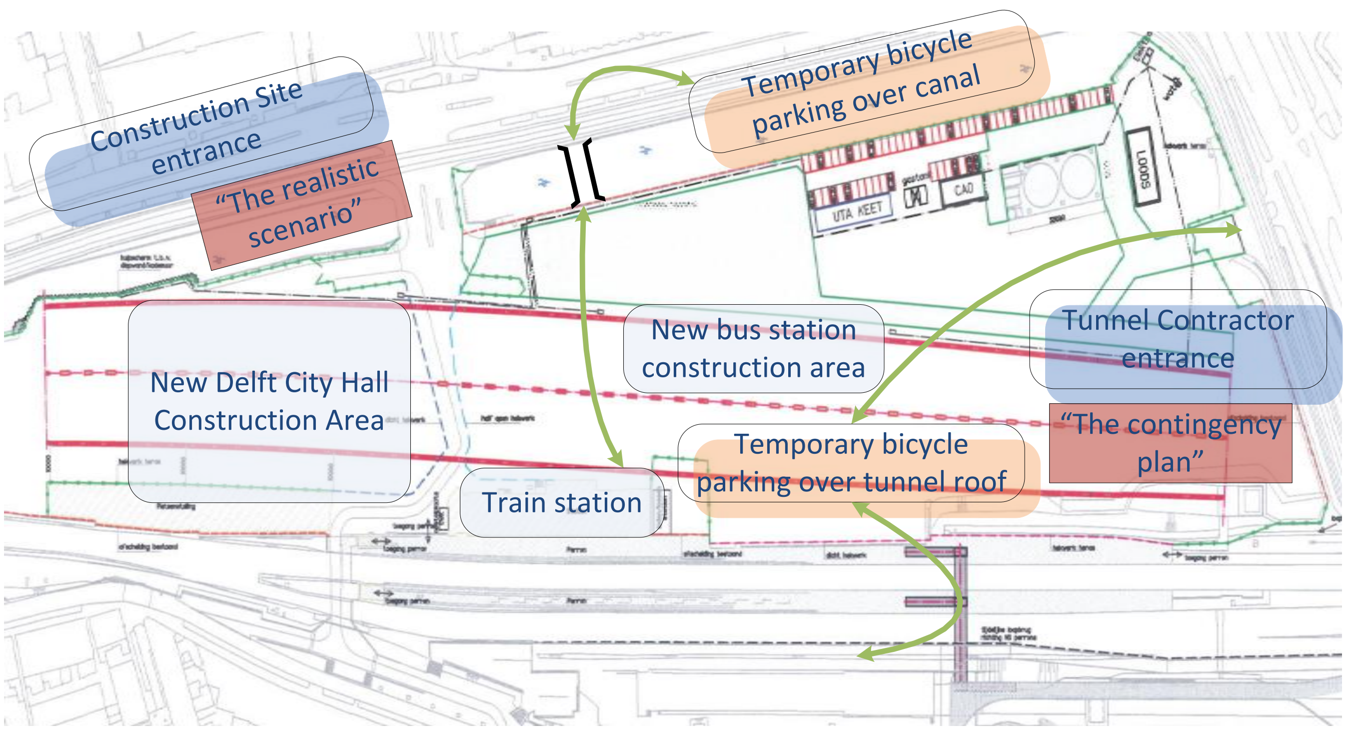


Figure 7-8: Future state proposal of pedestrian and cyclist routes

On the other hand, there might be some complications regarding the period that this parking will be able to be used, as the area around the parking should be prepared for the future bus station. Also, special consideration should be given to the cyclist route which will provide access to the bicycle parking. One possibility will be through the tunnel contractor entrance and another will be by a temporary bridge which can be placed on the canal next to Westvest Street. Both options should be carefully assessed as there will be points where the construction traffic will be mixed with the public traffic. The pedestrian and cyclist routes depending on the future state of the surrounding area are depicted in *Figure 7.8*.

7.4.4. Workers route

Whilst vehicle, pedestrian and cyclist traffic will form a significant part of the traffic to the site and around it, the issue of how workers will arrive to the site should also be considered in a logistics plan. In the case of Delft there is no space available for parking on site or near the site as the construction site is located next to the city center which means restricted parking space. Furthermore, usually there is a short window of time for all the workers to clock in. A specified area should be registered for the workers parking, which ideally would be close to the construction site. From there the workers will arrive on site through the main entrance, with the use of specified vehicles that will transport them or on foot. Due to the fact that the workers will probably carry their own materials, shuttles could be a good suggestion for the workers transportation, but at the end this is a decision the future contractor will make. It is assumed that around 3 to 5 shuttles will be needed for the workers transportation on the peak of construction.

Several areas can be considered regarding the workers parking. The tunnel contractor that is working already on site has rented a few places is the Koepoort parking, while there are also some parking space on the south side of Delft which can also be considered.

Following the discussion about the traffic management processes, the following guidelines can be derived for the vehicle access, pedestrian, cyclists and workers route for the construction of the new Delft train station and City Hall.

7.4.5. Guidelines for traffic management

- Due to the uncertainty of the planning, several scenarios need to be evaluated
- The possibilities for the vehicle access and site entrance are either the bridge on Westvest or the current entrance of the tunnel contractor
- The bus station has already moved on the other side and should be taken into consideration for the decision regarding the allocation of the bicycle parking
- Preferable route for public traffic is the opposite side of the train station as it involves less safety risks
- The side of the small tunnel that will face the construction site should be closed, so as not to allow public traffic near the construction site
- Safety zone between the boundaries of construction site and the pedestrian route towards the train station
- Consideration of building temporary sheds for bicycle parking over the canal like the case of Amsterdam for “the realistic scenario”
- Consideration of the use of some space on the completed tunnel for bicycle parking in “the contingency plan”

- Bicycle parking should be in an area near the train station as the cyclist is not likely to accept a parking far away of the station and this may create congestion in the residential area near the station due to disordered bicycle parking
- GWK bank should be relocated in an area near the train station and reachable to the public
- Appropriate directional signage will be provided so as to ensure the clear distinction of construction and public traffic
- Vehicle maneuver around site should be in absolute segregation between them and any pedestrians and cyclists

7.5. Managing critical risks - Security

Good logistics will have a positive impact on productivity, but is should also be remembered that it can bring huge advances in a project through an efficient and holistic approach to some of the most important issues on site. More specifically, safety and security risks, along with other risks related with the negative external effects that the project can bring to the local environment can be effectively managed when they are taken into account in the development of a logistics plan.

Critical risks on a construction site as it has been identified by Health and Safety Executive (2010) include:

- Site organization
- Slips, trips and falls
- Work at height
- Structural stability
- Cranes
- Electricity
- Fire
- Mobile plant and vehicles
- Demolition

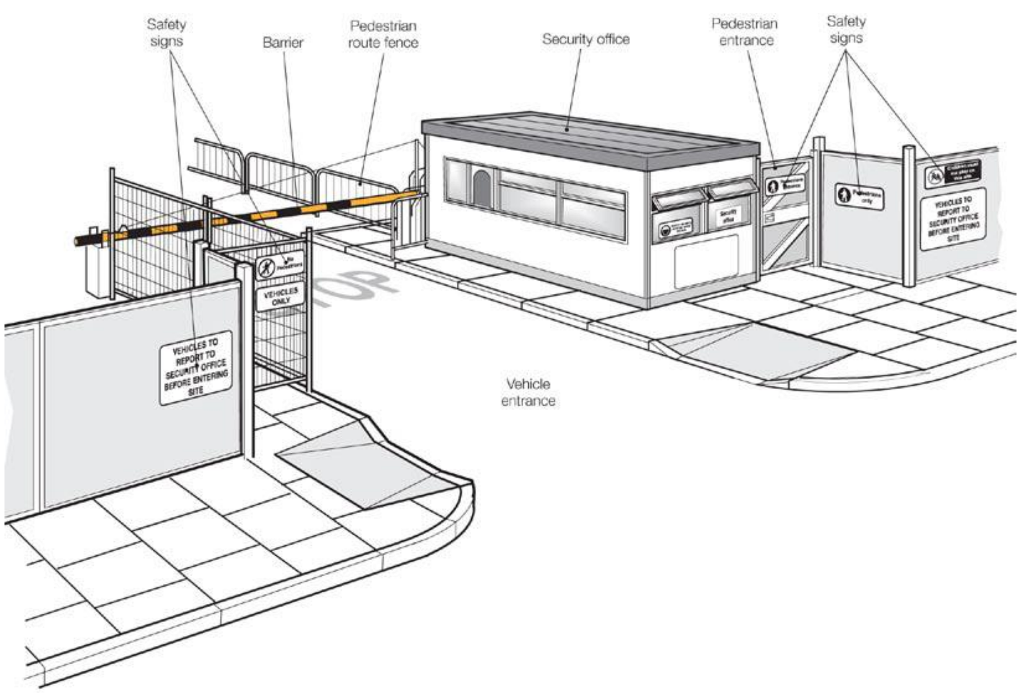


Figure 7-9: Security measures for a construction site (HSE, 2010)

All these risks and hazards will be identified by the principal contractor who will be responsible for controlling and treating these risks. A logistics plan can assist into the management process of the critical risks through the identification of these risks and the proper planning so as to allow the contractor to be able to deal with these risks. Comprehensive signage, fire points, exit routes are just some of the things that should be included in a logistics plan. Another important thing is the planning of the right first aid provision in case of emergency. A logistic plan should make sure that the area will be accessible for a fire-fighting vehicle, an ambulance or a first aid team. Moreover, the possibility of having first aid equipment and facilities in a permanent position on site should be taken into consideration. A parking spot for an ambulance on site for example may result into increased level of safety on site and mitigate important health and safety risks.

Apart from the health and safety critical risks, security is also important for the construction area. The principal contractor will usually provide a perimeter fence and gate security to protect the construction site, to not allow public traffic get mixed with construction traffic and to manage the access on site. *Figure 7.9* illustrates some security measures that can be taken on a construction site.

Following the discussion about the critical risks management and security on the construction site, the following guidelines can be derived for the construction of the new Delft train station and City Hall.

7.5.1. Guidelines for managing critical risks – Security

- The construction area should always be accessible for emergency vehicles like a fire truck or an ambulance
- Proper signage for escape routes in case of emergency should be clearly defined by the main contractor and communicated to everyone that will be working on site
- During the construction of the building, proper evacuation plan should be in place with clearly defined exits in the building
- Fencing and hoarding will be used for the segregation of construction site area
- Site personnel and visitors will gain access to the site via the main entrance which will be located either at the bridge in Westvest Street or in the side of Zuidwal, depending on the future state of the project
- A turnstile, a bar or slide gates will be provided to ensure that no unauthorized access is gained during the works or out of hours
- Due to the fact that material storage on site will be limited, no special security arrangements for material theft will be taken place
- Safety and security issues are strictly regulated and a main responsibility of the future contractor of the new Delft train station and City Hall

7.6. Waste Management

As it has been stated in *chapter 1* in the description of the research problem, construction waste is a noteworthy environmental problem. As sustainability issues rise even further up the agenda, the construction industry and the individual companies are reviewing its practices in the area. The significant cost involved with waste can be a leading driver for the industry to increase efficiency (Sullivan, Barthorpe, & Robbins, 2010).

Waste management is a pretty complex process that cannot be solved just by a proper logistics plan. The waste on a construction site is difficult to be defined and planned ahead due to the uncertainties that will arise during the execution of the project. Things that should be considered for the minimization of waste on site include:

- Practical measures associated with construction works to prevent waste entering on site
- Waste streams resulting from construction works which can be recycled or reused
- Consideration of alternative products containing recycled materials that could be utilized for the execution of the construction works

The waste management system that will be adopted on the construction site will be through the use of the separation bins for recyclable materials, and non-recyclable materials. The main contractor will be responsible for the waste bin system and shall involve a management plan for the supply, delivery, removal and certified disposal of site generated waste.

Additional bins will be provided where possible to further separate waste. Examples include nominated bins steel, wood, concrete, plastic, etc. These bins will be mobile and flexible to use and will be placed in a specified area or next to the construction work that generates waste. *Figure 7.10* illustrates several types of bins that are used for the segregation of construction waste.

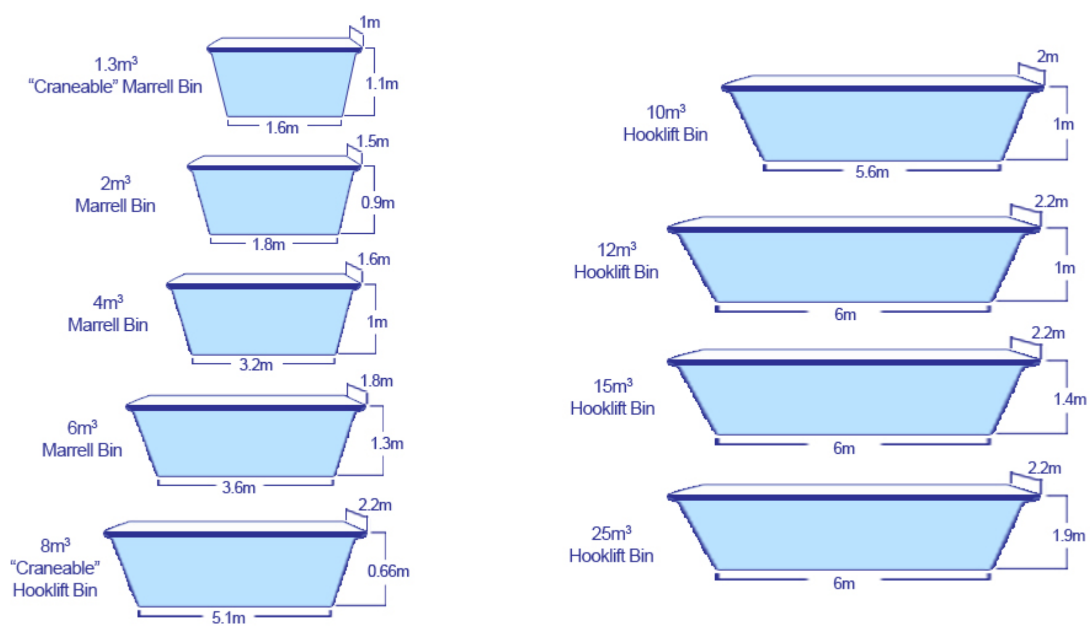


Figure 7-10: Illustration of waste bins used for construction waste segregation (Building Construction Bins, 2010)

Following the discussion about the waste management processes, the following guidelines can be derived for the construction of the new Delft train station and City Hall.

7.6.1. Guidelines for Waste Management

- Make contact with the main contractor to identify areas for waste reduction and materials reuse
- Environmental standards and local legislation for waste minimization should be met
- Project waste types should be identified prior to works commencing
- Waste segregation and recycling bins should be provided within the construction site area
- Waste should be segregated and transported to appropriate waste facilities
- As with critical risks management and security, waste management is strictly regulated and a main responsibility of the future contractor of the new Delft train station and City Hall

7.7. Construction Logistics Plan design process

This final section concludes the logistics plan design process and presents two integrated approaches (based on two different future states of the surrounding area) about the logistics plan for the construction site of the new Delft City Hall.

According to Sobotka, Czarnigowska, and Stefaniak (2005) the main task of an integrated logistic system is to provide just in time deliveries when needed to eliminate most of materials handling and storage on site, and to shorten the time of the project completion by eliminating reasons of work stoppage. The whole scope of the construction logistics plan for the construction site of the new Delft train station and City Hall has been based on this approach. *Figure 7.11* illustrates the basic logistics tasks that have been accomplished for the Delft project.

Logistics guidelines for the design	•Identification of the logistics constraints of the area resulted to promotion of prefabrication and just-in-time approach •Input to the design team regarding the material and construction element choice
Analysis of alternative structural designs and material utilization	•Analysis of the building structure •Old planning vs. new planning
Material requirement specifications	•Draft Bill of Material •Assessment of the most voluminous and large elements, recognition of any special requirements for transportation on site
Feasibility study of logistics concepts	•Identification of two future states of the surrounding area •Use of simulation in order to identify any vehicle access restriction on and to construction site •Crane positioning based on space exploitation
Logistics guidelines for tender preparations	•Guidelines presented for mobilization and site set-up, material delivery and handling, traffic management, managing critical risks - security, and waste management

Figure 7-11: Basic Logistics tasks during the design phase (Sobotka & Czarnigowska, 2005), adapted by the author

The process that has been followed for the development of an integrated approach for a logistics plan for the construction site has been presented in *figure 5.8*. This process has been based on four steps that have been discussed in *section 5.2*. A reflection of these steps is needed in order to finalize the analysis of the Delft case and present the logistics plan for the construction area.

Step 1- The general overview

The project planning has been assessed so as to be able to recognize the possible logistics constraints that may arise in the surrounding area. These constraints can be a result of delays on the neighboring projects that are running in parallel with the construction of the new Delft City Hall. Decisions related with the flow of resources on and to site and the public traffic around the site, are influenced by the progression of the whole area. The complexities that have been arisen in the interface of the different projects are described in *chapter 6*.

Step 2 – Looking into the problem

After identifying and understanding the local environment of the construction site of the new Delft City Hall, the analysis goes deeper into the core element which is the building itself. The logistics constraints of the environment have a direct impact to decisions related with the design of the building. The fact that the construction site is too small calls for a just-in-time approach for material delivery. The use of prefabrication speeds up the construction process but brings problems related with the handling of the large prefabricated construction elements. The process of dealing with these problems includes the consideration of alternative structural design and material utilization by the design team. The research comprehends this process and presents the results, the new planning of the new Delft train station and City Hall, in *chapter 6*.

Step 3 – Coming up with solutions

The new planning of the Delft project had an influence in logistics on and to site processes. Several areas of consideration has been identified from the literature and interviews, that has been used in this chapter so as to come up with solutions related with the logistics of the construction site of the new Delft City Hall.

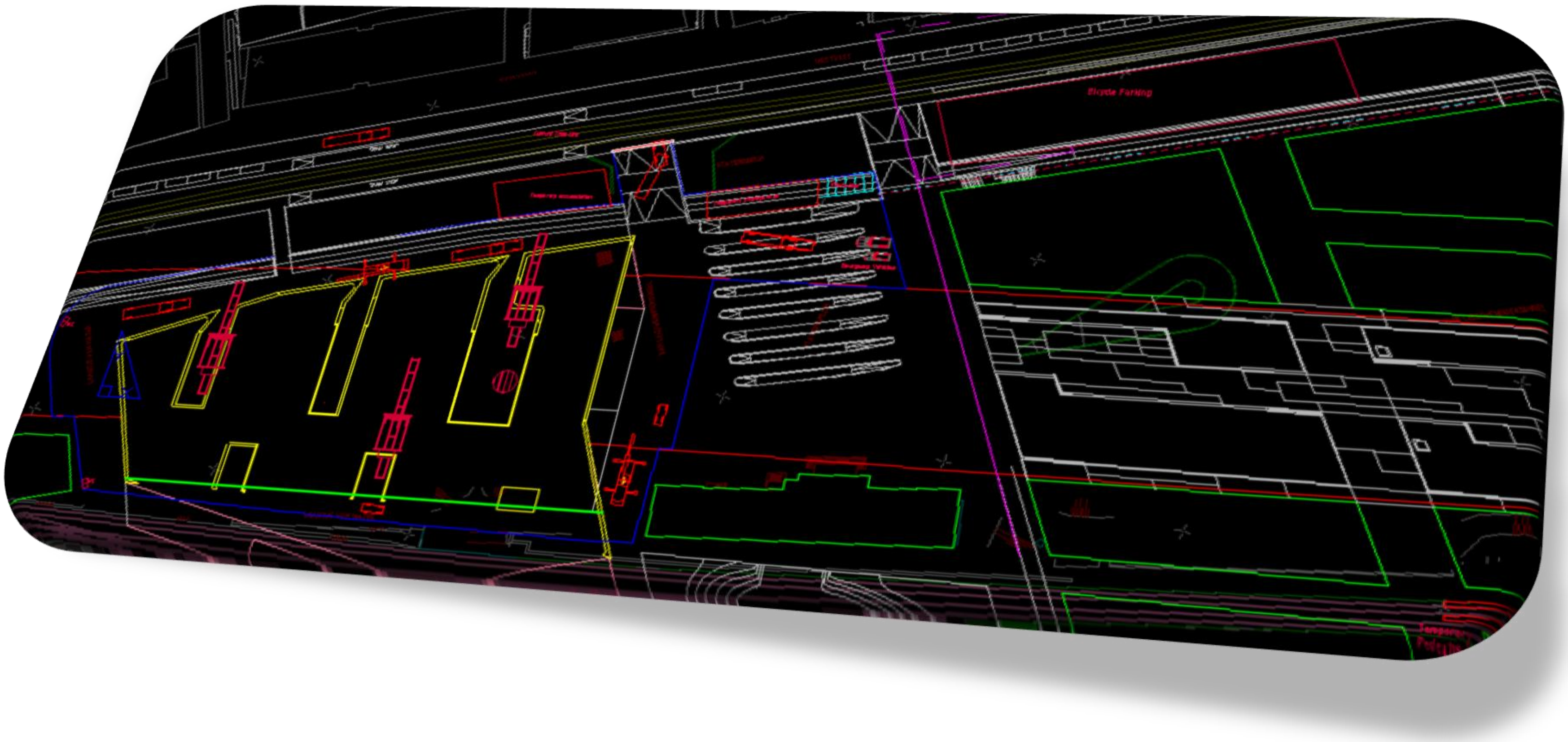
With respect to the resources flow processes, the type of equipment needed for delivery and handling of materials has been considered, along with the type of traffic that will flow on and around the construction site. In order to test the viability of the solutions that have been proposed, logistics concepts such as the crane positioning and the vehicle access on site have been tested for their feasibility. The result was the proposal of construction traffic that can be managed on this congested and small construction site, a proposal for an optimized crane positioning in order to optimize the space use on site, and suggested routes for the public traffic so as to achieve segregation between construction and public traffic.

With respect to the proposed positioning of the temporary accommodation for the construction site, the exploitation of the canal is being taken into account for the “realistic scenario”. The reason for this decision is based on the fact that the canal will be out of use during construction, the construction area is limited and the assembly process for a temporary construction for the accommodation is a common process that has been used in similar situations. For the “contingency plan”, the temporary accommodation is positioned next to the tunnel contractor’s temporary accommodation so as to be able to monitor and control the construction traffic that will be coming from this side.

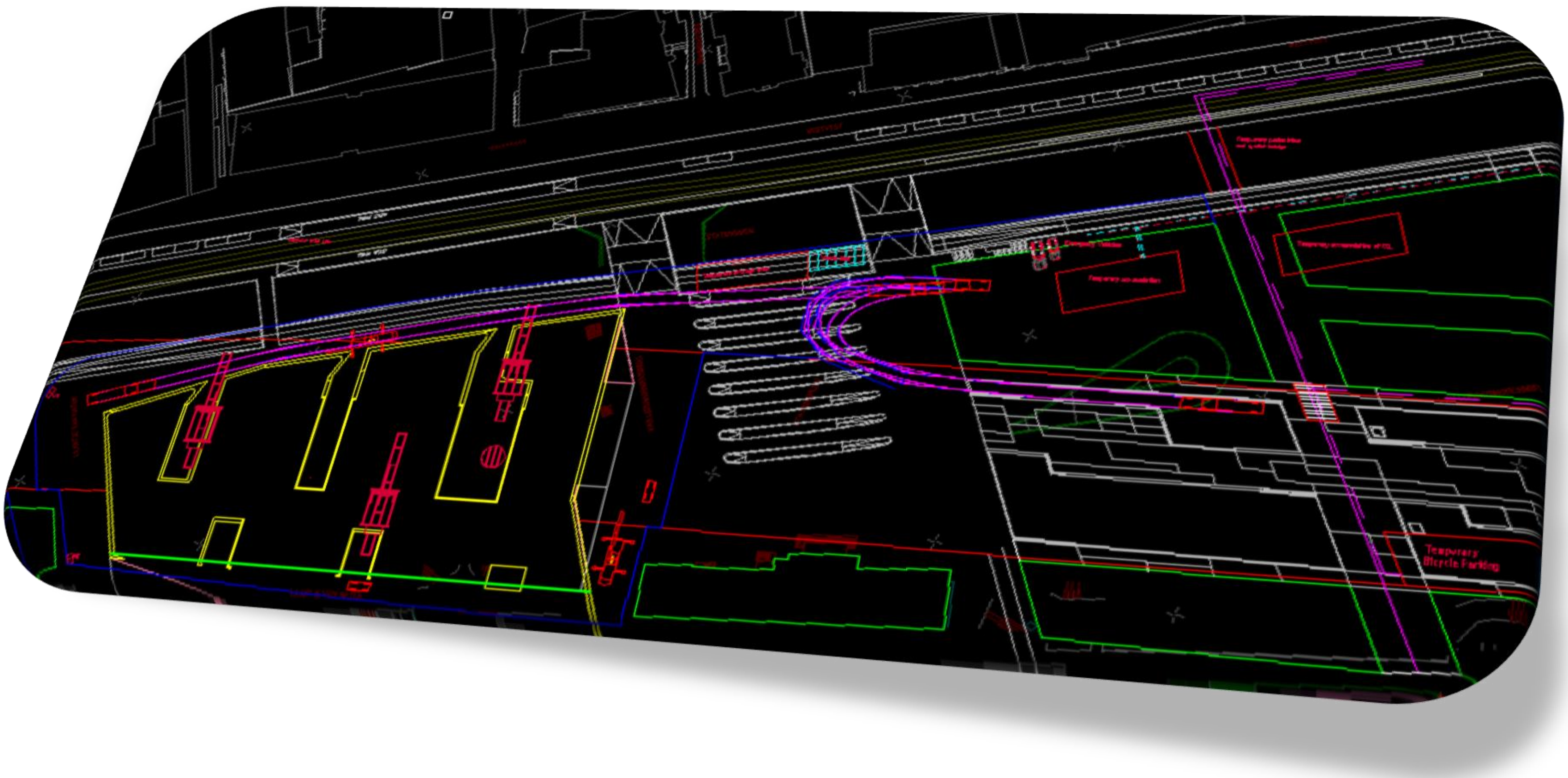
Step 4 - Optimize solutions

The final step consists of the completion of the logistics plan for the construction site, by taking into account possible side effects that may affect the plan. In the case of Delft, a full optimization of the plan cannot be achieved at the current project phase for reasons that have been explained on *section 1.4*, and due to the fact that the analysis has been based on several assumptions regarding the future state of the construction process. Nevertheless, in order to reach the maximum optimization level with respect to the current limitations, two future states of the surrounding area have been considered and two plans are delivered. These two plans will serve as a benchmark for the tendering process about future contractor of the new Delft City Hall, who will be responsible for the final optimization of the plan. The main approach of the two plans is consisted of the same principles. The points of difference between the two plans mainly consist of specific logistics constraints related with the future state of the surrounding area, which has been analyzed in *section 7.1.3*.

"The realistic scenario"



"The contingency plan"



Note: *It has to be mentioned that the two previous drawings are just a draft representation of the proposed logistics plan. The quality of the drawings is low due to the fact that there were restrictions regarding the format of the paper. The original drawing is depicted in A2 format and has been delivered to the relevant parties related with this research.*

7.8. Summary & Sub-conclusions

This chapter finalizes the case that has been studied for the conduction of this research through the analysis of the empirical findings that have been identified in *chapter 6*. Initially, an introduction about the case specific construction logistics analysis takes place and the areas of consideration for the progress of the analysis are discussed. Subsequently, each area of consideration is being analyzed so as to come up with recommendations and guidelines for the development of the logistics plan for the construction site of the new Delft train station and City Hall. Due to the uncertainty of the future planning of the construction area, two future states of the surrounding area are taken into consideration. After concluding the analysis, two integrated approaches for the logistics plan of the new Delft train station and City Hall are presented. The key points of this chapter, according to the topic that has been described are summarized in the following table:

Topic	Description
Construction Logistics Analysis	• Main areas of consideration for the development of the logistics plan: ➢ Mobilization and Site set-up ➢ Materials delivery and handling ➢ Traffic management ➢ Managing critical risks – Security ➢ Waste Management • A number of assumptions based on two future states of the surrounding area will be used so as to deliver an end result: *1. Bridges construction completed before the beginning of the City Hall construction* *2. Bridges construction in parallel with the City Hall construction and tunnel works on the south side of the building completed*
Mobilization and Site set-up	• It includes the positioning and set-up of the temporary accommodation and utilities for the construction site of the new Delft train station and City Hall • Not a core consideration for construction but a proper organization of the construction site is crucial for the success of the project as it can improve the flow of resources • Temporary accommodation: Temporary offices, Canteen, Welfare facilities, Reception area • Temporary utilities: Temporary power, Temporary water and plumbing
Materials delivery and handling	• Material management is one of the core activities of construction logistics with a lot of actors involved in it • The logistics plan can mitigate several risks regarding materials delivery and handling processes • Materials delivery ➢ *Large steel trusses*: The delivery of these elements needed special arrangements for delivery due to the use of prefabrication. After a logistical analysis, the designers decided to decompose them to smaller parts so they can be delivered by normal trucks. This resulted to a smoother material delivery process and benefits related with the time and realization risks

	➢ Analysis of material unloading points in order to minimize the distance between material delivery and handling points ➢ Analysis of material delivery process in five steps • Materials handling ➢ After the decomposition of the steel trusses the material handling processes could be executed by lightweight cranes ➢ Crane positioning will exploit the available space on site through the use of the building voids ➢ Several project related benefits occur by this choice ➢ Analysis of the material handling points
Traffic management	• Areas of consideration: Vehicle access on site, Pedestrian route, Cyclist route, Workers route • Vehicle access on site: ➢ Transportation of large elements by normal trucks minimize the impact to the local traffic and make vehicle access on site more flexible ➢ Analysis of the trucks turning circle • Pedestrian route: ➢ Problems with the interference of construction works with the public traffic coming from the city center ➢ Analysis of current state and future state of pedestrian route based on each future state of the surrounding area • Cyclist route: ➢ Main problem is the relocation of a bicycle parking with capacity of 2000 bicycles ➢ Analysis of possible relocation of bicycle parking based on each scenario • Workers route: ➢ No parking space on site, consideration about how workers will arrive on site ➢ Specified area for workers parking, consideration of use of specified vehicles for transporting them on site
Managing critical risks – Security	• Health, safety and security risks are taken into account for the development of the logistics plan • The principal contractor is responsible for controlling and treating these risks • Analysis of emergency vehicles access route
Waste Management	• Waste management is a complex process that cannot be solved just by a proper logistics plan • Waste management on site through the use of separation bins for recyclable and non-recyclable materials

Table 7-3: Summarizing Key Elements of the Chapter

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8. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this section is to gather and present the conclusions derived so far, in order to systematically answer the main research question posed from the early beginning of this endeavor.

Specifically, the question was:

> ***"How can construction logistics analysis during the design phase enhance buildings construction project efficiency in residential areas, while at the same time minimizing negative external effects in the local environment?"***

The following areas were explored before answering the research question:

- the application of a construction logistics analysis in a real project through the case investigation of the new Delft train station and City Hall construction, in cooperation with Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS)
- the project efficiency of a construction project and how it can be enhanced
- the negative external effects in the local environment of a construction project

Another important element to keep in mind while reading this section is the objective of this research, which was the following:

1. a) *To explore the contribution of Construction Logistics analysis towards the enhancement of construction project efficiency, by analyzing a real case of a building construction in a residential area in the Netherlands*

b) *To explore the contribution of Construction Logistics analysis towards the minimization of the negative external effects in the local environment of a construction project*

c) *To explore the trade-offs involved in the relationship between the enhancement of construction project efficiency and minimization of negative external effects*

2. *To present guidelines and recommendations to OBS with respect to the construction logistics of the new Delft train station and City Hall, through the development of a logistics plan for the construction site*

As it can be seen, the objective of this research has been always two-fold. Regarding the first part, it is satisfied by the derived conclusions. The second part, which is an illustration of a practical application of construction logistics analysis, has been satisfied through the development of a logistics plan for the construction site and the corresponding guidelines that have been proposed in *chapter 7*.

8.1. CONCLUSIONS

Construction logistics is a multidisciplinary process applied to a given construction that strives to guarantee at right time, cost and quality the availability of resources and information flow that will make the building process which is the core activity of construction feasible. Construction logistics is also a continuous process that goes on through the whole project life cycle. This report mainly presents an application of construction logistics analysis during the design phase of a project. The end result of the research is the development of a draft logistics plan for the construction site of the new Delft train station and City Hall. The reader should be aware that this report just covered a part of a construction logistics analysis, and therefore presented results concerning this part. The construction logistics analysis is therefore by definition not finished given the results of this research.

As it has been discussed in *chapter 1*, the research domain consists of three areas of exploration namely *construction logistics analysis*, *project efficiency* and *negative external effects*. At the end of this section the most important conclusions regarding the research domain will be presented. At this point a general discussion about the conclusions of this research will take place, followed by a discussion about the case-specific conclusions. In order to answer the main research question, five research sub-questions have been constructed. The individual answer of these questions took place in the previous chapters, but a synthesis of the most important conclusion will be demonstrated in the next lines.

Initially, the domain that construction logistics are applied consists of an industry with quite special characteristics and peculiarities as it has been described in *chapter 3*. Blasted by a critical credit crisis the last years, construction industry strives to find ways of saving money and improving efficiency. Quality costs related with services that have been found not to conform to specified requirements is an open wound for the industry and seems to be in an increasing trend. In addition to this, the complexity and uncertainty of construction projects, which are a result of the industry's peculiarities, add more boundaries to the pursuit of efficiency and increased productivity. As a conclusion it can be stated that any application that will be able to bring profits to the industry and to construction projects is being taken into serious consideration. Construction logistics have the potential to assist in the proper organization of a construction project, reduce inefficiencies related with non-core processes of construction such as the traffic management or the materials handling, and mitigate risks related with negative external effects resulted by the execution of a construction project.

The concept of construction logistics is not new for the industry, but as it has been mentioned before it is mostly involved with the management of activities that are fairly considered non-core. Nevertheless, while security, materials handling and delivery, waste management, traffic management, temporary works and accommodation cannot compete with the excavation processes, the sheet piling, or the assembly of steel structure which are considered more "sexy" for constructions, they are of equal importance. In case that these processes are not planned effectively and implemented successfully the overall project performance will suffer. *Chapter 4*, thoroughly analyzed the effect that poor logistics can have on a construction project, both in terms of efficiency and in terms related with negative external effects. The illustration of the importance of construction logistics should be further enhanced through case study evidence which will point to the massive space available for savings and efficiencies. Only then, construction firms will adapt an even more professional attitude towards logistics and integrate this way of thinking into their normal way of doing business.

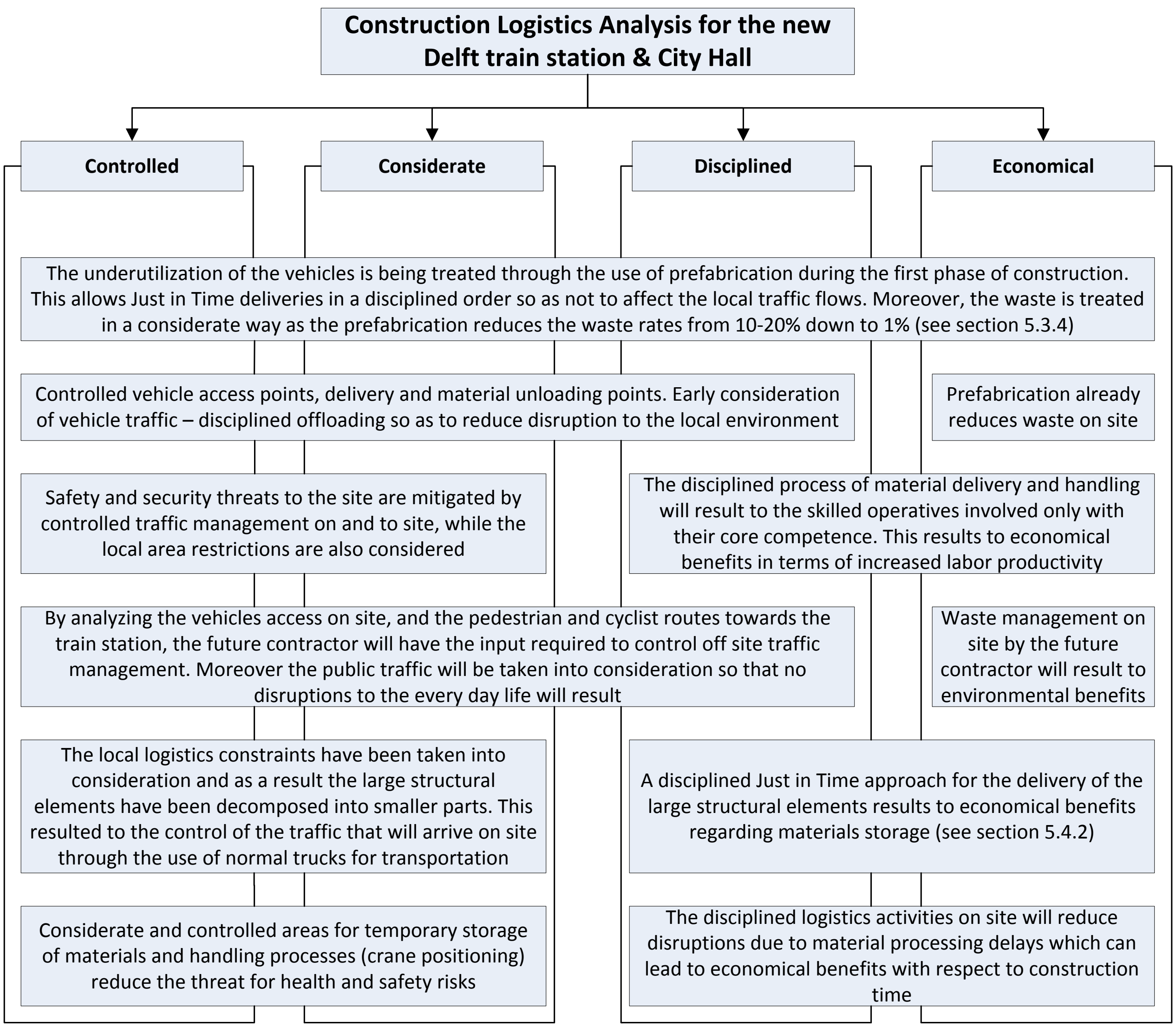
This research is adding a small brick in the large pile of construction logistics, by presenting the practical application of a logistics analysis during the design phase of a real complex construction project. Prior to this, a general overview of the applications of construction logistics in practice have been discussed in *chapter 5*. Several strategies can be used so as to improve the logistics performance of a construction project and it is decision for the actors involved in a construction project to make about how deep they will dive into this field. Construction logistics, as many other aspect of construction, has to be planned out in detail at the beginning of the project so as to fully benefit from its application.

The evaluation of the literature, which is not really there for construction logistics yet, the discussion with experts in the field and the assessment of the industry practice led to the consideration of mobilization and site set-up, materials delivery and handling, traffic management, managing of critical risks and security, and waste management as the foundation for the development of a logistics plan for a construction site.

Finally, with respect to the literature gap that has been identified at the beginning of this endeavor, it can be expected that the field of construction supply chain management and logistics will develop into a noteworthy area in the years to come. The body of literature of this specific field is not broadly developed yet, but as this research illustrated, construction logistics is a very interesting area of research for the further development of the construction industry towards a more efficient and sustainable future and is expected to get a lot of attention from the academic society and the industry itself.

Case specific conclusions

In *chapter 4*, several problems related with traditional approach of construction logistics has been identified. These problems have been addressed for the construction of the new Delft train station and City Hall, with an approach that can be summarized under four headings: *controlled*, *considerate*, *disciplined* and *economical.*



The consequences of the improper consideration of logistics in construction projects, as they have been defined in *chapter 4*, are divided in five categories. The proposed integrated approaches for the development of a logistics plan for the construction site of the new Delft City Hall positively influence these categories. Some examples of the benefits with respect to the identified consequences of poor logistics include:

1. *Unnecessary cost in the system*: The labor productivity on site is enhanced through the detailed material delivery and handling process description which reduces the time that skilled labor has to spend on logistics activities on site.
2. *Transportation and environmental issues*: By analyzing the material delivery and the traffic management processes, the future contractor will have the input required to control construction traffic. This may lead to reduced congestion on and to site.
3. *Poor quality in construction:* The production of high quality construction is assisted by the good organization of the construction site as it is presented in the logistics plan drawings.
4. *Increased project time*: The Just-in-Time approach for the transportation of the large construction elements reduce the time spent for movement of materials around site. The prefabrication reduces the secondary working of products on site.
5. *Added risks to health and safety:* The early consideration of material handling processes regarding the large construction elements in the first phase of construction and the optimized crane positioning lead to reduced manual handling of materials. A direct consequence is the reduction of health and safety risks for the people working on site.

The following paragraphs will present the main conclusions of this research in accordance with the research domain and based on the empirical findings of the case that has been studied, the construction of the new Delft train station and City Hall.

Construction logistics analysis

Conclusion 1

CONSTRUCTION LOGISTICS ANALYSIS CAN BE USED TO IDENTIFY AREAS OF INEFFICIENCIES OR IMPROVEMENTS REGARDING THE RESOURCES FLOW ON AND TO SITE

The conclusion is based on the following findings:

- ❖ During the first phase of construction, heavy traffic takes place in the construction site due to the need for large, heavy and voluminous materials. During this phase several inefficiencies can arise such as the lack of capacity of the construction site to accept heavy traffic, lack of proper material handling equipment, and inability of workers to handle materials. Having knowledge about these issues during the design phase can allow changes in material or construction elements requirements that will allow the proper resources flow on and to the construction site.
- ❖ In the case of Delft, the analysis of the logistics constraints of the local environment resulted to the decision for an alternative structure method for the building, through the decomposition of the large steel elements that were needed in smaller pieces, easily transferred and more flexible in the handling process (see *section 7.3.2*). Moreover, the logistics analysis identified the possibility for a bottleneck in the basement construction due to the fact that two different contractors would be mixed in the same construction area.

Conclusion 2

CONSTRUCTION LOGISTICS ANALYSIS CAN SERVE AS A VALUABLE TOOL FOR THE PROJECT MANAGEMENT OF A CONSTRUCTION PROJECT

The conclusion is based on the following findings:

- During the design phase of a construction project, the project management team may come with a new way of constructing or with a new plan that will lead to improved project performance with less negative external effects on the local environment. Construction logistics analysis can assist this process through the identification of possible logistics constraints in the new planning and by proposing an updated logistics plan that will allow the execution of the new planning.
- In the case of Delft, several logistics constraints were identified regarding the phasing of the project, the mixing of different contractors in the same area and the transportation of heavy construction elements. Moreover, from a project management perspective, the initial plan proposed for the construction of the building had several drawbacks. The most important was a conflict in the project schedule as the required deadlines could not be met. The project management team proposed a new planning which mitigated important risks (see *section 6.6.2*), including logistical risks such as the mixing of different contractors in a small and congested site. The construction logistics analysis served as a valuable assistance tool with the development of a logistics plan for the construction site in order to allow the proper execution of the project.

Project efficiency

Conclusion 3

CONSTRUCTION LOGISTICS ANALYSIS CAN LEAD TO THE IMPROVEMENT OF THE PROJECT PERFORMANCE THROUGH IDENTIFICATION OF PROJECT INEFFICIENCIES

The conclusion is based on the following findings:

- Decisions that can be made during the design phase of a construction project can have a big influence in the project performance. Construction logistics analysis can identify the resources flow requirements. The analysis of these requirements may lead to alternative scenarios regarding the building construction that can be assessed by the designers so as to come up with a more efficient design solution.
- In the case of Delft, several inefficiencies have been identified on the way of construction and the material transportation processes (see *section 7.3.1*). After the identification of these inefficiencies the designers came up with a solution about the structure elements that resulted to huge time and realization benefits (see *section 6.6*).

Conclusion 4

THE EARLY CONSIDERATION AND ORGANIZATION OF LOGISTICS PROCESSES ON A CONSTRUCTION SITE WILL ALLOW THE PROPER RESOURCES FLOW ON AND TO THE CONSTRUCTION SITE

The conclusion is based on the following findings:

- ❖ The flow of the resources needed for a construction site is a complex process that needs to be managed in detail. Effective traffic management and material delivery processes will allow the safe access and egress of construction resources in any construction site. The logistics constraints of the surrounding environment need to be assessed carefully and during an early project phase to provide the right information for the organization of the logistics processes on site.
- ❖ In the case of Delft, several logistics constraints, mainly physical, have been identified regarding the building location and the accessibility to site which could lead to extensive inefficiencies (*see section 6.4.1*). The analysis of material delivery and traffic management processes (*see section 7.3 and 7.4*), confronted the problems that would not allow the proper resources flow. The result was the proposal of two alternative plans that can be used depending on the future state of the project so as to allow the proper resources flow which will lead to improvements in the project efficiency.

Negative external effects to the local environment

Conclusion 5

CONSTRUCTION LOGISTICS ANALYSIS CAN IDENTIFY AND MITIGATE RISKS RELATED WITH NEGATIVE EXTERNAL EFFECTS IN THE LOCAL ENVIRONMENT OF A CONSTRUCTION PROJECT RESULTED EITHER BY THE CONSTRUCTION ITSELF OR BY THE APPLICATION OF CONSTRUCTION LOGISTICS STRATEGIES

The conclusion is based on the following findings:

- ❖ Negative external effects can be a result of a construction activity or a result of the application of construction logistics strategies so as to improve project efficiency (see *section 5.4*). Construction logistics analysis can identify the risks for these negative external effects at an early stage of the project and accordingly propose mitigation measures based on specific management actions.
- ❖ In the case of Delft, the analysis of the main risks (see *section 6.5*) identified the main areas that could result to negative external effects. The analysis of the main risks illustrates the importance of logistics actions towards the realization of the benefits of management actions needed so as to mitigate these risks.

MAIN RESEARCH QUESTION ANSWER

Construction logistics analysis during the design phase of a construction project in residential areas is an important process that can lead to important benefits realization. Initially, areas of improvement regarding the resources flow on and to site (materials, people, plant / equipment, waste) can be identified. Furthermore, construction logistics analysis can be a valuable tool of assistance for project management as it can identify inefficiencies related with aspects like material delivery, transportation, and traffic management that can be diminished and lead to increased project performance. At the same time, through the identification of the risks related with negative external effects for the local environment of the project, logistics tasks and guidelines can be derived for the proper mitigation of these risks. Constructions are always unpredictable due to the nature and the peculiarities of the industry, but it can be concluded that a proper construction logistics analysis during design phase has the potential to enhance building construction project efficiency while at the same time minimizing the negative external effects in the local environment.

8.2. RECOMMENDATIONS

After the conduction of this exploratory research some recommendations about the principles and designers involved in construction projects have been risen up and will presented in the following paragraphs. This is a result of the author's involvement with these specific linkages of the construction supply chain. The recommendations regarding Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS) for the current phase of the project have been covered in *chapter 7*. Nevertheless, some of the general recommendations regarding principles can also be used by OBS after the tendering process of the new Delft train station and City Hall.

Principals:

- Early consideration of logistics issues from the initiation phase for the proper completion of the project, as logistics decisions related with the choice of materials, the material transportation on and to construction site and the material handling can positively influence the progress and performance of a construction project
- Raise awareness of the main contractors about logistics strategies during the execution phase of a construction project because there are many opportunities related with logistics that can lead to the realizations of benefits regarding the project efficiency
- Create room for collaboration between actors of the construction supply chain so that requirements for resources are properly communicated towards the whole construction supply chain
- Implementation of a tendering process that will allow the early project involvement of potential contractors so that logistics related problems can be assessed properly

Designers:

- Early consideration of logistics during the design process can generate robust drawn information about construction elements that can assist the main contractor of a construction project towards the efficient delivery of the project
- Consideration of alternative structures can bring huge benefits for a construction project regarding logistics performance
- Assessment of the surrounding area of the project so as to identify any logistic constraints at early stage

Further research:

- Continue this research by expanding the scope and including the future contractor of the project who will be responsible for construction logistics, and investigate the use of alternative logistics strategies
- Gathering of quantitative data so as to test the derived conclusions and produce information that will convince all parts of the industry and academic society to look deeper into the topic of construction logistics
- Case studies during the execution phase of a construction project so as to assess the problems that may arise regarding construction logistics processes in practice
- Investigation of the relationships between construction companies and suppliers in relation with the logistics arrangements between them
- Further exploration of the interrelation between construction supply chain management and logistics and project management in constructions so as to create a clear body of literature for the field of construction logistics

8.3. Reflection

This research has been initiated by the author and the first supervisor of this research Marcel Ludema, in the beginning of April 2010. The initial goal has been to gain insight into the possible use of the concept of Supply Chain Management and Logistics in a construction project as a possible solution for problems related with efficiency and negative external effects to the local project environment. The initial inspiration was to assess the relationships between the different members of the Construction Supply Chain, have interviews with experts that would facilitate the development of a toolbox of modern logistics ideas that could be used in a real project and then check their applicability in practice. During that period, Ontwikkelingsbedrijf Spoorzone Delft B.V. (OBS) was at the initial stage of the logistics investigation of the construction of the new Delft train station and City Hall. On the beginning of June 2010, the author has been involved with OBS in order to assist the investigation of the Delft case. At that point, it became obvious that a completed solution regarding the construction logistics of the building construction was not feasible due to the uncertainties of the planning and the fact that a main contractor had not been assigned yet for the project. After discussions with OBS it had been agreed to concentrate on the development of a draft logistics plan for the construction site that could be used later in the tendering process as a reference for the future contractors. As a result, the initial idea about the creation of a construction logistics toolbox that could be used in a construction project has been transformed into a more practical situation where an actual construction logistics problem needed to be solved.

Moreover, due to the fact that the research has been focused on a single case study, it was sometimes quite hard to preserve the academic focus in the research. The generalization of the conclusions has not been an easy task, but the case findings made it possible to formulate some hypothesis. Nevertheless, the derived conclusions have to be tested in similar or even more expanded case studies. Having experienced a small part of the construction environment, it should be mentioned that some of the industry’s peculiarities resulted to some research planning setbacks. Sometimes, it has been difficult to gather the information needed due to the fact that several actors had to be involved to the information exchange process. It has to be mentioned that due to the lack of a specific body of literature for construction logistics, more time than planned has been spent on reviewing the relevant literature. If this research was re-done, less time should have been spent on trying to identify the concept of construction logistics in literature and more time should be planned for conducting interviews with experts on the field. The tacit knowledge regarding the topic is there and is enormous. Future researchers on this field should spend more time on the investigation of the practice of construction logistics as in reality the knowledge lies with the people that are responsible for the construction process management.

As a last point, it should be mentioned that the results of this research could have been more comprehensive in case that the author had knowledge of the Dutch language. Numerous information and archived data had to be translated so as to be assessed and as a consequence this resulted to several drawbacks in terms of time delays and punctuality of the information conception. Furthermore, construction site workers could be a valuable source of knowledge for the processes of construction logistics, but the language factor made it quite difficult to arrange a number of interviews.

In conclusion, the results of this exploratory research can be considered to fulfill the expectations of the research goal and raise several questions that can be a subject for future research. The field of construction logistics still has a lot of things to be studied. It is now to be seen whether the notion of construction logistics will develop along with the construction industry in a more efficient and sustainable future.

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APPENDICES

APPENDIX I – SEMI-STRUCTURED INTERVIEWS

Introduction

Several experts have been consulted in order to get deeper insight on the issues described in the research and more specifically on the relations between construction logistics, project efficiency and local negative external effects. The three most valuable interviews are summarized on the following section.

For the following interviews a semi-structured questionnaire framework was developed. The framework was developed after the literature review in order to assist the researcher to answer the sub-research questions and get a deeper insight on the current state of art of construction logistics. Based on the research domain o which is presented in *chapter 1* the areas under investigation are Construction Logistics, Project Efficiency and Negative External Effects. These are the main themes on the semi-structured questionnaire, but there is also the theme of Building Logistics Strategies added in order to assess how is building logistics applied in practice and what is the current state of art. The main themes of the interview framework are presented in *figure 1*.

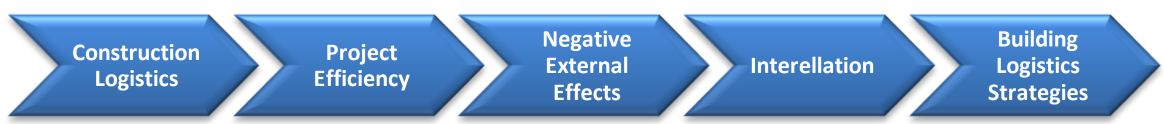

Figure 1: Main themes of interview framework

Table 1 illustrates general research questions that were generated through the literature study and the researcher's personal interpretation of the literature. These questions are organized under general representative themes, considered to capture the entire spectrum of the research topic. Each research question is used in the questionnaire either unchanged or slightly changed to become more neutral, more flexible and in general more appropriate for a semi-structured interview question.

At this point we have to stress the fact that, due to the different fields of expertise of the interviewees, not all the questions were answered from each interviewee. The interview framework is presented in the following paragraph.

The interviewee's response has been elaborated by theme, because the questions have not been followed as strictly as they stated in the interview framework. The questions are mostly used to assure that the research theme is covered satisfyingly.

Research Areas	General Research Questions
Construction Logistics	• What is Construction Logistics? • What kinds of problems exist in construction logistics? • What kind of processes does construction logistics include? • How can the involved processes be optimized? • What would be the benefits of optimizing construction logistics processes? • What are the consequences of poor construction logistics?
Project Efficiency	• What are the determinants of project efficiency, in terms of cost and time, for the construction of a building in a residential area? • What influences project efficiency? • In what degree is project efficiency influenced by negative external effects? • How can construction logistics influence project efficiency?
Negative External Effects	• What are the risks for negative external effects for the local environment that are involved with construction logistics? • How can these negative effects be minimized? • What would be potential complications in the minimization of the negative external effects?
Interactions/ Interrelations	• At what extent are project efficiency and negative external effects interrelated?

Table 1: General research questions

Semi-structured Interview Framework

Introduction

This research is about how construction logistics can enhance building construction project efficiency while at the same time minimizing negative external effects in the local environment. For this research, the logistics involved with the construction of the new Delft City Hall next to current Delft train station will be investigated, and the goal is to provide some recommendations and guidelines, together with ABT which is the company involved with the logistics plan of the project, to OBS Delft which will be used for the procurement phase of the project. This research involves both theoretical and practical parts. A “toolbox” of logistic strategies through literature review and interviews will be created and then the possibility of using some of them for the development of a logistics plan for the case of the Delft City Hall will be investigated. I believe that a discussion with you will provide me with valuable knowledge in order to better understand what kind of problems occur in this kind of projects and the way logistics can influence them.

1. ***What is your previous experience with construction logistics?***
2. ***How positive or negative is your opinion about the applicability of logistics in construction?***
3. ***What would be the main opportunities for improvement in this field?***

Construction Logistics

The main tool of my research is Construction Logistics. From my interpretation of the literature regarding this topic I found out that the concept can be defined in many different ways. For the purpose of my research I define it as "a multidisciplinary process applied to a given construction to ensure the supply, storage, processing and availability of material resources on the construction site, to dimension the production teams and to manage the physical flows of production", divided into supply logistics and site logistics. The processes involved are: material supply, storage, processing and handling, manpower supply, schedule control, site infrastructure and equipment location and site physical flow management.

4. ***Based on your experience, do you agree with this definition of construction logistics and the processes identified?***
5. ***If not what are your suggestions? What other kind of processes are identified?***
6. ***What can you tell me about the problems related with construction logistics?***
7. ***What would be the benefits from improved construction logistics?***
8. ***What are the consequences of poor construction logistics?***

Project efficiency

As I mentioned before, my goal is to see how logistics can enhance the project efficiency. Of course, it is hard to disagree that for example reduction in transport movements, less money tied up in stock, less waste, and the more efficient use of skilled craftsmen, will reduce the costs of projects, reduce construction time, improve quality, reduce risks to health and safety of those who operate on them, and generally improve the image of the industry. The challenge is to produce the information that convinces all parts of the industry that things need to be done differently in order to improve logistics.

9. ***Based on your experience, what are the most important determinants of construction project efficiency?***
10. ***In what degree is project efficiency influenced by negative external effects in the local environment, like death or serious injuries, distortion of the life of local citizens, noise, waste, environmental pollution, etc.***
11. ***At what extent can construction logistics influence the project efficiency?***

Negative external effects

While reviewing the literature, I found a classification of the construction related external effects under four categories: traffic, economic activities, pollution and ecological/social/health related impacts.

12. ***Do you agree with this classification? If not, what other external effects related with the construction can you identify?***
13. ***How can these negative effects be minimized?***

Interrelation/Interactions of project efficiency and negative external effects

Someone can say that these negative external effects can be minimized but with a big increase in the project cost and with possible delays of the construction process.

14. ***What would be potential complications towards the minimization of these negative external effects?***
15. ***At what extent can construction logistics minimize these negative effects, while at the same time enhancing project efficiency?***

Building Logistics

As I mentioned before, I try to gather potential logistic techniques that can be used in the case I study about the new Delft City Hall. So far, from the literature and from examining some companies that are involved in this field I came up with the following strategies:

- **Just-In-Time**
- **Logistic Centers (Construction Consolidation Centers)**
- **On-site Logistic Specialists**
- **Pre-Fabrication and Off-Site Manufacturing**
- **Delivery Management Systems (collaborative planning tools) and ICT Support (e.g. RFID)**
- **Early constructor involvement**
- **Traffic Management**
- **Materials Handling**

16. ***What is your opinion about these strategies? Is this how building logistics really work?***
17. ***What is the practice? What is the current state of art? What do you believe?***
18. ***How are logistics affected by the different phases of the project (beginning – prefabricated large elements, high volume, not frequent deliveries, finishing - smaller parts, installations, frequent deliveries)?***
19. ***In your opinion, which construction elements can cause the biggest problems regarding logistics?***
20. ***Can you tell me how does building (materials) volume relates with the logistics?***
21. ***Do you have any experience with innovative ways of transferring materials?***

Conclusion

At this point, I would like to recap this interview and summarize your argumentation.

22. ***Listening to this summary, would you like to add or reconsider an argument?***
23. ***Finally, do you have anything else to add that I can use for the completion of my research in the right direction?***

Interview results

Bart Luiten – Manager Building Innovation at TNO, Head of department at TNO Bouw en Ondergrond

Introduction

Bart Luiten is an employee of TNO for the last 8 years. Before that he worked for a construction company, HBG which is now taken over by BAM. While he was working for HBG he was involved in a project called "Half Time Bouw" in cooperation with TNO which was aimed to half the construction time for mass housing (one family house attached to another, etc.).

Construction Logistics

Mr. Luiten opinion about construction logistics is ambiguous which gives a first signal about one of the problems of construction logistics that it is difficult to define. He mentions that some people believe that logistics is everything in construction while some others totally disagree with that. The most important phase for construction logistics is the first phase where you have a lot of prefabricated elements and you need just in time deliveries.

Project Efficiency and Negative External Effects

Mr. Luiten view is that the most important step in order to increase project efficiency is to tender on time and to give incentives for reducing time. Their experience with the "Half Time Bouw" was that when you reduce the project time, you improve quality, reduce cost and decrease the disturbance for the local environment. He also mentions that you should give the space to the contractor to come up with innovative ideas about reducing time and handling the problems related with the negative external effects.

Building Logistics

Mr. Luiten worked on the "Half Time Bouw" project for 4 years and it involved all kind of measures like Supply Chain Management and team's organization, relationships between the companies involved, the workforce and teams who had all the disciplines required to deliver the project. Logistics, ICT, project management and prefabrication were some of the tools used in order to assess how they could reduce the construction time. They managed to reduce the construction time from 175 days to 50 with normal working conditions although the total cost did not decrease.

According to Mr. Luiten's belief, logistics were extremely important to increase the efficiency of the project as they had to make sure that the processes would go very smoothly and with predefined pace. By this, they could follow the plan without any uncertainties. From a logistics point of view they used containerization for the small equipment and materials needed for a specific number of houses, and doing so they manage to decrease the distance needed to travel to get the equipment, there was no time lost in the availability of materials and tools, and there was no time lost on quality check as everything was checked beforehand.

What were very important on the realization of this project were the long term relationships of the contractor with his subcontractors, the mass customization with the use of prefabricated elements which was feasible for this kind of project and that the whole construction supply chain which was aligned towards the same direction. From a logistics side, they built a tent so that they could work without any problems regarding the weather conditions. Also a very important logistical aspect was the structural design which helped them speed up the process with the use of prefabrication and special concrete and formwork which allowed them to finish two floors per day. Concluding about the "Half Time Bouw" project, Mr. Luiten stated that what they realize at the end was that the clients did not ask for this kind of project due to the increased cost.

Conclusions

- The structural design influences a lot construction logistics and accordingly the efficiency of the project as the use of prefabricated elements in the first phase of the project is the most important and you need just in time deliveries
- The most important determinant of the project efficiency is the time. When you reduce time you improve quality, reduce total cost and decrease the disturbance for the local environment.
- Construction logistics is extremely important to increase the efficiency of a project by smoothing the processes involved and decreasing the uncertainties of the project
- Long term relationships of contractor and subcontractors, prefabrication and the alignment of the construction supply chain are important factors for improving construction logistics

Nienke Maas – Senior Advisor spatial development at TNO

Introduction

Nienke Maas is a civil engineer in origin and she used to work at the logistics department of TNO where she has been busy with city logistics. The project that she has been involved and is related with this research was her involvement in the risk management and logistics in the city in order to prevent from building hindrance. She was the project leader of the risk management project about helping municipalities to reduce risks involved with building logistics in the city.

Construction Logistics

Mrs. Maas belief is that the construction industry can influence logistics through the construction design which influences the traffic that arrives at the construction site, the size of the construction elements, day or night traffic and the layout of the construction site. On the other hand she mentions that the construction industry can be characterized as conservative and from this point of view they want to build in a traditional way and do not want to be involved in complicated processes. She illustrates her argument with an example of the project around Den Haag train station where there were a lot of suggestions about the traffic that would be involved in the project but at the end they couldn't or wouldn't apply them due to the fact, according to her opinion, that construction industry wants to do things in a way they can steer and can influence instead of being dependent to other people or organizations. The construction industry is an industry that is very good at solving problems. Give them a lot of problems and they will solve them. But they are not focused on preventing problems. That's thinking the other way around.

Mrs. Maas believes that there is room for improvement in the field of construction logistics when all the actors involved realize that this is not only a problem of construction industry but a problem of all the stakeholders involved in a project, when there will be a feeling that this is not individual but common problem.

Mrs. Maas partly agrees with the definition that was introduced to her regarding construction logistics but she mentioned that the influence the construction design has on logistics should be part of the definition as the things that you can do during the design process to prevent logistical problems are very important.

Project Efficiency

Mrs. Maas also presented another project of TNO which was about logistics of high-rise building project where they made a kind of checklist and special logistic attention points. The conclusion was that logistics can do two things; in order to build in a quicker way you have more special logistic attention points which need to be addressed and on the other hand when you have better logistics you can build in a shorter time, so it is influence in both directions. Also, it is very important to have more preparation time for the design as it will help to prevent the logistics problems.

Negative External Effects

Mrs. Maas agreed with the classification of the negative external effects, and she mentions that logistics is about logical thinking. This means that you have to think about all the different construction elements you can use, all the types of materials, all the transportation modalities, etc. The problem is that it is common that the contractors are used in working in a specific way and maybe a different way of transportation will have to make them change their perspective about how they work. For example, train transportation of materials can be used in Delft but you have to arrange a lot of things with Prorail and NS and maybe you need to build a separate train line. In general these recommendations have to be more practical and justifiable.

Mrs. Maas believes that when there is the perception that construction logistics problems regards all the involved actors of a project the local negative external effects will be reduced. Moreover, she mentions that during the hindrance free project they found out that improved construction logistics will create less hindrance to the city, which means less negative external effects.

Building Logistics

Mrs. Maas presented a kind of framework for the logistics organization. She mentioned that you have to think what you need, how much you need, when do you need it and how to handle it. It includes all the processes about the building construction, procurement, preparation of the work, design, programming of the materials, storage and transportation on site, which are all the parts where logistics influence the project. She also stresses the fact that risk analysis is very important for the construction logistics and she provided a report from TNO that includes a risk analysis on construction logistics for the construction of a parking in Delft.

Mrs. Maas agrees partly with the logistical strategies presented to her but she points out that early involvement of logistic thinking in the design is a very important strategy because a building is not designed on the best logistics, first the architects design something and then they start thinking about the logistics. When you take logistics into account, other designs will occur.

Finally, Mrs. Maas concludes that logistics in the construction industry is not so far that important as construction industry does not look at the business in a repetitive manner.

Conclusions

- Construction design influences construction logistics
- Local negative external effects can be reduced through construction logistics when there is a perception that this is a common problem and not an individual problem
- During the hindrance free project they found out that improved construction logistics will create less hindrance to the city, which means less negative external effects.
- Construction logistics influence project efficiency in two ways, in order to improve the efficiency there should be special attention to logistics and when there is already good logistics the efficiency is improved
- Enough preparation time for the design and risk analysis are very important for construction logistics
- Mrs. Maas agrees with the classification of the negative external effects and the logistical strategies presented, but she also adds the early involvement of logistic thinking in the design process
- Mrs. Maas provided a report with the title "Verkeer en bouwlogistiek Koepoortgarage: mogelijke ongewenste gebeurtenissen en beheersmaatregelen"

Bas van der Moolen – Consultant at TNO Mobility & Logistics

Introduction

Bas van Moolen works at the department of Logistics at TNO which until one year ago was general for several sectors, looking at the supply chains and how they could make them more efficient. The last year they got more and more questions about logistics in construction, so now he is focused in construction logistics which he considers a very premature field.

Construction Logistics

Mr. van Moolen begins with a statement that it is a fact that logistics in building in not really there, in comparison with the distribution or production. In construction they do not care much about logistics as the construction companies do not care about how the supplier arranges the logistics because everything is included in the price. According to his belief, the construction companies do not realize that they pay a lot for the logistics of their supplier. At the end everybody makes profit so nothing changes but nowadays the market situation is in a condition that the industry starts to think how to be more efficient and how to optimize their supply chains.

Moreover, Mr. van Moolen mentions that there are not many strategic relationships between construction companies and suppliers as the focus is on short term benefits based on the lower price which leaves no space for supply chain management. The construction projects are unique but there are processes that are the same in every building and the construction companies do not learn from the construction sites and projects, they start all over again. There is not much difference between the production of a car and the construction of a building.

Mr. van Moolen stresses that the main opportunity for improvement in construction logistics is to think outside the box, develop a smart way to distribute benefits and risks because you cannot measure the benefits because there are no reference projects, the projects are unique. He agrees with the given definition of construction logistics and points out that contractors look only at the site logistics. He also agrees that the building processes are different than the automotive sector for example due to the uncertain environmental conditions of a construction site in comparison with a factory but also because in the automotive industry the supply of goods is more constant, there are specific time slots, forecasts of demand and not so many negative external effects.

Project Efficiency

According to Mr. van Moolen, the logistic problems exist mostly at smaller projects where the construction manager is not that well educated and experienced. He states that logistics in construction is about how efficient you can construct without any failure costs. He also believes that the contractors should focus on the estimation of the benefits they will have from improved logistics and that there is need for research that will present the savings from improved logistics organization.

With respect to the consequences of poor construction logistics, Mr. van Moolen mentions the time delays and increased costs but he emphasizes on the failure costs –products that are disappearing, goods that are damaged, etc., failure costs are high in construction. With respect to the determinants of the project efficiency he refers to the number of failure points- the points that need to be reworked after the completion of the building because they are not according to the specifications- as one of the most important aspects. Logistics has a direct influence on this aspect because if the building processes were efficient the communication between the contractor and the suppliers should be efficient and there would be no failure points. With improved logistics the number of faults at the end is decreased. His definition about logistics is how people parties work together in order to realize a common goal and believes that logistical guidelines should be oriented towards this direction.

Negative External Effects

One of the possibilities for improvement in construction logistics are the innovative ways of transferring materials. Mr. van Moolen gives two examples of innovative and smart ways of materials handling. The first example is about the metro station in Amsterdam where they deliver all the parts of the tunnel by boat. By this they can always deliver Just in Time and there are no traffic jams in the surrounding area. The second example is a new truck of a manufacturer of prefabricated walls. In the old way the truck loaded with a concrete wall drove to the construction site and had to wait for the crane to pick it up and set it into the site which resulted delays due to the waiting time for the availability of the crane or increased cost due to the rent of more cranes. The new truck gives the driver the opportunity to offload the concrete parts himself and leave to bring the next element to the site. Another innovative solution is the use of a pontoon in the water which serves as a consolidation center, and depending on the progress of the construction you deliver small parts from the pontoon to the site. By doing so you combine different means of transportation, you become more flexible and independent and you reduce the negative external effects from the material transportation.

Building Logistics

Mr. van Moolen illustrates an example of a project he was involved with the construction of a large building in the center of Den Haag where logistics was a big problem because of the limited construction space. He describes that the utilization of trucks was too low and that there was one truck that was just in time loaded with only one pallet. He mentions that during the beginning of the construction truck loads are generally full, while at the end there are only small deliveries, while in the beginning of the construction there are few trucks fully loaded and at the end there are a lot of trucks with small deliveries and this is where the opportunities for consolidation of loads exist. There is not one solution for logistics in construction; logistics have to grow with the construction itself. Just in time deliveries of full truck loads are most important in the beginning while consolidation is more important at the end of the project. For the project in Den Haag they come up with a consolidation center nearby Den Haag, where full truckloads went straight in the construction site and less than truck loads went to the consolidation center to pick up some other loads and deliver later as a full truck load. The consolidation center should be part of the construction site itself and managed by a logistics specialist and with that a construction company can build more efficiently.

Mr. van Moolen agrees with the logistical strategies presented and he states that in real life it is a combination of this techniques, for example if you want to deliver Just in Time you will need some traffic management and if you use prefabrication some trucks may not have to go to a consolidation center but straight on the construction site. When the discussion comes to the construction elements that may cause the biggest logistical problems he mentions the main problems are caused by the construction materials that have the biggest volume like steel or concrete, but he also stresses the fact that from a logistic point of view there are many possibilities for improvement in handling the smaller materials.

Conclusions

- Building logistics are not really there, interest is growing nowadays because of the market condition
- There is not one solution for logistics in construction; logistics have to grow with the construction itself.
- Small project are facing more problems regarding construction logistics due to uneducated and less experienced personnel
- No learning process takes place in the construction companies
- Failure costs are high in construction and a consequence of poor construction logistics
- Logistics has a direct influence on project efficiency as with improved logistics the number of failure points of the project decrease
- Construction materials with large volume like steel and concrete causes the biggest logistical problems
- Negative external effects in the local environment can be reduced if you become more flexible and independent regarding the materials transportation

APPENDIX II – BILL OF MATERIALS

Station Hall

Sheet piles

***1e fase* - damwand AZ 26, lengte 15 m1**

5,03 m1 - damwand getrild

88,20 m1 - damwand gedrukt

***2e fase* - damwand AZ 26, lengte 15 m1**

1,44 m1 - damwand getrild

12,50 m1 - damwand gedrukt

Basement floor – Sand

82,50 m3 bodemafsluiter zand dik 200 mm

3,64 m3 bodemafsluiter zand dik 200 mm

Foundation beams concrete

(110 kg/m3) 77,10 m1 funderingsbalk 600x300(600) mm inrit

(110 kg/m3) 39,60 m1 funderingsbalk 600x600 mm

Foundation piles

7,00 st prefab betonplalen [] 400x400 mm

lengte 25,0 m1

22,60 st Fundex palen Ø 380/450

lengte 24,0 m1

Outer concrete basement walls

(130 kg/m3) 79,90 m2 Kelderwand dik 300mm

(130 kg/m3) 12,90 m2 Kelderwand dik 550mm

(120 kg/m3) 243,00 m2 Inritwanden dik 350mm

Inner concrete walls

(110 kg/m3) 19,60 m2 Kern-/stabiliteitswanden dik 250 mm

(110 kg/m3) 38,90 m2 Kern-/stabiliteitswanden dik 300 mm

(110 kg/m3) 13,50 m2 Kern-/stabiliteitswanden dik 400 mm

(110 kg/m3) 15,10 m2 Kern-/stabiliteitswanden dik 550 mm

Concrete basement floor

(130 kg/m3) 228,00 m2 keldervloervloer dik 300mm

Steel structure station hall

57.594,00 kg Staalconstructie stationshal

Steel trusses

1.018,16 ton Stalen spanten

Top layer floors

206,81 m2 vlinderen vloeren

1.437,73 m2 cementdekvloer 60mm

1.821,58 m2 belgisch hardsteen tegels, gezet

153,23 m2 belgisch hardsteen tegels, gezet ORCR

15,41 m2 vloertegels gezet 100x100 mm, kleur ntb

86,26 m2 schoonloopmat

52,97 m2 beton geolied

1.505,31 m2 , geen vloerafwerking/inrichting

201,58 m2 buitenruimte vloerafwerking, vlinderen

Office building

Sheet piles

1e fase - damwand AZ 26, lengte 15 m1

32,30 m1 - damwand getrild

88,20 m1 , - damwand gedrukt(voor rekening station)

2e fase - damwand AZ 26, lengte 15 m1

9,26 m1 - damwand getrild

80,00 m1 - damwand gedrukt

Support steel for sheet piles

1e fase - damwand AZ 26, lengte 15 m1

181,00 m1 gording HE300A

181,00 m1 gording HE500B

224,00 m1 stempels Ø 400x10 mm, hoh 6 m1

227,00 m1 stempels Ø 600x10 mm, hoh 6 m1

2e fase - damwand AZ 26, lengte 15 m1

25,30 m1 gording HE300A

25,30 m1 gording HE500B

197,00 m1 stempels Ø 600x10 mm, hoh 6 m1

426,00 m1 stempels Ø 900x10 mm, hoh 6 m1

Concrete foundation beams

(110 kg/m3) 205,00 m1 funderingsbalk 600x300(600) mm

(110 kg/m3) 94,50 m1 funderingsbalk 600x300(600) mm inrit

(110 kg/m3) 47,10 m1 funderingsbalk 600x600 mm

(110 kg/m3) 67,20 m1 funderingsbalk 800x600 mm

Concrete basement walls

(120 kg/m3) 52,80 m2 liftputvloer dik 300mm

(120 kg/m3) 41,10 m2 liftputwanden dik 300mm

(120 kg/m3) 5,50 m2 liftputwanden dik 350mm

(120 kg/m3) 5,50 m2 liftputwanden dik 550mm

Foundation piles

300,00 st prefab betonplalen [] 400x400 mm

lengte 24,0 m1

30,20 st Fundex palen Ø 380/450

lengte 24,0 m1

Concrete outer walls basement

(130 kg/m3) 617,00 m2 Kelderwand dik 300mm

(130 kg/m3) 18,50 m2 Kelderwand dik 550mm

(120 kg/m3) 287,00 m2 Inritwanden dik 350mm

6,40 m1 wanddilataties

Concrete inner walls (staircases, elevator shafts)

(110 kg/m3) 164,00 m2 Kern-/stabiliteitswanden dik 250 mm

(110 kg/m3) 1.520,00 m2 Kern-/stabiliteitswanden dik 300 mm

(110 kg/m3) 137,00 m2 Kern-/stabiliteitswanden dik 350 mm

(110 kg/m3) 28,60 m2 Kern-/stabiliteitswanden dik 400 mm

(110 kg/m3) 92,30 m2 Kern-/stabiliteitswanden dik 450 mm

(110 kg/m3) 15,10 m2 Kern-/stabiliteitswanden dik 550 mm

Basement floor

(130 kg/m3) 1.983,00 m2 keldervloervloer dik 300mm

Concrete ground floor above basement

(120 kg/m3) 1.633,00 m2 breedplaatvloer 280mm

(120 kg/m3) 253,00 m2 breedplaatvloer 350mm

Office floors, 1st and up

24.638,38 m2 kanaalplaatvloer d=260 mm

Aangepast 275,40 m2 kanaalplaatvloer d=260 mm, hellend

Roof composite concrete/steel

6.303,70 M2 + Staalplaatbetonvloer

Steel structure for station hall

977.914,00 kg Staalconstructie stadskantoor

Concrete column

(350 kg/m3) 24,00 st betonkolom 500x500x 2670mm

APPENDIX III - RISK ANALYSIS MATRIX

GENERAL		RISK			QUALITATIVE ASSESSMENT		CONTROL	
Nr.	**ARTICLE**	**CAUSE**	**EVENT**	**CONSEQUENCE**	**likelihood**	**impact**	**MANAGEMENT ACTION**	**ACTION HOLDER**
1	Technical / Design Phase	Misalignment with third party components (tunnel, station, storage, etc.)	Design unsuitable as a solution	Wrong estimates of forces and settlements, increased costs due to reworking	**Low**	**Medium**	Regular scheduled consultation from initial phase of the project	Architect / Designer
2	Technical / Design Phase	Misalignment with third party components (tunnel, station, storage, etc)	Inadequate technical specifications in tender documents	Failure costs by faulty connections, more work in the execution phase	**Low**	**Medium**	Appoint persons responsible for coordination, clear definition of boundaries of work responsibilities	Principal
3	Technical / Design Phase	Building construction on top of the tunnel	Unequal load on tunnel shell	Differential settlements, increased failure costs	**Low**	**High**	Agreement between the parties from an early stage, tuning of the expansion in tunnel construction	Principal
4	Technical / Design Phase	Building construction on top of the tunnel	Unequal load on tunnel shell	Crack formation, increased failure costs	**Low**	**High**	Building loads adapted to tunnel foundation and reinforcement	Architect / Designer
5	Technical / Design Phase	Deflection of steel trusses	Construction defect	Excessive deflections, Deflections of the main support construction make the finishing difficult	**Medium**	**Medium**	Precise calculations for deflections, particularly bearing trusses together, Designer adapts expected deflections to finishing	Designer
6	Technical / Execution Phase	Small and congested construction site and work field layout	Lack of access on site	Resources not available, supplies delay	**High**	**High**	Consultation and agreement with CCL for construction site and work field	Principal / Contractor
7	Technical / Execution Phase	Small and congested construction site and work field layout	Limited opportunities for crane placement	Machinery not in right place, delays on construction	**High**	**Medium**	Procurement based on final design so that a contractor can timely contribute implementation expertise	Principal / Contractor

GENERAL		RISK			QUALITATIVE ASSESSMENT		CONTROL	
Nr.	**ARTICLE**	**CAUSE**	**EVENT**	**CONSEQUENCE**	**likelihood**	**impact**	**MANAGEMENT ACTION**	**ACTION HOLDER**
8	Technical / Execution Phase	Difficulties in assembling large trusses due to site positioning	Falling objects near public area	Danger to passengers and train service	**Low**	**High**	Provide adequate safety measures for passengers and railway	Contractor
9	Technical / Execution Phase	Transportation of large construction elements	Prolonged closure of local road lanes	Extensive traffic jam, local residents complaints	**High**	**High**	Alternative modes of transportation, split the large elements in smaller pieces	Designer / Contractor
10	Technical / Execution Phase	Use of tower crane	Tunnel shell defection due to the load of tower crane	Extra construction work to support tower crane, increased cost	**Low**	**High**	Consideration of using alternative type of cranes for the building construction	Designer / Contractor
11	Technical / Execution Phase	Transportation of large construction elements	Traffic accident near construction area	Train, tram delays, danger for people safety	**Medium**	**High**	Transportation of the large elements during night, safety plan for transportation of materials	Contractor
12	Project Management	Uncertainty on the plan of the tunnel construction project	City Hall construction delay	Penalty clauses, delay on planning	**High**	**High**	Basement along with tunnel section entirely by CCL	Client / Principal
13	Project Management	Change of passengers route to reach the train platforms	Protests of current station shop owners	Loss of income for people working on the surrounding area	**High**	**Low**	Careful assessment of the alternative passenger routes so as not to skip the shops	Principal
14	Project Management	Different contractors working on the same area	Excessive equipment and material deliveries on construction area	Construction site congestion	**High**	**Medium**	Logistic plan for the execution of the project	Principal / Contractor
15	Social	Building construction on the area of the current bicycle parking	Inconsiderate bicycle parking on the area around the train station	Local citizens life disruption	**Medium**	**High**	Early consideration of the repositioning of the bicycle parking	Principal / Contractor
16	Social	Construction works while the train station is operational	Falling objects and materials, construction vehicles overturn	Death or injuries due to struck of materials or moving vehicles	**Medium**	**High**	Health and safety plan	Contractor

GENERAL		RISK			QUALITATIVE ASSESSMENT		CONTROL	
Nr.	**ARTICLE**	**CAUSE**	**EVENT**	**CONSEQUENCE**	**likelihood**	**impact**	**MANAGEMENT ACTION**	**ACTION HOLDER**
17	Financial	Delays on tunnel construction	Uncertainty on the planning of Delft City Hall	Expensive tender due to the uncertainty of the project	**High**	**Medium**	Make City Hall project as independent from the tunnel construction as possible	Designer / Principal
18	Financial	Adding load to the tunnel after the train started operating	Settlements on the tunnel shell	High maintenance cost for the tunnel	**Medium**	**Medium**	Add as much load as possible before the new railway operation	Designer / Principal
19	Health & Safety / Environment	Long term construction activity in a city center	Local traffic disruption	Local roads damage due to detours, increased traffic accidents rate	**Medium**	**High**	Traffic management, special attention to material delivery on site	Principal / Contractor
20	Health & Safety / Environment	Long term construction activity in a city center	Reduce accessibility to local business, landslide, traffic delays	Property damage, loss of income, productivity reduction	**Medium**	**Low**	Good communication with the local community, compensation wherever is needed	Principal
21	Health & Safety / Environment	Combination of underground tunnel and upper ground building, the constructive possibilities are limited by the foundation and the route of the tunnel, concurrent work between the two phases	Falling objects, traffic congestion	Disturbance of the local environment, damage to the public image of the actors involved in the project	**High**	**High**	Supply and delivery routes in consultation with road authorities to be determined, public and visitors in the construction site should be banned, escape routes	Contractor
22	Health & Safety / Environment	Construction of underground tunnel and basement	Disruption to surface and soil composition which may include the groundwater, cable/lines, old foundation, explosives	Toxic material diffusion, Electrocution, Explosion, danger for workers and public	**Low**	**Medium**	Check for soil contamination, mapping of cables and pipes, historical research for old foundations, explosives	Principal / Contractor
23	Health & Safety / Environment	Demolition, explosives, driving, vibration, construction equipment	Noise pollution	Public disturbance	**Medium**	**Medium**	Sound requirements based on the "Circulaire Bouwlawaai 1991"	Contractor

APPENDIX IV – PROJECT PLANNING

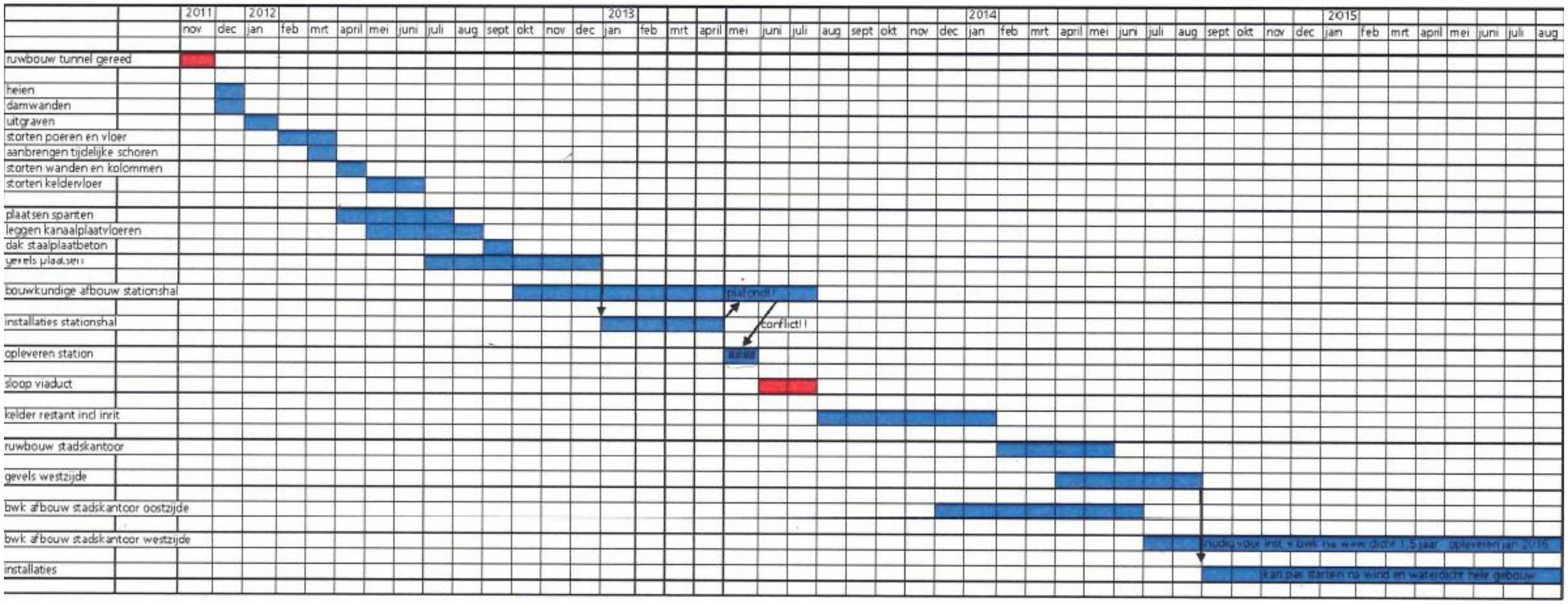

Figure 1: Old planning of the new Delft train station and City Hall

Figure 2: New planning of the new Delft train station and City Hall

APPENDIX V – STEEL TRUSSES DECOMPOSITION