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The potential role of urban waterways in sustainable urban freight transport

- A case study of mass transport from the construction of Västlänken.

Master of Science Thesis

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”When we delay the harvest, the fruit rots. When we delay resolving problems, they continue to grow.”

- Paulo Cohelo

Abstract

Urban freight transport (UFT) is becoming increasingly important; a well working transport system is a precondition for economic growth of cities and as more people and business move to urban areas the amount of goods transported to, from and within cities increases. However, it also results in emissions, congestion and safety issues. The city of Gothenburg is in need of an updated infrastructure to meet the increased transport need and as part of this update, the planning of a railway tunnel, Västlänken, under central Gothenburg is taking place. The construction work is planned to start in 2018 and is estimated to run for ten years. The new railway system will include three new stations under the city centre and simplify commuting to and from the city. One of the main issues during the construction time is the removal of a large amount of mass from the sites and thus increased levels of UFT within the already constrained infrastructure.

This thesis was initiated to find transport solutions for this mass and started as a part of the sustainable UFT project Sendsmart that aims for finding both technical and soft solutions for sustainable UFT. When looking at possible transport solutions for the mass, the waterways in Gothenburg are of particular interest, as they are not fully utilized and would decrease the congestion on the roads. This leads to the purpose of this thesis that was *to evaluate the feasibility and sustainability of using urban waterways for mass transport in urban areas during the construction of Västlänken in Gothenburg*. In order to fulfil the purpose, two research questions were assessed. First, it was examined if the usage of urban waterways is feasible when transporting mass during the construction of Västlänken. Second, it was examined if the usage of urban waterways is a sustainable alternative to road transport.

The feasibility study was conducted through theoretical studies, benchmark of six similar cases to the one in Gothenburg and studies of the context specific conditions in Gothenburg. In addition, three barge suppliers, two construction machine manufacturers and one construction truck manufacturer were interviewed to gain a technical understanding and knowledge of the available vehicles and vessels on the Swedish market. It was concluded that both barge and truck are feasible modes of transport in this context. Both modes of transport however need different transhipment methods, and the belt conveyor investigated for the vessel alternative showed not to be suitable for clay or for shafts located close to streets and instead a truck is recommended for these transhipments.

The sustainability study was divided into an environmental study, a cost study and a social impact study. In the environmental and cost study, it was concluded that a larger carrier results in less environmental impact and costs for both trucks and vessels. The largest vessel investigated was however outstanding and would also be better from a congestion point of view. From a social perspective, vessel also showed to be the best solution, as it is safe and results in less noise and visual intrusion impact on the city. This is also in accordance with the stakeholder analysis performed.

In conclusion, the large vessel investigated outclasses all other transport solutions both regarding feasibility and sustainability. When taking on a system view perspective, it is shown that two large vessels with mixed types of mass is the most efficient combination for the total flow of mass from the three shafts investigated. The infrastructure of Gothenburg allows for efficient barge transport flows and the short distances gained when using the seaways result in sustainable transport solutions. A well working transport system is a precondition for economic growth of cities and the urbanisation of Gothenburg requires mitigation actions in order to handle congestion. Barge transport is an efficient way of making the transport system in Gothenburg more sustainable and would also facilitate the need of more frequent and efficient deliveries in the city centre.

Keywords: urban waterways, urban freight transport, sustainable transport, barge.

Preface

Due to our great passion for sustainability issues and interest in transport solutions we really felt fortunate when we this spring came in contact with Sendsmart - a project with the aim to create sustainable freight transport solutions for urban environments. At the same time the discussion about the planned train tunnel Västlänken really took off in the local media in Gothenburg. The combination of those two factors served as the starting point of this thesis and strengthened our commitment to contribute to this area of research.

The thesis work has been very interesting and educative, and we will take these valuable experiences with us into our upcoming working life. We would like to thank all project members in Sendsmart. Without this multidisciplinary platform, the aim of this report would not have been possible to achieve. Especially, we would like to thank Trafikverket and Göteborgs Stad for your openness, support, and enthusiasm during the whole project. We hope that the findings of our project will be a valuable input for you in your future planning of Västlänken. We are also grateful for all the interesting discussions with specialists and scientists during the project, who have contributed to an increased knowledge within the various areas of research that we had to dig into. We would also like to thank the interviewed operators and manufacturers for interesting site visits - we greatly appreciate your hospitality.

We also want to express our gratitude to our supervisors: Björn Södahl – thank you for your valuable feedback throughout this project and for contributing with knowledge in the marine area. Maria Lindholm - our examiner, project leader for Sendsmart, and the initiator of this project, thank you for your support, enthusiasm, and for helping us stay on course through the entire process.

Finally, we hope that the findings of our project will be further developed within Sendsmart and pave the way for future sustainable transport solutions.

Vanja Carlén, Andreas Josefsson and Lina Olsson

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TERMINOLOGY

In this section, the terminology used throughout the report is explained. First, the organisations referred to are specified. Second, technical vocabulary used is explained and finally abbreviations used in calculations and charts is stated.

RELEVANT ORGANISATIONS

Fastighetskontoret	Local Property Management Department in Gothenburg. Fastighetskontoret is together with Trafikverket the ones responsible for finding a suitable destination for the excavated mass and thus have the power to determine what mode of transport that possibly can be used in the project.
Göteborgs Stad	The City of Gothenburg, which through its various municipal departments is one of the main members govern the project.
IMO	International Maritime Organization
IVL	Swedish Environmental Research Institute
Miljöförvaltningen	Local Environmental Management Department in Gothenburg
SCB	Statistics of Sweden
Sjöfartsverket	Swedish Maritime Administration
Stadsbyggnadskontoret	Local Urban Planning Department in Gothenburg. Stadsbyggnadskontoret, who is one of Göteborgs Stad's representatives in the project, is responsible for the overall cityscape and the long term planning of the city and raise the importance to think about the visual aspects when designing the transport system.
Trafikkontoret	Local Traffic and Public Transport Department in Gothenburg. The responsibility to plan for well a functioning traffic situation including the mass transport is carried by Trafikverket together with Trafikkontoret.
Trafikverket	Swedish Transport Administration, the other main governing organisation for the project of Västlänken. Trafikverket decides on how the transport should be executed in the tender and where the mass should be transported.
Transportstyrelsen	Swedish Transport Agency

TECHNICAL VOCABULARY

Cargo hold	A ship's hold is a space for carrying cargo.
Cut-and-cover technique	The cut-and-cover technique means that mass is excavated to form a deep trench, which is supported by sheet piling, furthermore trusses and beams are placed across the trench to fix the sheet piling. The concrete tunnel is then constructed and finally backfill is placed on top of the tunnel roof creating the new surface.
Draft	The depth of a vessel's keel below the surface.
Drill and blast method	A number of holes are drilled into the rock, which are then filled with explosives, which causes the rock to collapse.
Dredging	An excavation activity or operation usually carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location.
Fairway dues	A fee for navigating on a fairway.
Gault	The most common type of clay in the Gothenburg area.
Granite	The most common type of rock in the Gothenburg area.
Hull	The watertight body of a ship or boat.
Landfill	A site for the disposal of waste materials by burial and is the oldest form of waste treatment.
Natura 2000	Areas included in the EU network of valuable nature.
Shaft	Describes the building of vertical openings such as raises and shafts. Shafts are vertical openings used for supplying equipment, personnel and support systems to the horizontal tunnel where the pipeline is installed.
Turnkey contractors	Where the contractor is responsible for the technical planning, subcontractors and finalization of the project.
Urban waterways	Inland waterways in an urban environment.
Quayage	Fee for docking at a quay.

ABBREVIATIONS

Belt	Used in charts, abbreviation for belt conveyor
CH_4	Methane
CO_2	Carbon dioxide
HC	Hydrocarbons
ISPS	International ship and port facility security
MKB	A description of the consequences for the environment
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxide
OP	Abbreviation for operator.
PM	Particulate matters
SO_x	Sulphur oxide
T1	Used in charts, abbreviation for Truck 1
T2	Used in charts, abbreviation for Truck 2
Tkm	Tonne-kilometre is a unit of freight transportation quantity
UFT	Urban Freight Transport
WL	Used in charts, abbreviation for wheel loader

1 Introduction

This chapter provides a background to urban logistics, and identifies the purpose of this thesis. The research questions and the scope and delimitations of the thesis follow. In the end of the chapter, the outline of the thesis is presented.

1.1 Movement of goods - a prerequisite in cities

Urban freight transport (UFT) is becoming increasingly important; a well working transport system is a precondition for economic growth of cities and as more people and business move to urban areas the amount of goods transported to, from and within cities increases. Without UFT, people would not get their medicine, commodities and postal service, businesses would stop their production, waste would overload cities and construction sites would have to shut down. The movement of goods is a prerequisite for a city to work. The situation of today's increased amount of urban transport is however unsustainable (Lindholm, 2012a) and freight planning of cities is lagging behind (Dablanc, 2007).

The amount of urban transport increases as more businesses and residents are moving to cities (MDS Transmodal Limited, 2012). At the same time there is a need of more frequent deliveries, as lead-times are becoming shorter, product life cycles shrink and storage areas in urban areas are getting more expensive. In order to meet these new conditions, the transport mobility is fundamental to sustain our existing lifestyle (Anderson et al., 2005; Plowden and Buchan, 1995) and a prerequisite to meet this demand is to develop an efficient and sustainable transport system (Dablanc, 2007).

1.1.1 Unsustainable European Cities

The congestion of European cities results in longer and more unpredictable travelling times, and even though freight transport only represent 8-12% of the total traffic flow in cities, the loading and unloading often results in reduced road capacity. Despite the small share of the total traffic flow, the share of emissions from freight transport is usually 20-30%. This is mainly due to frequent stops, the use of diesel motors and old vehicle fleets. Another problem is the level of safety in the cities, as the rising number of serious accidents involving freight vehicles is increasing. (MDS Transmodal Limited, 2012)

The focus within the area of logistics has historically been to minimize the costs and to maximize the outcome and efficiency (McKinnon et al., 2010). However, the negative impact of logistics such as emissions, noise, congestion and accidents is nowadays a well-known fact. The European Commission (2011) has set a goal that by 2030, UFT should not result in any CO_2 emissions and in order to succeed with this goal and move towards sustainable urban freight - change is necessary.

1.1.2 Definition of Urban Freight Transport

UFT is not a unison term, and different definitions are to be found within academia. Dablanc (2007) provides a definition that has become widely used. This is the definition used in this thesis:

'Urban freight transport is the transport of goods carried out by or for professionals in an urban environment'

The definition is general and gives no specific directions on what transport that are included. The European Commission is using a similar definition in their paper on UFT (MDS Transmodal Limited, 2012):

'The movement of freight vehicles whose primary purpose is to carry goods into, out of and within urban areas'

This definition adds the aspect of transport in and out of urban areas. However, it is not clear what type of freight vehicles that are included in the definition. For the purpose of this thesis, it is important that transport on inland waterways in urban areas is included in the definition as well as the transport of construction material and waste. Thus, in this thesis the definition by Dablanc (2007) is used, and is interpreted in a way that includes transport on inland waterways and transport of construction material and waste.

1.1.3 Urban waterways is nothing new

The unsustainable situation of urban transport requires new efficient and sustainable ways of organizing transport systems in cities and this is when inland waterways are taking on an important role (Bacab, 2012). Traditionally, most transport have been performed by truck, however inland waterways are underutilized and allow for an energy efficient and reliable way of transporting goods if used efficiently (Lowe, 2005; Konings, 2009). In the White Paper of 2011 the European Commission states that there is a need of shifting the balance between different modes and that the integration of inland waterways into the transport system should be stimulated (European Commission, 2011).

Using inland waterways is nothing new as such and has had an important role in the history of urban transport. Inland waterways is the oldest way of transporting goods, but was taken over by railway traffic as the industrial revolution developed (Platz, 2009). However, many inland waterways are still being used, and the old infrastructure of cities offer a potential use of the under utilized inland waterways. Today, the situation of congested cities makes local policy makers look for alternatives to road transport. The use of inland waterways still only represents 5% of freight transport in the EU (Vierth et al., 2012), but taking the growing amount of freight transport and the larger consciousness of sustainability from local authorities into account, inland waterways has great potential (Konings, 2009). The environmental benefits of inland waterways are strong and when including external costs of accidents, congestion, noise, emissions and other environmental impact, inland waterways result in seven times lower external costs than that of road transport (Lowe, 2005).

1.1.4 Västlänken modernizes the infrastructure of Gothenburg

The city of Gothenburg is undergoing steady growth, with a yearly increase in population of 1.3% (SCB, 2013). In order to cope with the increased urban transport demand, the city is in need of an updated infrastructure. Today, the region of Västra Götaland accounts for more than a quarter of Sweden's export and Gothenburg railway station serves as the hub for the railway system in the west of Sweden (Trafikverket, 2013a). The railway system is using its maximum capacity and in order to meet the current transport need, the infrastructure has to be updated. As part of this update, the planning of a railway tunnel, *Västlänken*, under central Gothenburg is taking place. The construction work is planned to start in 2018 and is estimated to run for ten years. The new railway system will include three new stations under the city centre and simplify commuting to and from the city. This will in turn reduce the number of cars driving on the roads and also lead to an increased capacity of the railway system as a whole. However, during the construction time, residents, businesses, public transport services and road traffic will be affected. One of the main issues during the construction time is the removal of mass from the sites and thus increased levels of UFT. The city is already having problems with its congestion and an efficient and sustainable transport solution for transporting the excavated mass is needed in order to handle the increased levels of freight transport.

1.2 Purpose

This thesis was initiated as a part of the sustainable UFT project Sendsmart that aims for finding both technical and soft solutions for sustainable UFT. The project focuses on cooperation between different stakeholders and has participants from industry, academia and public authorities. One important part of the project is to develop solutions for the transport in connection with the construction of Västlänken in Gothenburg. When looking at possible solutions for mass transport from the construction work, the waterways in Gothenburg are of particular interest, as they are not fully utilized and would decrease the congestion on the roads. This leads to the purpose of this thesis:

The purpose of this thesis is to evaluate the feasibility and sustainability of using urban waterways for mass transport in urban areas during the construction of Västlänken in Gothenburg.

The use of urban waterways when transporting mass from the construction of Västlänken is not isolated from the urban traffic in Gothenburg at large, why the conclusions made regarding the feasibility and sustainability of using urban waterways will also be applicable on other transport solutions in the city area.

1.3 Problem Definition and Research Questions

The preceding background shows that along with urbanisation, it becomes more and more crucial with efficient urban transport. Urban areas require large quantities of goods and freight transport has in recent years gained a more important role in urban planning in larger cities in Europe (Lindholm, 2012b). Urban transport is a complex matter as it is a driver of the economic growth in urban areas, while also contributing to social and environmental issues

(Lindholm, 2012a). Dablanc (2007) presents three different characteristics of UFT in large European cities that further contributes to the complexity of UFT. First, goods movements are largely indifferent to the internal structure of cities. Second, urban policies targeted on freight mobility appear to be inefficient. Third, the provision of appropriate urban logistic services is slow in emerging despite growing needs. This is why it is crucial to understand the characteristics of Gothenburg, the policies that affects transport solutions in the city and to find ways of transporting goods in a proactive, efficient and sustainable way.

The focus of this thesis is the feasibility and sustainability of utilizing urban waterways for the excavated mass resulting from the construction of Västlänken. There is a need of finding new intermodal solutions in order to be more efficient and sustainable (European Commission, 2011) and the usage of inland waterways has a large potential (Bacab, 2012). The large amount of mass that will result from the construction work will put a demand on an efficient transport system that can remove and dispose the mass without leading to congested streets in the city centre and increased levels of noise and emissions. By utilizing the waterways for transporting construction waste, the increased levels of freight transport during the project could potentially be minimized. The waterways such as canals and rivers available in Gothenburg provide the right conditions, however a similar transportation solution has not been used in the city of Gothenburg in modern time and hence the research questions focus on the feasibility and sustainability of using urban waterways in this context.

1.3.1 Research Question 1 - Is the usage of urban waterways feasible when transporting mass during the construction of Västlänken?

The first research question approaches the context in which the transport takes place and regards the conceivability of using urban waterways. It is important to understand if the transport solutions investigated are feasible for the excavated mass, if its suits the quality and quantity of the mass and if the geographical location of the shafts and the destination of the transport allows for urban waterways to be used. According to Konings (2009) and Platz (2009) barges and waterway transportation in general have a strong position in the transportation of bulk products and has a leading position in the transport of ores, coal, sand, gravel and chemical products. This makes it interesting to investigate whether barge is a feasible alternative for the excavated mass in the case of Gothenburg.

1.3.2 Research Question 2 – Is the usage of urban waterways a sustainable alternative to road transport?

The second research question focuses on sustainability, and aims to investigate whether inland waterways is a sustainable way of transporting mass than road transport. The problems caused by UFT can be seen from economic, social and environmental perspectives, as urban freight results in congestions, emissions, noise and accidents (Andersson, 2013; Konings, 2009). European Union aims to achieve a sustainable transport system; both on regional and national level (European Commission, 2011) and in the White Paper of 2011 a general objective to highlight the impact of transport on economic growth, social welfare and environmental protection was initiated. The use of inland waterways for freight is generally said to be reliable and congestion-free and provides a high level of safety (Lowe, 2005; Konings, 2009). When considering barge from a sustainability perspective, it is claimed to be cost-efficient to operate, environmentally friendly and socially acceptable (Lowe, 2005).

Inland waterways have not been used in a similar context in the modern time of Gothenburg, thus the sustainability aspect of the case study and a comparison with conventional transport solutions is needed.

1.4 Scope and delimitations

In order to create validity in the chosen scope, it is important to be aware of that UFT has many definitions and interpretations, when using statistics from other cities and cases. As mentioned earlier, the general definition of UFT by Dablanc (2008) is used in this thesis, and is interpreted in a way that includes transport on inland waterways and transport of construction material and waste. As this differs from the definition of city logistics and UFT that is normally used, this is something that might affect the result of the literature study. Also, within the scope of this thesis, the case study is performed in the urban area of Gothenburg and the system studied is the urban freight context during the construction work of Västlänken. As the construction of Västlänken is still in its planning phase, it is important to note that figures and data from the case study is based on available material, which might differ from the actual construction. The transferability of the results is discussed in the end of the thesis.

Due to the long construction time, the context of Västlänken is complex. The conditions will most likely be changing during the ten years that the project is constructed. Other on-going projects in the area and local city plans have been studied in order to foresee what might affect the choice of mode for mass transport. However, as the construction of Västlänken is only in its planning phase, and a construction site is a dynamic environment, assumptions are sometimes needed, and the scope is thus limited to the information available when the thesis is written.

The geographical limitations are the three shafts that will be constructed in Rosenlundsgatan, Rosenlundsplatsen and Stora Badhusgatan in the centre of Gothenburg and the transport of excavated mass to two potential destinations in Frihamnen and the Port of Gothenburg. The shafts will be constructed at the chosen areas, however the destinations are only assumptions as this is not decided when this thesis is written. Frihamnen will need mass to fill out the harbour space and plans for this is available to the public. Port of Gothenburg is nothing that is decided and is an assumption made by the authors in order to understand how a longer distance affects the transport choice. At the three shafts chosen, the geographical limitation is set to the entrance of the work tunnels, due to that this thesis is written from an urban freight perspective and it is hence the transport that is taking place in the urban area that will be investigated and not the transport taking place within the work tunnel or shaft. Finally, the end of the geographical limitation is set at the end of the transport chain when the vessel or vehicle has been un-loaded.

In the analysis, the feasibility and sustainability of the transport choice is investigated. The feasibility study mainly regards available technology and has been conducted in cooperation with leading firms and operators in the separate areas of construction machines and vessels. This however only gives an as-is feasibility of the transport modes, why future possibilities is discussed in the end of the thesis. The sustainability analysis consists of an environmental analysis, a social impact analysis including a stakeholder analysis and finally a cost analysis. The environmental analysis compares the external costs of emissions and congestion and the social impact analysis consists of a qualitative analysis of safety, noise, and visual intrusion. The scope of the analysis is including emissions from the transportation activities within the geographical limitations. The data is collected from transport operators, vehicle manufacturers, IVL, Cooper and Gustavsson (2004), IMPACT (2007), and Trafikverket (2012b). The calculation of fuel consumption is limited to average values and hence fluctuations in fuel consumption due to different road conditions, hills etcetera are outside the scope of this thesis. For the environmental impact a quantitative analysis is made whereas the social impact is limited to a quantitative analysis. The stakeholder analysis is based on the stakeholder definition by the European Commission (MDS Transmodal Limited, 2012) and focuses the five most crucial stakeholders; the shippers, the receivers, the transport operators, the residents and the administrators/authorities. As the project is in its planning phase, it is not decided who the contractors (shippers), the receivers and transport operators are. Potential stakeholders interviews have thus been conducted. The cost analysis is based on cost data collected from the transport operators, manufacturers, labour unions, SCB, and trade organisations. The cost analysis is furthermore based on a rather simple calculation model that does not include for example inflation and assumed a solid interest rate. The cost analysis will not consider pricing and is only used to get a general cost picture and is directional.

The aim of this thesis is to come up with a possible transportation solution and to give recommendations and suggestions on what mode of transport that is most feasible and sustainable to use for the excavated mass from Västlänken. Hence, the thesis is delimited from giving instructions of implementation of the transport.

1.5 Outline of the thesis

The outline of this thesis is based on a theoretical framework followed by six examples from other European and Swedish construction works similar to the one investigated in Gothenburg. A technical framework and a case study of chosen construction sites in the construction of Västlänken are then presented. Different transport solutions for the excavated mass from the construction sites are presented and analysed from both a feasibility perspective and a sustainability perspective. After this analysis, a discussion of the results and changing conditions is presented, followed by the final conclusion of the thesis. The thesis is structured accordingly:

Chapter 1 presents the introduction to the thesis, starting with a background to UFT and presents the purpose and the research questions of the thesis.

Chapter 2 constitutes the theoretical framework, including a general description of transportation and sustainability of transport, followed by a more thorough presentation of UFT and the role of inland waterways in both Europe and Sweden.

Chapter 3 describes the methodological approach of the thesis, followed by the research process of the project. The chapter also discusses the research quality, validity and transferability.

Chapter 4 presents six examples from other European and Swedish cities from which conclusions and benchmarking can be made. The cases do all have similarities with the case investigated in Gothenburg.

Chapter 5 covers the empirical study and presents the case study of Gothenburg. The chapter gives a basic understanding for the project of Västlänken and provides the reader with an understanding of the technical aspects of the excavated mass and shafts investigated. It also describes how the transport decision is made, what stakeholders that are affected by it and what laws and regulations that needs to be taken into account when making the transport decision.

Chapter 6 presents a technical framework, where the different vehicles, construction machines and vessels investigated are presented. Further on, the distances from the shafts to the landfill locations are presented

Chapter 7 covers the results and both the results from the feasibility study and the sustainability study is presented. It is first concluded what transport chains that are feasible in the context of this thesis and second the fuel consumption, environmental impact, economical impact, and social impact of the transport chains is presented in the chapter.

Chapter 8 covers the analysis, and the results of this thesis is further analysed. A general analysis of the results is presented, as well as a system analysis in order to gain broader understanding and put the results into a larger context. The chapter also presents a risk analysis and a final recommendation of transport chain. Finally, the chapter also covers the authors' reflections, areas of future research and contributions made by the thesis.

Chapter 9 provides answers to the research questions and presents the major conclusions made in this thesis.

2 Theoretical Framework

This chapter explains the complex system of UFT and further provides the basis for a feasibility and sustainability analysis of introducing urban waterways in a transport chain. The section starts with a broad definition of freight transport and narrows down to freight transport in the urban environment. A background to sustainability in an urban freight context is presented and the use of inland waterways is described in more detail. Finally, in order to perform an analysis of a complex freight transport system, a stakeholder and a risk perspective on transport is also provided.

2.1 Freight Transport

Freight transport is a fundamental component of the economy and in order to understand its complexity, the basic elements that the freight transport system is built upon needs to be identified. Wandel et al. (1992) presents a model of how different components in the transport system are related, see Figure 1. The transport system can be structurally divided into three layers: a material flow, a transport network, and an infrastructure system. *The material flow* is created through the demand for moving material and goods between different nodes. *The transport network* consists of all the available vehicle and vessel movements that perform the transportation of goods and products (Lumsden, 2012). Finally, *the infrastructure* is a prerequisite for the transport network's existence and consists of all the facilities and equipment included in road networks, rail systems, sea passages, and harbours (Wandel et al., 1992).

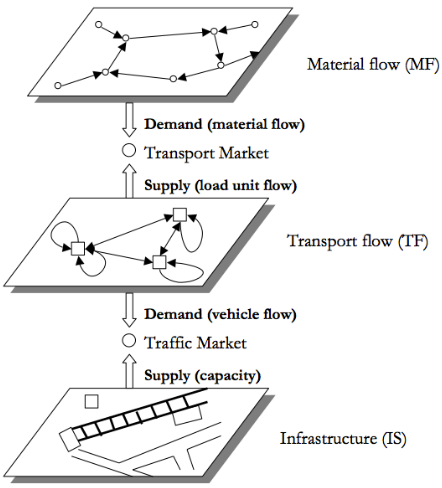

Figure 1. The three layers of freight transport and their interrelated markets (Lumsden, 2012).

In addition to the three layers of freight transport, it is fundamental to identify their interrelations (Lindholm, 2012a). Lumsden (2012) identifies a transport market and a traffic market, created from the interrelation between the layers. *The transport market* is generated from the relationship between the need to move goods and available vehicle and vessel movements (Wandel et al., 1992). The effectiveness and efficiency of this market can be measured as load factor, unsatisfied demand, and service quality. *The traffic market* is generated from the need to move vehicles and vessels within the boundaries of the existing infrastructure.

A well-functioning freight transport system is vital for a sustainable economy, since it enables economic growth and creates employment (European Commission, 2011). The amount of freight transport is closely related to the growth of GDP, and between year 2000 and 2010 the index for inland freight transport increased by 13% in the EU-27 countries, while for Sweden the increase was slightly lower, at approximately 7% (Eurostat, 2012a), which correlated with the GDP growth for the same time period (Eurostat, 2012b; McKinsey, 2012).

The GDP correlates with the amount of goods transported, however the mode of transport also plays a major role when it comes to infrastructure capacity and the environmental impact of transport (Lumsden, 2012). Looking at the distribution between different modes for land based freight transport in Sweden, road represents approximately 65%, while rail stands for the remaining 35% (Vierth et al., 2012). In EU-27, road transport has an even larger share of 73%. In the White Paper on Transport the European Commission states that GHGs from the transport sector need to be reduced by 60% to year 2050 (European Commission, 2011). In order to achieve this goal the European Commission identify a need of shifting the balance between different modes, and further on that the integration of inland waterways into the transport system should be stimulated.

2.2 Urban freight transport

UFT is fundamental to sustain our existing lifestyle, and plays an important role for the economic growth and vitality of cities (Anderson et al., 2005; Lindholm, 2012a). However, UFT also results in congested and polluted cities. This is why freight transport needs to be incorporated in urban transport planning (Ogden, 1978), and UFT has gained even more attention, as the level of urbanization increases and as existing freight policies are not measuring up to the changes of today's production, distribution and consumption sectors (Dablanc, 2007).

The UFT also serves industrial and trading activities, contributes to the competitiveness of the industry in the region, affects the logistic costs of commodities, and has a direct effect on the environment (Anderson et al., 2005). Browne et al. (2011) show that the level of interest and the resources devoted to urban freight increases every year and there are many tests and established projects to draw on; both on local, regional, national and sometimes even international level. Nevertheless, space dedicated to logistic activities is disappearing from cities and the development of cities is not in pace with the transport demand of its residents and businesses (Dablanc, 2007).

At the same time as road traffic damage the environment of cities, the amount of freight transport increases. More people and businesses move to cities and the demand on urban transport is growing (Anderson et al., 2005). Today, almost three quarters of the European population live in cities and the urbanization rate of 0.6% shows a steady increase. In coastal areas, like Gothenburg, the rate is even higher (EEA, 2013). At the same time, more goods are transported to and from the city, the passenger traffic of commuting residents increases, the amount of waste transport increases, construction sites need to transport material, shops in the city centre need frequent deliveries as their storage areas are so expensive and residents in cities require home deliveries (Andersson, 2013). The more people that move into urban areas, the larger amount of freight transport are needed, and the higher the level of traffic congestion, noise, emissions, and accidents becomes (Taniguchi and Thompson, 2003). The problem of

UFT of today need action, and investigating alternative modes of transport is one way to decrease the congestion and sustainable impact on cities.

2.2.2 Complexity of Urban Freight Transport

When evaluating a transport mode, it is important to understand the complexity of UFT. The complexity is due to the fact that the freight transport operations are no isolated events, but rather interrelated events dependent on other urban, regional, national and international activities (Lindholm, 2012a; Hesse et al. 2004). Specific requirements of freight transport makes it even more complex; for instance, freight transport is dependent on greater areas of space than passenger traffic, as there is a need of loading and unloading of goods, and material handling (Dablanc, 2007). Lack of loading space in central business districts causes problems for both loading operations and passenger traffic and leads to unreliable deliveries (Lindholm, 2012). Urban freight is also influenced by new technology and is affected by legislation on local, national and international level. Dablanc (2007) stresses the complexity of UFT and points out three characteristics:

- Goods movements are largely indifferent to the internal structure of cities.
- Urban policies regarding freight mobility are inefficient.
- The provision of appropriate logistic services is slow in emerging despite growing needs in urban areas.

Another aspect that adds to the complexity of cities is their geographical, political and cultural differences (Lindholm, 2012a), which may aggravate the transferability of knowledge between cities. Browne et al. (2011) further points out the type and quality of transport infrastructure, traffic levels, automation in vehicle loading/unloading, the extent of freight transport regulation by government and the operation of waste collection services as important differences between cities. All these aspects have to be taken into account in order to transfer knowledge of UFT between cities and create a sustainable and efficient transport system.

However, many problems and characteristics of urban areas are the same and the growth of freight transport is a problem seen in all urban environments (Browne et al., 2011). The lack of infrastructure capacity is a common challenge and as more people and businesses move to cities, the problems of congestion, emissions, noise and accidents are rising. In order for cities to keep their competitiveness, they need to provide an efficient transport system (Docherty, 2004) and evaluating potential transport modes is one way of moving to a more sustainable urban environment.

2.3 Inland Waterways

In the late 17th century and well into the 19th century it was a golden era for inland waterways in Europe (Davies and Marsh, 2013). During this period the network of waterways was extended dramatically with the construction of new canals forging the missing links between the natural waterways. One example from northern Europe is the construction of Göta Kanal, linking the Baltic Sea with Skagerrak, which facilitated transport of timber and mineral products. In the late 1700s Adam Smith, which is usually regarded as the founder of modern economics, wrote (Smith, 1776, p. 21):

‘As by means of water--carriage a more extensive market is opened to every sort of industry than what land-carriage alone can afford, so it is upon the sea-coast, and along the banks of navigable rivers, that industry of every kind naturally begins to subdivide and improve itself...’

Also, Hesse (2008) points out that cities situated at shorelines or at large inland waterways have been the traditional place for goods exchange. However, with the development of rail transport in the 19th century, inland waterways lost its position as the dominant mode for carrying freight in Europe (Davies and Marsh, 2013). Today, there is a large unutilized potential in the European inland waterway network, and currently only 5% of the total inland freight transport in EU-27 use waterways (European Commission, 2011). There are however big regional differences between different member states; in the Benelux countries for instance, as much as 30% of the inland freight is transported on water (Eurostat, 2012a). In the European Commission’s White Paper on Transport it is however stated that the inland waterways must play a more important role in the future freight transport system, in order to cope with the environmental goals for the transport sector (European Commission, 2011).

According to the UN, inland waterways can be defined as protected waters with a wave height maximum of 2.0 meters over time (Sjöfartsforum, 2011). European Commission has also adopted the same definition. In 2006 the European Parliament and the Council presented a directive in order to harmonize the market and conditions for inland navigation among the different member states within the union (2006/87/EC). The directive 2006/87/EC on the inland waterways means that special rules apply for vessels operating the inland waterways and includes changes in technical regulations and reduced staffing requirements compared to seagoing vessels.

In order for the transport to be classified as inland waterway transport within EU each member state must introduce the European Parliament and Council Directive 2006/87/EC. Sweden has not introduced the directive yet and maritime transport carried out on Swedish rivers, lakes, and canals are thus subject to the same rules as for seagoing vessels (Vierth et al., 2012). Thus Sweden shows no usage of inland waterways in the statistics from EU, even though there currently is some inland navigation performed by seagoing vessels. The Swedish government has however recently decided to adopt the directive in order to improve the competitiveness for Swedish shipping industry and it is believed that it will be introduced in the second half of 2014 (Proposition 2012/13:177). The waters considered for the definition inland waterways in Sweden would according to SOU (2011) be: Trollhätte Kanal, Göta Älv, Vänern, Mälaren, and Södertälje Kanal. This is an aspect to consider when evaluating the possible usage of urban waterways in Gothenburg, as the new rules will apply for the area relevant in the Västlänken case.

Transport on inland waterways provides high *reliability* owing to the high capacity on the waterways enabling congestion free transport (Konings, 2009; IMPACT, 2007). This is also argued to be one of the main potentials for increased transportation on the inland waterways (European Commission, 2011). Moreover, inland waterway transport is known for a high level of *safety* (Konings, 2009). Lowe (2005) even argue that inland waterway transport including barge transport is the safest of all transportation modes due to the low number of accidents and fatalities. Inland navigation is also able to compete on *price*, for example a study by PLANCO and BfG (2007) shows that the price level for container transport on inland waterways in the EU is on average 30% lower compared to road and rail transport for door-to-door shipments.

Finally, the *environment* can also benefit from a freight transport system that employs inland waterways (Konings, 2009). In several cases when the inland waterways are used effective they offer a more energy efficient and less polluting means of transport (Konings, 2009; Lowe, 2005). When calculating the total external cost in terms of accidents, congestion, noise, emissions, and air pollution of inland waterway transport it is proven to be seven times lower compared to road transport (Lowe, 2005).

In conclusion, inland waterways have shown to be reliable, safe, and environmentally friendly and require a low cost per tonne-kilometre when transporting high and frequent volumes of goods (Lowe, 2005). On the other hand, the relatively low speed of barges and the limited infrastructural network of waterways compared to road network represent some inherent disadvantages (Konings, 2009). Furthermore, most inland vessels are usually built for particular types of goods, which decrease the flexibility. It can also pose problems when trying to redirect vessels along the waterways much due to the limited infrastructural network (Vierth et al., 2012). Inland waterways can also be heavily dependent on weather conditions such as ice and wind.

2.4 Sustainable Urban Freight Transport

Historically, the focus within the area of logistics has been to minimize the costs and to maximize the outcome and the efficiency (McKinnon, 2010). As the main objective has been to organize logistics in a way that maximizes the profitability, the negative effects of logistics and transportation such as emissions, noise, congestion and accidents has not been prioritized. However, the negative impact of logistics on the environment and on society in general is nowadays a well-known fact and according to the European Commission (2011) the challenge is now "to break the transport system's dependence on oil without sacrificing its efficiency and compromising mobility". Transportation is one of the major sources of environmental problems and it is expected to increase even faster than the general growth of GDP (Aronsson and Brodin, 2006).

In order to counteract this development, it is clear that EU will increase its involvement in order to decrease the emissions from the transport sector and in the White Paper on Transport, the European Commission (2011) determines that new transport patterns must emerge and that the future development within transport must rely on more energy-efficient modes.

2.4.1 Definition of Sustainable Development

The term sustainable development more or less took its starting point in 1987 with the report "Our Common Future", also known as the Brundtland Report. Brundtland (1987, pp 54) defined sustainable development in the following way:

'*Sustainable development is a development that meets the need of the present without compromising the ability of future generations to meet their own needs*'

Furthermore, the concept of sustainability generally is said to include three different dimensions and the aim of a sustainable transport development is (UK Round Table on Sustainable Development, 1996):

'*To answer, as far as possible, how society intends to provide the means of opportunity to meet economic, environmental and social needs efficiently and equitably, while minimising avoidable or unnecessary adverse impacts and their associated costs, over relevant space and time scales*'

Freight and passenger transport contributes to a number of different economic, environmental and social aspects (Anderson et al, 2005). Urban freight is more polluting than long-distance freight transportation due to the frequency of short trips and stops (Filippi et al, 2010) and in urban areas, transportation results in various external impacts (Anderson et al, 2005).

2.4.2 External effects on the urban environment

When discussing the effects of freight transport on the urban environment, Richardson (2005) identifies five effects of transportation, which indicates transport sustainability: safety, congestion, fuel consumption, vehicle emissions and access. Coherently, it is argued by Andersson (2013) that the most commonly discussed effects of UFT are congestion, emissions, noise, and health injuries/safety. When taking the context of this thesis, with the comparison of trucks and urban waterways, these four major effects are significant factors when urban transport is discussed and analysed.

McKinnon (2010) argues that the logistical impact on climate change and the emissions of greenhouse gases has received increasing interest in recent years, due to tightening controls and enforcements on other sustainability impact such as road safety and waste products. Under the Kyoto Protocol, industrialised countries aim to reduce greenhouse emissions with at least 5% from 1990 to 2008 (Eurostat, 2012a). Within the EU, the total emission of greenhouse gases decreased with 15% in all sectors but the transport sector. The goal for transport is to reduce greenhouse gas emissions to 20% below the level in 2008 by 2030 and given the increase of transport activities and emissions during the last decades, this would imply 8% above the 1990 level of emissions (European Commission, 2011). The goal for UFT more specifically is to be essentially CO_2 free by 2030.

In contrast to the benefits of transport activities, the cost of the negative effects such as environmental impact, accidents and congestion are not borne by the transport users (IMPACT, 2007). Hence, without policies and legislation the negative effects are usually not taken into account when the transport users make transport decisions, which imply that the transport users make decisions based on incorrect incentives if not including the external costs. Due to this, internalisation of external costs has been an important issue both globally and locally for several years in order facilitate fair and efficient transport decisions.

2.4.3 Environmental Impact

UFT results in environmental impact such as pollutant emissions, waste products such as tyres, oil and other material, the loss of wildlife habitats and associated threats to wild species (Anderson et al., 2005) and results in emissions both on local, regional and global level (McKinnon, 2010). Air pollution refers to the pollution caused by the use of fossil fuels, i.e. gasoline or diesel, as well as particles that occur due to friction between tire and road (Trafikverket, 2012b). The amount of emission largely depends upon the type of fuel used when operating the freight vehicle or vessel. Urban transport is responsible for about a quarter of CO_2 emissions from transport (European Commission, 2011), and apart from CO_2, freight transport also results in emissions of other greenhouse gases. Hence, making transportation sustainable implies further actions than cutting carbon emissions.

Table 1. The effects of UFT on global, regional and local level. Adopted from McKinnon (2010).

Effect	PM	NO_X	HC	SO_2	CO_2	CH_4	NMVOC
GLOBAL							
Greenhouse indirect		✗				✗	✗
Greenhouse direct					✗	✗	
REGIONAL							
Acidification		✗		✗			
Eutrophication		✗		✗			
LOCAL							
Health and air quality	✗	✗	✗	✗			✗

The effects of the different emissions are illustrated in Table 1. The emissions on *local level* are the most obvious to stakeholders in urban areas and are experienced in the immediate closeness to the pollution source. The local effects on atmospheric pollution are mainly NO_X, HC, and PM. NO_X, results from combustion at high temperatures where nitrogen and oxygen gets combined (McKinnon, 2010) and results in both water and air pollution, and long-term exposure to even relatively low levels can result in issues with the functioning of lungs. NO_X can furthermore result in other health related issues such as problems with the immune defence, irritated throat and eyes and problems with the respiratory system. HC is the result of incomplete combustion of organic materials and for example contribute to air pollutions and health issues in cities (McKinnon, 2010). HCs such as benzene can cause cancer, although it is not known what exact level that is likely to cause damage. Moreover, HCs can cause hereditary diseases and effects on the nerve- and respiratory systems and irritatated throats and eyes. PM results from many different sources and comes in different sized and varieties, for example badly tuned diesel engines in trucks result in particles in the shape of soot (McKinnon, 2010). The main issue resulting from particulates are the health related issues such as carcinogenic effects, respiratory issues and cardiovascular problems, asthma and irritation of throat and eyes.

The main *regional effects* of UFT are acidification and over-fertilization. Acidification, which is a result of emissions of SOx and NO_X, causes issues for flora and fauna and the water-life (McKinnon, 2010). Acidification partly results from land-based freight transport but mainly it is the high level of sulphur in bunker fuels used in the marine sector that cause these issues. Over-fertilization, or Eutrophication, is partly caused by emissions of NO_X and SOx. In lakes and oceans, eutrophication results in increased primary production with algal blooms and subsequent oxygen deficiency, which results in that lakes and streams turn into wetlands instead (Hav och Vattenmyndigheten, 2013).

On a *global level*, the emissions from UFT result in emission of greenhouse gases, which affects the global warming. Higher water levels, expansion of deserts and increased risk for tropical storms are some of the consequences observed. The UN has listed 27 greenhouse gases, which are divided into the following six main categories: CO_2, MH_4, NO_X, HFC, PFC, and SF_6 (McKinnon, 2010). In this thesis, CO_2 is the main focus at a global level.

The external costs resulting from pollutant emissions are caused by emissions of air pollutants such as PM, NO_X and SO_2. The main cost components for the external costs from air pollution are dominated by health costs and also includes building/material damages and costs for future damages on the ecosystem. The external cost drivers for climate change on the other hand are more complex to determine, as they are long-term, global and have a risk pattern that is hard to predict. Due to this it is hard to determine the national value of climate change costs. The main impact on climate change is caused by the emission of CO_2 and NO_X and impacts the sea level rise, agriculture, and health of living creatures. For road transport, the most important driver of external costs is the emission standard of the vehicle, which depends on the speed, fuel type, and the combustion technology of the vehicle. For inland waterways, the main drivers are engine- and vessel type, fuel quality, operation mode and if driving upstream or downstream. (IMPACT, 2007)

2.4.4 Economic Impact

The external effects of UFT can be divided into economic impact, environmental impact and social impact. The economic impact of UFT is for example congestion, inefficiency and resource waste (Anderson et al, 2005). One of the main reasons to time losses, increasing operating cost, and excessive fuel use in transport industry is the congested infrastructure network in European cities (IMPACT, 2007; McKinnon, 2010). Congestion is caused when the volume of both freight and passenger traffic is greater than the capacity of the network, which leads to increased travel times and lowered reliability (IMPACT, 2007). When operating in congested areas, a vehicle cannot reach the speed attainable in un-congested areas and when driving at a speed lower than 30 kilometres per hour, the fuel consumption and thus the emissions increases significantly (McKinnon, 2010).

The rate of congestion greatly depends on what mode of traffic that is used, the time of day, and the local infrastructure characteristics. In general the main congestion in urban environments regards the road network is during rush hours. Inland waterway network on the other hand is argued to be a congestion free mode of transport (IMPACT, 2007; MDS Transmodal Limited, 2012; Konings, 2007). The congestion not only results in increased costs for the transport operator per se, the vehicle movement also puts even more pressure on the infrastructure leading to external congestion costs borne by other infrastructure users and the society as a whole (IMPACT, 2007). The European Commission estimates that congestion in the EU-27 costs approximately 125 billion EURO annually (Woxenius and Sjöstedt, 2003).

2.4.5 Social Impact

The social impact of UFT includes safety, noise and vibration, visual intrusion and other quality of life issues (Anderson et al., 2005). Social impacts are difficult to measure compared to economic and environmental impacts, as they are more subjective.

2.4.5.1 Safety

The number of serious accidents involving freight vehicles and pedestrians and cyclists has resulted in major concern in urban areas for the movement of freight and 69% of road accidents and one in three fatal accidents occur in urban areas (European Commission, 2011). Road transport result in fatalities and injuries every year and accidents also cause delays and inconveniences for other road users (McKinnon, 2010). There is a clear distinction between different modes when considering the safety risk and external costs. Inland waterways are generally considered as a safe mode, and according to IMPACT (2007) the lack of information is noticeable. Road transport on the other hand increases the safety risk and the drivers of external costs with regards to safety comply with the ones mentioned in Chapter 2.5.4.

2.4.5.2 Noise

Noise generated by freight vehicles is nowadays a fact in urban areas, and is especially regarded to bother residents in urban areas during night-time (MDS Transmodal Limited, 2012). The most common effects of noise emissions are annoyance, communication problems, sleep disturbance and concentration issues (McKinnon, 2010). When considering noise emissions from an external cost perspective, the external costs usually gets divided into costs of annoyance and health costs (IMPACT, 2007). Cost of annoyance regards the undesired social disturbances caused by noise emissions, such as restrictions on enjoyment of desired activities, discomfort or inconvenience. Health costs includes the physical health damages caused by noise emissions, such as hearing damage (caused by noise levels over 85 decibels), nervous stress reactions caused by lower decibels and increased blood pressure. For the calculation of external costs for noise emissions, data on the number of exposed people is necessary.

Noise effects differ from for example pollution, as the noise emissions are restricted to the actual time of the emission. The knowledge about noise emissions from the shipping industry and inland waterways is inadequate, and people in urban areas are generally only affected to a very small amount of noise from ships (IMPACT, 2007; Trafikverket, 2012b). It should furthermore be emphasized that noise resulting from shipping is similar to industrial noise, generated by loading of the vessels (Trafikverket 2012b). The noise problem is something that can be relatively easily addressed with for example quieter ramps, while noise from road, air and rail traffic is of a different nature and more difficult to reduce. From road transport, the noise emissions are mainly resulting from the sound of rolling and the propulsion system, and the level of emissions depends on the vehicle speed (IMPACT, 2007). Other important cost drivers for external costs resulting from road transport are type of vehicle and tyre, vehicle age, and the state of maintenance.

2.4.5.3 Visual Intrusion

Visual intrusion implies that the presence of freight vehicles spoil the surrounding areas and the outlook from properties (McKinnon, 2010). This social impact is rather hard to measure as it is highly subjective and the opinion on size and design of vehicles differ from one person to another. According to IMPACT (2007) the level of perceived visual intrusion increases in Alpine areas, where freight carriers can be seen from a longer distance than in a flat area and also when the amount of transport is high, as it will amplify the perceived impact.

2.4.6 Sustainable Freight Transport

An understanding of UFT and sustainability in general has been provided. However, what is important when evaluating the sustainability of a transport mode is what sustainability is in a freight transport context. As mentioned, sustainability normally refers to the Bruntland Commission’s (1987) definition. Derived from this definition, sustainable transportation is the ability to meet today’s transport needs without compromising the ability of future generations to meet their transport needs. Sustainable transport also includes the three aspects of sustainability; social, economic and environmental welfare (Richardson, 2005). The urban context also adds the aspect of balancing these three factors in a way that do no harm to the cultural heritage of a city (Bandarin et al., 2012), which is an important aspect when re-introducing the use of urban waterways in a city like Gothenburg.

The institute for transport studies at the University of Leeds (2012) defines sustainable urban transport and land use system as a system that:

- Provides access to goods and services in an efficient way for all inhabitants of the urban area.
- Protects the environment, cultural heritage and ecosystems for the present generation.
- Does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.

This definition has been accepted by more than 85% of European cities (University of Leeds, 2012). However, there is no common definition used in academia and the differences between freight transport and passenger traffic is not highlighted in most definitions (Behrends, 2009). Richardson (2005) shows that the main differences when analysing passenger and freight transport is that the primary influencers of passenger transport are physical, psychological and social needs, whereas the primary influencers of freight transport is market forces and government policy. This shows that freight transport is influenced of economic factors to a higher extent than passenger transport. Anderson et al. (2005) further strengthen this statement and define government and businesses as the two most important driving forces of a sustainable urban freight system. Also, many definitions of sustainable transport highlight the movement of goods and citizens in cities, however, the urban transport system is not isolated from other activities (Behrends, 2009) and the larger systems in which transportation activities are taking part in should not be ignored (Goldman and Gorham, 2006). This is why a wide perspective of effects on local, regional and global level needs to be taken into account when analysing the sustainable impact of urban waterways.

2.5 Buying transport services

Efficient logistics and transport solutions are an important competitive factor for all types of businesses, including companies in the construction sector. When the shippers purchase the transport service they are in the power to restrict or create opportunities for how the transportation provider delivers the service, for example regarding what mode to use for the transport (Rogerson, 2012).

When evaluating a potential transport mode and when comparing different transport chains, the cost aspect is a major parameter in the transport decision (Lammgård et al., 2013). In a survey by Lammgård et al. (2013) among Swedish shippers, it is also shown that the shippers were asked to distribute weights of 100% between four different characteristics of transport services according to their importance. Price received a weight of 54%, followed by on-time delivery (22%), transport time from door-to-door (16%), and finally environmental efficiency was attributed 8%. Lammgård et al. (2013) argues that the environmental aspects, which have limited impact today, will most likely be of higher importance in the future when buying transport solutions. Price however proved to be the outstanding most important selection criteria when buying transport. This result is also in line several previous surveys, which have also identified cost and service as the most important selection criteria for shippers (see for example: Pedersen and Gray, 1998; Matear and Gray, 1993; Lammgård, 2007).

Furthermore, the purchasing policy for the public sector has some specific characteristics as the EU procurement law prescribes how purchases and tendering processes should be performed in order to promote free competition on the market (van Weele, 2010). The law includes a transparency principle, which means that the contracting authorities must communicate and be clear about what criteria and weight factors that will be used to assess suppliers.

The choice of mode is a complex process and in order to understand what transport mode that is the most competitive for each distance in the transport chain, a supply chain perspective is needed (Behrends, 2009). The right quantities should be distributed to the right locations and at the right time in order to minimize system wide costs while at the same time satisfying the service level requirements (Chopra et al., 2012). Product characteristics like volume, value and required delivery time decides the transport network, and also what service level that is required by the shipper. Also, the transport needs to meet particular packaging requirements; security conditions and the handling facilities needed should be available. However, there are also less tangible issues that may affect the mode decision (Lowe, 2005). Arnäs (2012) provides a model of transport quality that can be used to compare different transport modes:

$$Transport\ Quality = \frac{Security \times Safety \times Reliability \times Sustainability}{Cost}$$

To conclude, the choice of mode is complex, however the opportunities of a more cost efficient and sustainable transport network is promising. This is why it is of such interest to look at the potential use of urban waterways, when the need of transporting large amount of mass from a construction work is rising.

2.6 Stakeholders in urban freight transport

There are several stakeholders involved in UFT and in order to provide clarity and evaluate the transport solutions, it is crucial to identify the different stakeholders and their specific interests in the transport decision. When discussing the many stakeholders involved in UFT, authors like Taniguchi et al. (2001) and Quack (2008) use different definitions. MDS Transmodal Limited (2012) however takes on a broad stakeholder spectrum in a report prepared for the European Commission when defining the stakeholders defining the stakeholders and their interest in UFT, and divides them into *supply chain stakeholders* (shippers, transport providers, receivers and consumers), *resource supply stakeholders* (infrastructure providers, infrastructure operators and landowners), *public authorities* (local government and national government), and *other stakeholders* (residents, visitors/tourists, and economic stakeholders located in the urban area such as service providers and manufacturers).

It is argued by several authors that the most crucial actors involved in the actual movement of goods within UFT are the *shippers* and the *receivers*, the *transport operators* who actually move the goods, the *residents* who live or work in the city and the *public authorities,* as illustrated in Figure 2 (Taniguchi and Thompson, 2003; Wohlrab and Harrington, 2012;

Taniguchi et al, 2009). Ballantyne et al. (2013) argues that it is appropriate to include a broader set of stakeholders in urban freight studies, instead of as traditionally focus on a single stakeholder or actor. This is why the stakeholder definition by MDS Transmodal Limited (2012) is used in this thesis. The focus is however on the five most crucial stakeholders as defined above; the shippers, the receivers, the transport operators, the residents and the administrators/authorities.

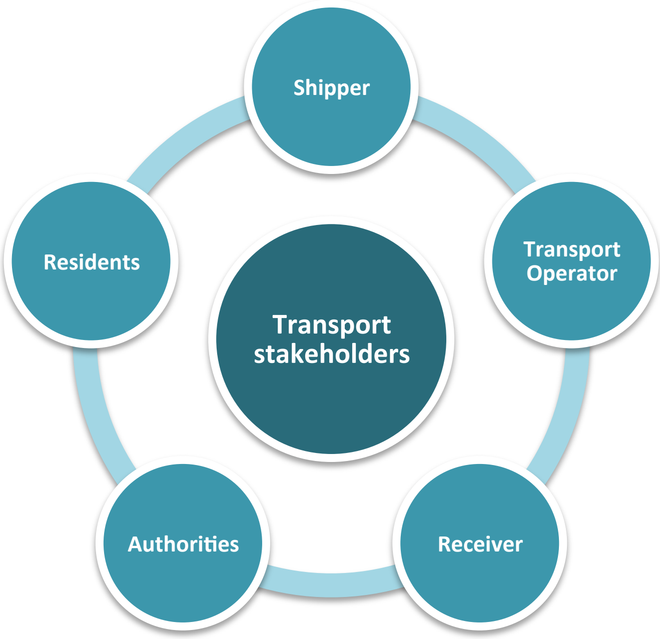

Figure 2. The most important transport stakeholders, adjusted from Taniguchi et al (2009).

The interaction between all the involved stakeholders results in increased complexity of finding sustainable freight solutions for urban areas (MDS Transmodal Limited, 2012). Each stakeholder has its own interests, behaviours and perceptions about what issues freight transport in urban areas result in, as presented in Table 2. For example, shippers try to minimize the costs in their supply chains, transport operators try to meet the shippers' demands whereas residents main request is a quiet urban area with clean air. UFT affects stakeholder groups differently (Quack, 2008). However, what they all have in common is that they all face the effects of UFT; increased risk of congestions, pollutant emissions, accidents and increased noise. In order to evaluate and improve urban logistics, it is hence important to understand the behaviour of all the different stakeholders involved before making logistical decisions. Historically, local authorities has hindered freight transport in urban areas through policies and legislation, but according to Ballantyne et al. (2013) local authorities are now beginning to acknowledge that there is a need for well-functioning urban freight in cities.

Table 2. Stakeholders' main interest in the context of UFT adapted from Ballantyne et al. (2013).

STAKEHOLDER	MAIN INTEREST IN CONTEXT OF UFT
Supply chain stakeholder	
Shippers	Delivery and collection of goods at the lowest cost while meeting the needs of their customer.
Transport operators	Low cost but high quality transport operations and satisfaction of the interests of the shippers and receivers.
Receivers	On time delivery of products, with a short lead-time.
Public authorities	
Local government	Attractive city for inhabitants and visitors, with minimum inconvenience from freight transport, while also having an effective and efficient transport operation.
Other stakeholders	
Residents	Minimum inconvenience caused by UFT.

2.7 Transport risks

A freight transport system in an urban environment is complex and as described above, many stakeholders are affected by and try to influence transport decisions. When deciding on what transport modes to be used for a transport chain, the risks thus have both direct and indirect influence on the transport decision (Ostrom and Wilhelmsen, 2012). Risks of accidents, emissions, damages on infrastructure, congestion, and stakeholders, affect not only the financial performance of firms and government, but also the health and well-being of the residents of the city. It is therefore considered essential to explore and evaluate the different risks associated with implementing a new transport mode in a transport chain in the urban environment.

Rausand (2011) provides two definitions of risk; the probability that an outcome occurs, and the probability that an outcome occurs multiplied by the consequence of it. The latter is normally used in decision-making processes (Taniguchi et al., 2009). Rausand further describes that risk management consists of three steps; risk analysis, risk evaluation, and risk control. A risk analysis is the systematic use of available information to identify hazards and to estimate the risk to individuals, property, and the environment and is performed to establish a risk picture (Rausand, 2011). A risk evaluation evaluates the risks and proposes risk-reducing measures to minimize the risks identified. The two processes together form a risk assessment, as can be seen in Figure 3. In the risk control phase, the risk measures are implemented, monitored and communicated. As this paper only concerns the transport mode decision, the risk control phase is excluded from the analysis.

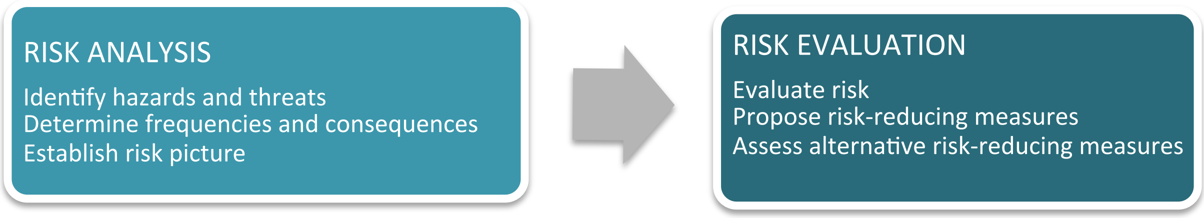

Figure 3. Risk Assessment adjusted from Rausand (2011).

A risk analysis provides answer to the following three questions (Rausand, 2011):

- What can go wrong?
- What is the likelihood of that happening?
- What are the consequences?

When assessing the risks in urban transport, a stakeholder perspective is important, as the different stakeholders have different motivations, objectives and behaviours in facing risk (Taniguchi et al., 2009). When the frequency and the consequences of the risks have been analysed, a risk picture is presented. The risks are then evaluated and risk-reducing measures proposed. The risk assessment is then used as an input for the transport mode decision process.

In order to get a transport decision accepted, it is sometimes more important to understand the perceived risk, rather than the scientific risk and even if the public assessment to risk is sometimes illogical, it is important to understand its perceived benefits and risk in order to present findings so that they are publicly acceptable (Fukushi, 2008). The voice of the public is usually an important issue in governmental decision-making, and risks used in decision making in the public sector often relates to public health, welfare and a high quality of life in the urban area (Fukushi, 2008).

When making transport decisions, risk trade-offs are made between risks and benefits. One example is the car driver, who even though exposure of the risk of a car accident, decides to drive a passenger car to work, because the perceived benefits are greater than the risk of an accident. Coming back to Rasuand's (2011) three questions, they include the probability and the consequence of the identified hazards, however, in the decision-making process, cost is an added aspect. When a high level of risk is acceptable, the cost for preventing it is low, but if a risk should be prevented or if zero risk is wanted, the cost can rise a lot. When making a transport decision, some risks need to be accepted to make it economically feasible, however, an optimum level of risk/consequence and cost is usually aimed for.

2.8 Summary of Theoretical Framework

The theoretical framework provides the basis for analysis and in order to answer the research questions, the theoretical framework focus on urban freight transport, inland waterways, sustainability, transport buying, and finally transport risk. In this section, the theoretical framework is briefly summarised and connected to the research questions. In Figure 4 below a summary of the theoretical framework is presented.

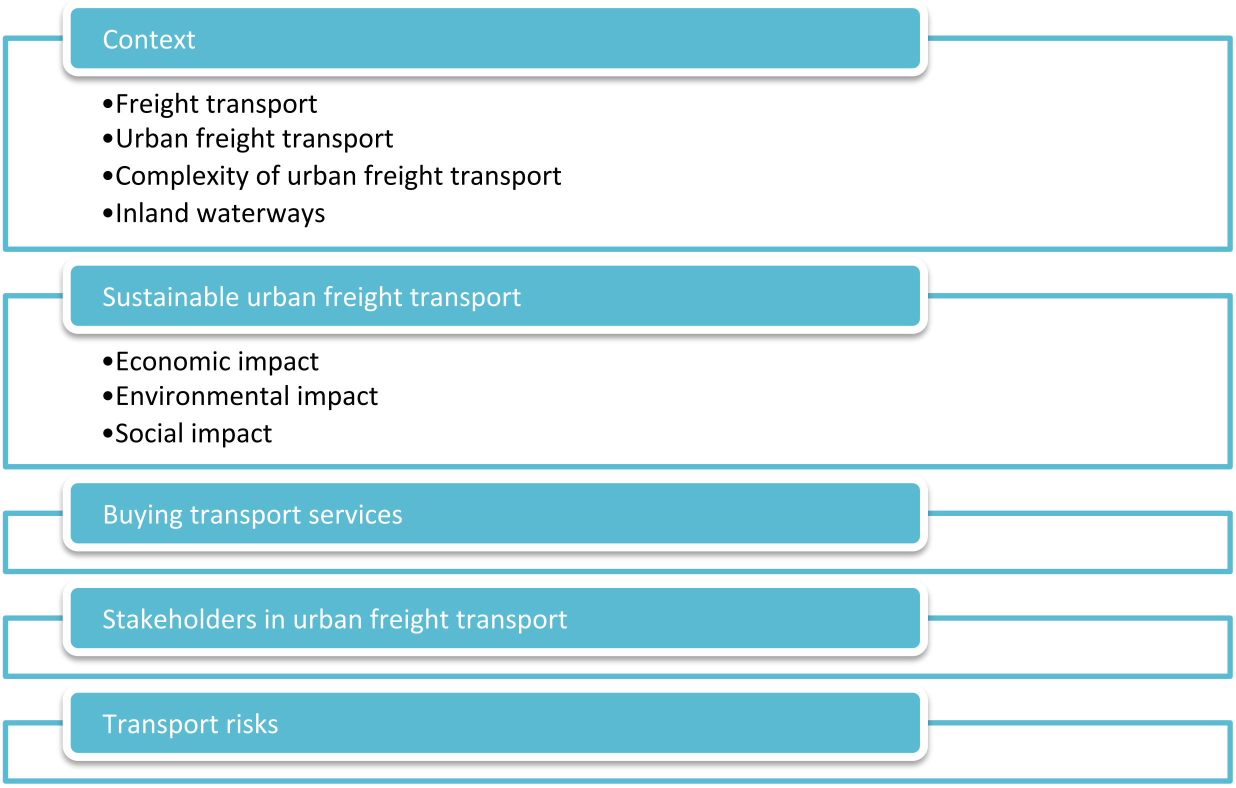

Figure 4. Summary of the theoretical framework.

The first research question address whether it is feasible to utilize urban waterways for mass transport in an urban context, and a thorough definition of freight transport and UFT is thus required. The presented model by Wandel et al. (1992) is crucial when further analysing the feasibility of the investigated modes of transport. Also, it is concluded in the theoretical framework that the level of complexity of UFT is high and an aspect that adds to the complexity of cities is their geographical, political and cultural differences. This is important when making conclusions with regards to feasibility. Finally, the sections that address inland waterways and transport risk is also crucial when analysing feasibility as inland waterways is a relatively untried transport method in the context provided in this thesis.

The second research question address sustainability and hence the environmental, economical, and social impact of the investigated transport chains. In order to further analyse this research question a thorough definition of freight transport and UFT is first of all required, in combination with the section Sustainable UFT that includes a definition and the external effects of UFT from an environmental, economical, and social perspective. Also, the sections that covers buying transport services and stakeholders in UFT are crucial when further analysing the sustainability of transport methods in an urban context.

3 Methodology

This chapter describes the research approach of the thesis and the research process used to answer the two research-questions and presents the method used for data collection. The chapter discusses and argues for the chosen methodologies and also reflects upon how the choice of methodology affects the results of the thesis, its reliability and its validity.

3.1 Research approach

The purpose of this thesis was to evaluate the feasibility and sustainability of using urban waterways for mass transport during the construction of Västlänken in Gothenburg. In order to fulfil the purpose a proper research method was needed. In logistics research, three methodological schools are commonly used; the analytical school, the systems school, and the actors school (Gammelgaard, 2004). In this thesis, the systematic approach was chosen as the research method as the context is complex with many stakeholders involved. The approach is based on two fundamental ideas (Arbnor and Bjerke, 2009, p. 103):

1. *All phenomena can be regarded as a web of relationships among its components.*
2. *All systems have common patterns, behaviour and properties, which can be explained and/or understood to develop greater insight into the behaviour of complex phenomena.*

Thus, it was crucial to understand what relationships that affect the use of urban waterways for mass transport in an urban environment and according to the systematic approach this can be achieved by evaluating similar systems to find common patterns and properties. However, Arbnor and Bjerke (2009) state that the systematic approach can never perfectly predict a future system, thus the outcome of this thesis is directional.

During a research project, the work moves between different levels of abstraction where the general theories and the specific empirical data form the endpoints (Björklund and Paulsson, 2003). When addressing the purpose of this thesis an abductive approach was used, thus both inductive and deductive methods are combined. Dubois and Gadde (2002) refer to the abductive method as systematic combining and describe the approach as a process where the theoretical framework, the empirical data collection and the case study evolve simultaneously. Dubois and Gadde (2002) also argues that by going back and forth between different research activities, the researchers understanding of both worlds, i.e. the empirical and the theoretical, increases. The research process used for this thesis is further described in the next section.

3.2 Research process

The research process of this thesis was based on theoretical studies in the area of UFT, sustainability, urban waterways, and studies of available construction machines and vessels, in combination with empirical studies performed through a benchmark of six similar cases in Europe and Sweden and data from the case study performed in Gothenburg. The six similar case studies were identified and located in an urban environment, involve a similar type of mass as in the case study in Gothenburg and be interesting from an urban waterway perspective. The theoretical knowledge was gained throughout the writing of the thesis, and evolved as the six studies were examined and when the authors increased their knowledge of the case study in Gothenburg.

The first part of the research process resulted in different transport chains from three planned shafts in Gothenburg, to two assumed destinations for the excavated mass. A conventional transport solution was compared to a transport chain where barge was the main mode of transport. The transport solutions were analysed from feasibility and sustainability perspectives, in accordance with the research questions. In order to understand what impact the conclusion had, a system view analysis and a risk assessment were also performed. The risk assessment was conducted in accordance with Rausand (2011), as described in the theoretical framework, and consisted of a risk analysis were risks were identified and a risk evaluation were the risk was evaluated and risk reducing measures introduced. The risk assessment provided answer to the questions of: what can go wrong, what is the likelihood of that happening and what are the consequences? The research process is illustrated in Figure 5.

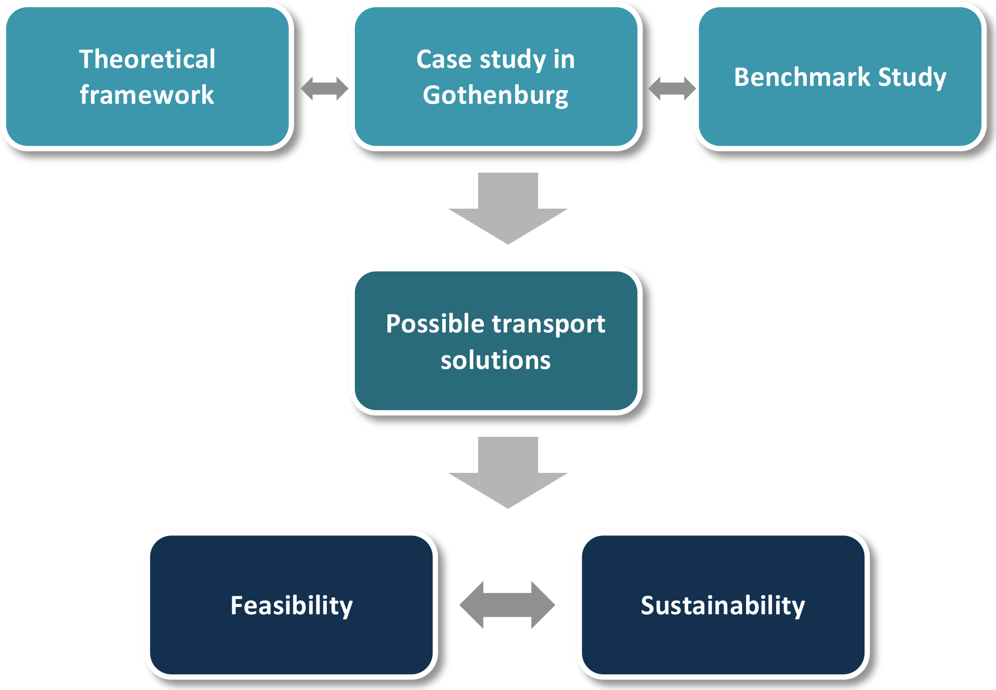

Figure 5. The research process.

3.2.1 The feasibility study

As described, the feasibility study of the transport solutions required theoretical studies, benchmark of six similar cases to the one in Gothenburg and studies of the context specific conditions in Gothenburg.

The theoretical studies were based on general theory on UFT, urban waterways, basic geology and theory on construction machines and vessels. In addition, three barge suppliers, two construction machine manufacturers and one construction truck manufacturer were interviewed to gain a technical understanding and knowledge of the available vehicles and vessels on the Swedish market.

The benchmark study of six similar cases started by identifying similar cases to the one in Gothenburg; four were found in Sweden and two European projects that have gained large attention within the area of urban transport were chosen. The data collection focused on was: type of project, type of mass, transport mode, intermodality, quantity, frequency of delivery, length of transport and geographical context. People in charge of the mass transport were contacted in order to get the information needed.

Simultaneously, the case study of Gothenburg and Västlänken was performed. Interviews with Trafikverket, Trafikkontoret, Sjöfartsverket and Stadsbyggnadskontoret were performed in combination with the collection of data from the geological department of Gothenburg. The methods used for the interviews are described later. Laws and regulations for specific vessels and vehicles were conducted and missing data of measures of the canal and height of bridges were measured by hand.

After conducting the study, an analysis of the feasibility of the transport chains was performed, were the transport chains were analysed from a transport, network and infrastructure perspective, in accordance with Lumsden's (2012) model of the transport system, presented in the theoretical framework.

3.2.2 The sustainability study

Similar to the feasibility study, theoretical studies, studies of six similar cases to the one in Gothenburg and studies of the context specific conditions in Gothenburg were needed to perform the sustainability study. The sustainability analysis was then divided into an environmental study, a cost study and a social impact study.

The theoretical study was based on general theory on UFT, urban waterways, sustainability, transport decisions and stakeholder theory in UFT. In addition, interviews with experts in the area of urban waterways and experts on emission audits were performed in order to fully understand the different aspects of sustainability and urban waterways.

The benchmark of six similar cases was conducted by identifying cases from Europe and Sweden, similar to the project of Västlänken. The collection of data was conducted through interviews and published material. Similarities of contexts in other cases were transferred to the case study in Gothenburg. The main interest was the tender process and what decided the transport choice made in each case. Further interviews with responsible members from each construction project were conducted in order to fully understand the conditions at the most relevant cases.

At the same time, the case study in Gothenburg was conducted. An understanding of the environmental laws and regulations, the transport decision process, the organization of the project, stakeholders affected by the mass transport and costs aspects of different transport modes were collected in order to answer the research question, interviews with all relevant stakeholders were also conducted. The relevant stakeholder groups were identified in accordance with accordance with Taniguchi and Thompson (2003); Wohlrab and Harrington (2012) and Taniguchi et al (2009).

After conducting the basic studies, calculations to gain results from the three aspects of sustainability was conducted. As a base for the calculations, the different transport chains and actual distances were identified. The fuel consumption for the different transport chains was then calculated and served as a base for the rest of the calculations. To gain an understanding of the three sustainability aspects of the transport choice; an environmental analysis, a cost analysis and an analysis of the social impact, including a stakeholder analysis were performed.

The environmental analysis was based on the results of fuel consumption for each transport chain and resulted in an emission audit that followed the methodology of the Life Cycle Assessment presented by Baumann and Tillman (2004) as seen in Figure 6. Life Cycle Assessment (LCA) is a tool to quantify the consumption of natural resources and pollutant emissions for a certain product or transportation (Baumann and Tillman, 2004). The transport solutions were compared and the scope of the transports was limited to start at the top of the shafts and finish at the identified landfill positions at Frihamnen and Port of Gothenburg.

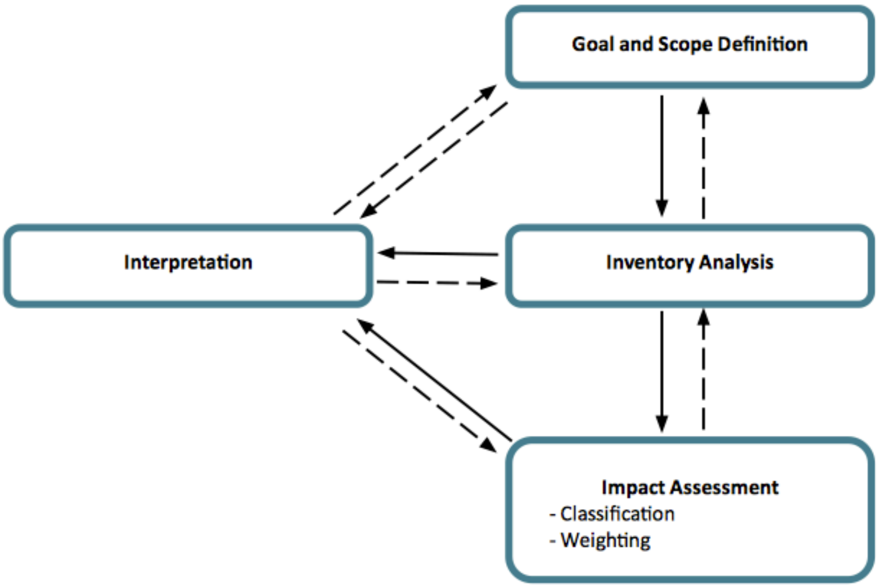

Figure 6. The LCA Methodology.

Generally, when comparing transport costs for different modes of transport, one should take the view of the producer of the transportation service, as its costs are relatively easy to define (Lumsden, 1995). Thus, this approach was used for *the cost analysis* and was performed in accordance with the method presented by Styhre in Vierth et al. (2012). According to the method the costs for each transport leg was divided into five groups:

1. Operating costs (primarily fuel)
2. Personnel costs (salaries)
3. Infrastructure costs (e.g. rail charges, road toll)
4. Vehicle costs (e.g. interest rates, depreciation of vehicles and vessels, insurance, maintenance)
5. Loading, unloading and transhipment costs

These costs were then regarded either as time-dependent costs or stretch-dependent costs, which is a common way to classify and calculate transportation costs (Lumsden, 1995). In this case the time-dependent costs included personnel costs, infrastructure costs, vehicle costs and costs related to the loading, unloading and transhipment. However, some maintenance, transhipment and operating costs were regarded as stretch dependent costs. The different costs was calculated as follows:

*Time-dependent cost = Total time for transportation * Cost per time unit*
*Stretch-dependent cost = Total distance travelled * Cost per kilometre*

The cost categories for each mode of transport were based on collected data from transport operators, manufacturers, labour unions, SCB, and trade organisations. The total cost for each transport chain was then calculated based on the previous calculated fuel consumption and work cycles. The results were then compared to draw conclusion of what the most important cost factors were and how barge affected the cost picture.

The social impact analysis was performed by comparing the theoretical study and interviews with the results gained in the LCA study and cost analysis. The analysis was also complemented by the substantial stakeholder analysis, which was performed by interviews with all relevant stakeholder groups. According to Lindholm (2012a) the different stakeholders are often interdependent and the complexity of the transport system is high, as many actors are involved. Several models for evaluating stakeholders in UFT are available and most of them include similar stakeholders, however, residents and estate owners are sometimes excluded from the models. The stakeholder groups interviewed belonged to the relevant stakeholder groups identified by Taniguchi and Thompson (2003); Wohlrab and Harrington (2012) and Taniguchi et al (2009) and were; shippers, receivers, transport operators, residents and the administrators/authorities.

Finally, a study of the total material flow from the three shafts was conducted in order to understand the system in which each mode of transport operates within. The results gained from the feasibility and sustainability studies were put into a system, and the total mass transports were analysed in a system analysis. This was also complemented with a risk assessment, as described in the theoretical framework.

3.3 Data collection

Four different methods can be used when collecting data; questionnaires, observations, interviews and literature studies (Holme and Solvang, 1997). In this thesis, data was collected through interviews and literature studies, i.e. both primary and secondary data was used. Primary data is collected data intended for the specific study (Björklund and Paulsson, 2003). Secondary data is data that has been developed for another study that usually has a purpose other than that of the current study. According to Björklund and Paulsson (2003) it is therefore important to be aware of that the secondary data may be biased or non-comprehensive. The secondary data used in this thesis was collected through a literature review. The literature review and interviews performed in this thesis are described in the sections below.

3.3.1 Literature review

One of the primary goals of the literature review was to form and develop a general knowledge in the area of UFT, sustainability, and how urban waterways can be used in this context. The literature review was developed throughout the writing of the thesis, as the knowledge in the area of research increased and the empirical data collection brought on new sides of the transport decision. Literature studies of earlier performed cases, similar to the one in Gothenburg, were also studied in order to present transport chains for the case study.

To find relevant literature, multiple channels were used. First, searches for academic articles and reports were performed within academic databases such as Science Direct, Pro Quest, and Emerald. Second, Chalmers University of Technology Library's search engine Summon and Google Scholar were used complimentary. Here, keywords such as 'UFT', 'sustainable transport', 'city logistics' and 'inland waterways' were used among others. Third, contacted researches in relevant areas were providing non-published or non-available academic reports. Fourth, general searches at Google were conducted in order to find relevant Internet websites and reports to gain a general understanding of on-going projects, research and conferences in the subject. Finally, literature was also collected through lecturers at Chalmers University of Technology, and provided by interviewees in the empirical study.

3.3.2 Interviews

The empirical data collection through interviews had two major purposes. First, it further contributed to the general knowledge within the area of sustainable UFT and the utility of urban waterways. Second, it created the basis for the case study and the proceeding analyses. According to Lantz (2007) a well-executed interview must fulfil the following:

- The interview method must meet the requirements of *reliability*.
- The interview method must meet the requirements for *validity*.
- It must be possible for others to *critically examine* the interviewer's conclusions.

Furthermore, according to Lantz (2007) interviews can be divided by its structure. An interview can be *open*, which means that the interviewer asks broad, open-ended questions that the respondents can answer in a non-directed way. The interview can also be *structured*, meaning that the interviewer asks pre-formulated questions in a predetermined order and the respondent answers with pre-formulated response options. The obtained data varies depending on the method chosen; the open interview method often results in qualitative data while quantitative data is to a higher extent obtained through structured interviews. These are the two extremes, however most common is that the two methods are mixed. This is often referred to as semi-structured interviews.

In this thesis semi-structured interviews were used as the respondents had different academic background and the knowledge of the case study were not known in advance. Thus, in order to gain as much information as possible, the interview started in a structured way, presenting the subject and the area of interest and ended in an open way, asking open questions like 'what is your opinion of using barge transports?' and 'what other aspects do you see as important?'. It was seen as important that the respondent told what the most important aspect when introducing a transport solution was to them, why an open discussion was also needed. The order and type of questions have differed depending on the purpose of the interview and position of the responder. In total, 38 interviews were conducted (see Appendix 8), and all stakeholder groups identified were then covered. Complimentary non-structured meetings with researcher in the area of Geology, Civil Engineering and Transport at Chalmers were also conducted in order to gain theoretical knowledge and access to reports and lecture material.

3.4 Research Quality

In this section, the implication of the choice of method on the quality of research is discussed. As mentioned, it is important to discuss whether the choice of methodology in addition to the assumptions made affects the results of this thesis, as well as its reliability and validity. First of all, the data collection has partly been made through 38 semi-structured interviews and generally, the reliability of interviews is a great concern, due to the risk of subjectivity and human factors, e.g. misunderstandings (Ejvergård, 2007). However, allowing the respondents to review their answers after the interview, in order to detect possible errors, can increase the reliability. To further increase the reliability it is also crucial to ask the same questions to different respondents to reduce the risk of subjective opinions. Thus, this thesis was sent for approval to the interviewees before publishing. The same questions have also been asked to different interviewees to increase the reliability of the study. The validity of the thesis might be affected by the dissension in terminology, as some terms have several definitions. To reduce the risk of misunderstanding the authors were careful when using such terms and acted explanatory. Furthermore, at least two of the authors have been present at each interview session in order to reduce the risk for misinterpretations and subjective perceptions.

When it comes to the first research question and the feasibility, several assumptions have been made. First of all, the transport models investigated are limited to the Swedish market. For transhipments, three construction machines and one belt conveyor have been analysed and the results are thus not optimized for the specific material flow. All machines used for the flow are however regarded feasible and the scope size has been chosen to be within the optimal range of 3-5 scopes to fill a truck; hence an optimised flow would not have significant influence on the results. Also, the cycle times for construction machines used in the calculations are based on on-going research at The Royal Institute of Technology in Stockholm, and are based on the context of large construction sites. Hence, the cycle times might differ somewhat for an urban context as the one described in this thesis, and more research would be needed in order to find the correct cycle times for this context. The feasibility study is also based on geographical conditions and rules and legislation, and as the project of Västlänken is planned to start in 2018 these conditions might have changed. However, in this thesis the rules, legislation, and geographical conditions are assumed to the currently valid conditions. In the end of the thesis possible changes and how these could affect the results presented in the thesis will be discussed.

When considering the sustainability analysis made, with the three aspects environment, economy and social included, several assumptions have been made in order to draw conclusions. First of all, when calculating the environmental impact from the different transport chains different sources have been used for finding figures in order to calculate emissions and external costs for each mode of transport respectively. Euro 5 was used when calculating the emissions for the trucks but most likely a combination of Euro 5 and Euro 6 will be used during the project, as Euro 6 will be introduced from September 1, 2014. However, as up-to-date figures and sources have been used it can be argued that the results presented are reliable despite the assumptions made.

The results presented with regards to economy are based on a rather simple calculation methodology, which do not include for example inflation and was assumed a solid interest rate, which is further explained in Appendix 4. In reality, a more thorough analysis could be needed where the market situation, inflation, fluctuations in fuel price, taxes, and wages for example also were taken into consideration. Moreover, figures used when calculating costs for each mode respectively are based on figures from operators and manufacturers for each mode except for truck, which is based on a discussion with trade organisations and labour union. The same cost categories are used for all modes, but due to the different sources for figures it can be argued that the cost categories for truck provides a better average cost. Hence, for the trucks the cost categories do not represent the specific trucks referred to in the thesis but rather an average for the entire industry, which could affect the actual result both positively and negatively.

The third aspect of sustainability addressed in the thesis is the social impact, namely safety, noise, and visual intrusion. It is important to note that the results presented regarding social impact is based on a qualitative discussion, unlike the results in economic and environmental impact. The conclusions drawn are not based on the freight carriers used as references in the thesis but rather on theory and interviews about the discussed mode of transport in general. This could somewhat affect the validity of the results, and in order to draw conclusions about social impact from a quantitative perspective further research would be necessary.

4 Benchmark study of similar cases

In this chapter a benchmark study of similar cases to the one investigated in Gothenburg is presented. The chapter aims to highlight the lessons learned from the other cases and also examine the most important decision factors when implementing a transport mode. Six different cases are investigated; first, the use of barges in the reconstruction of Potsdamer Platz in Berlin 1990 and in the construction of the Olympic Park in London 2012 were investigated. Both cases have gained international attention, due to their innovative use of barges and show how urban waterways have been used in an urban environment. Second, four Swedish construction cases were studied, in order to understand how the Swedish context affects the use of urban waterways.

By studying six construction projects similar to the one in Gothenburg, it is seen that barge is not always used for mass transport, even though the construction site is located close to waterways and is regarded a sustainable mode of transport. Out of the six studied cases, four cases have been using waterways for mass transport. In the constructions of Potsdamer Platz in Berlin, Olympic Park in London, BanaVäg i Väst between Gothenburg and Trollhättan, and Förbifart Stockholm, barges or vessels have been used for mass transport. In Citytunneln in Malmö and Citybanan in Stockholm on the other hand, the alternative of barge transport solutions has been turned down.

The conditions for each case is summarized in Table 3 and presents the type of construction project, the type of mass, the transport mode, the transhipment methods used, the amount of mass, the excavation rate, the length of each transport and the geographical context of each case.

Table 3. Summary of conditions at the investigated cases.

CASE SUMMARY	Potsdamer Platz	Olympic Park	Citytunneln	Citybanan	BanaVäg i Väst	E4 Förbifart
Type of Project	Construction of city area	Construction of city area	Construction of train tunnel	Construction of train tunnel	Re-construction of railway and highway	Construction of new bypass highway
Type of Mass	Excavated earth, Miscellaneous supplies	Waste material, Construction materials	Limestone	Rock and soil.	Rock, soil, contaminated soil	Rock and Soil
Transport Mode	Push-barges	50 % barge and train, 50 % trucks	Trucks	Trucks (mainly 11-12 tonnes bogie trucks)	Ship and trucks (mainly tridem trucks)	30 % vessel and 70 % lorries
Transhipment	Crane, conveyor bridge	Crane	Belt conveyor	-	Wheel loader and excavator	Dumper truck to crushing station, belt conveyor to vessel
Quantity	7.4 Mtonnes	-	3 Mm3	4.5 Mtonnes	11 Mm3	9.2 Mm3

Excavation Rate	1 Mtonnes/year, 4000 tonnes/day	1300 tonnes/week (barge transport twice a week).	-	300 000 shipments of mass in total performed by lorry.	2000 tonnes/shipment by vessel.	1300-2000 tonnes/shipment.
Length of Transport	Intermodal transport: 500-1000 metres	-	-	-	Ship transport: 200 kilometres.	-
Geographical Context	Urban area, trafficked roads, waterways close (<1000 metres).	Urban area, waterways close (<1000 metres).	Partly dense urban area, waterways close (<1000 metres).	Dense urban area, close to waterways.	Rural area, waterways relatively close.	Partly urban area, World Heritage, Waterways close.

In the cases were barges have been turned down, the reasons normally referred to have been cost and feasibility. In the case of Citytunneln in Malmö, transport with barges was discussed early on in the project (Malmö Stad, 2013). The reason why barges never were seen as a realistic option was the transshipment difficulties and that it would be an uneconomical transport solution[1]. In the project of Citybanan in Stockholm Trafikverket (2009) argues that barge transport is costly, time consuming, and that it would further on result in negative environmental impact. However Moback's and Josefsson's opinion is that the main reason to why barge transport was turned down in the Stockholm case was the predicted issues related to the transhipments[2] [3]. Instead, both projects resulted in increased congestion in the city centres due to the use of lorries. When asking for further investigations of the alternatives, none of the cases investigated are able to show quantitative data that supports the choice of excluding barge as an alternative to conventional transports, and the reasoning has mainly been qualitative.

In the cases where barges are used for the mass transport, the authorities have often demanded it in an early stage in the process, such in the case of the construction of the Olympic Park in London and in Förbifart Stockholm. In London, the Olympic Delivery Authority demanded that 50% of construction materials had to be transported via sustainable means, namely rail and water (Olympic Delivery Authority, 2011). In Förbifart Stockholm a limited road network in combination with that trucks had to pass the world heritage Drottningholm Palace, the authorities made a demand on alternative transport modes (Trafikverket, 2011). However, for the mass transports in the projects of BanaVäg I Väst, cost reductions was the main reason to why choosing vessel for the transport of contaminated mass[4], as the average costs for truck was 2-5 SEK/tkm and for the vessel only 0.4 SEK/tkm.

All cases where barges have been used show creative and feasible solutions of transhipment and storage. It has also been shown that rock and clay are suitable types of mass to transport on barges and trucks. It is however hard to make any general conclusions on what type of

[1] Klas Nydahl (Senior Advisor, Malmö Stad Gatukontoret) interviewed via phone October 3, 2013.
[2] Fredrick Moback (Environmental and Technical Manager Citybanan, Trafikverket) interviewed via phone October 9, 2013.
[3] Anna-Sara Josefsson (Environmental Coordinator Citybanan, Trafikverket) e-mail conversation with the authors October 17, 2013.

[4] Jesper Mårtensson (HMSQ Manager BanaVäg i Väst, Trafikverket) interviewed October 15, 2013.

vehicles and construction machines that have been most successful, as each location implies specific conditions. When it comes to the use of barges for contaminated mass, it is seen that vessels are sometimes regarded non-feasible, as in the case of the Olympic Park in London, where hazardous waste was instead transported by truck (Olympic Delivery Authority, 2011). In the case of BanaVäg i Väst, contaminated mass was instead the only type of mass transported by vessel[5]. No general conclusions of the use of barges for contaminated and hazardous mass can thus be made, and a need to investigate the effects and risks of using barges need to be compared to the risk if conventional transport chains in the transport choice.

Another aspect of the cases is the urban context, which implies that more stakeholders are affected by noise, dust, visual intrusion and safety risks. Conveyors have been one issue discussed to avoid heavy trafficked areas and in the case Portsdamer Platz, a conveyor bridge was used to load the barge (OECD, 1997). However, in the project of Citybanan in Stockholm, the non-feasible conveyors were instead one of the reasons to why the barge alternative was turned down[6]. The rock that was transported could not be crushed in the tunnel, due to working conditions for the staff, why the conveyor could not be used. The alternative of using trucks for the transhipment was instead regarded too expensive. In the same project, noise, dust and visual intrusion were other reasons why barges were not used. However it is shown in Förbifart Stockholm that covered conveyors and noise-dampening cones used when loading the vessels could reduce these problems (Trafikverket, 2011).

The urban context also results in scarce storage space. Intermediate storage areas were needed in many of the cases investigated, and it was important to make an efficient transport flow. For the mass transport from the Olympic Park in London, temporary storage areas were set up to allow an efficient transport flow and to make it easier for the operators to forecast and organize the transport (Olympic Delivery Authority, 2011). In Förbifart Stockholm, the intermediate storage was regarded important to decouple the production from the transport, and to avoid the vessel to be a bottleneck (Trafikverket, 2011). The same reasoning was identified in the project of BanaVäg i Väst, however the storage used was too small, and when the vessel was out unloading, the storage filled up quickly and became a bottleneck in the project[7]. Mårtensson, who was HMSQ manager (responsible for health, environment, safety and quality) for the project also stated that the most important aspects to consider regarding mass handling in large construction projects are the location fo origin of mass, the destination of mass, the volume of mass, the quality of mass and the time aspect. Figure 7 shows the loading process in BanaVäg i Väst.

Figure 7. Loading of Vessel in BanaVäg i Väst (Trafikverket, 2013b)

[5] IBID

[6] Fredrick Moback (Environmental and Technical Manager Citybanan, Trafikverket) interviewed via phone October 9, 2013.

[7] Jesper Mårtensson (HMSQ Manager BanaVäg i Väst, Trafikverket) interviewed October 15, 2013.

In conclusion, barge seems to be a feasible alternative to conventional transport solutions and has been used in similar cases to the one studied in this thesis. The scarce space in the urban context however implies difficulties for finding necessary areas for storage. Also, stakeholders need to be taken into account, as the effects of noise, dust, visual intrusion, and safety are important aspects when evaluating the use of barges. Even though the cases where barges have been turned town argue that barges are expensive and transhipments non-feasible, it has been shown that this is not always the case. The four cases where barges have been used instead show that barges can surely be a sustainable, feasible and cost-efficient alternative to conventional transports.

5 Case Study – Västlänken

This chapter presents the case study of Västlänken and makes it possible to answer the two research questions in the upcoming chapters. First, the conditions and time frame for the project of Västlänken are described. Second the process of the transport decision for the excavated mass for the project is identified. In order to make a transport recommendation, the type of mass, the landfill positions and the conditions at each shaft investigated are also described. Finally, the rules and legislation for different modes of transport in the area are presented followed by an identification of the most important stakeholders that are affected by the transport decision.

5.1 Västlänken

An important part of the modernization of the infrastructure of Gothenburg is the planned train tunnel that will run under the city centre. The tunnel is planned to have three stops strategically placed at the Central Station, in Haga, and at Korsvägen, that will provide commuters with easy access to the city of Gothenburg, see Figure 8. In total, 34 000 people are living less than ten minutes from the stations (Trafikverket, 2013a), 100 000 inhabitants will have walking or biking distance to a station and 130 000 people are working or studying close by the new stations (Göteborgs Stad, 2013a). This will make it easier for more people to live outside the city and commute to work and it also prepares for the yearly increase of population in Gothenburg of 1.3% (SCB, 2013). The city of Gothenburg is undergoing steady growth and congestion in the city centre is a rising problem. The planned train tunnel would lead to less private cars in the city centre and at the same time simplify commuting to and from the city.

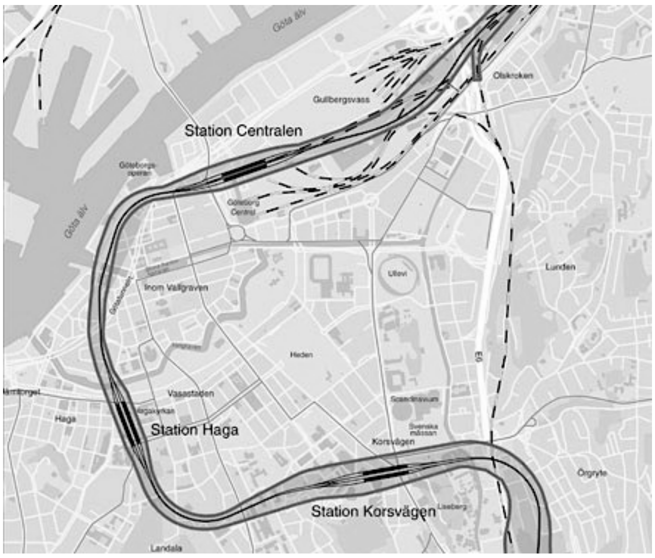

Figure 8. Route of Västlänken (Trafikverket, 2013b)

The project is budgeted at a total of SEK 20 billion and is currently in its planning phase. In 2014, the detailed plan of how to construct the tunnel will take place and in 2018 the actual construction work is planned to start. The construction work will run for ten years and is planned at SEK 13 billion (Trafikverket, 2013a). The project of Västlänken is large and complex, as both state and municipality are involved in the planning and execution. Trafikverket is responsible for a railway plan for the project and Göteborgs Stad develops local plans for the stations and the city development in the areas.

The tunnel will be six kilometres long, of what around four kilometres will run through rock and two kilometres through clay. The construction of the tunnel will result in a large amount of excavated mass; some of what is going back to the area, and some of what will be used as landfill in other areas. The movement of excavated mass will lead to increased transport in the already congested city centre of Gothenburg. The shafts from where the mass will be transported are located in central areas, with little space and residents and enterprises close by. The work of finding a transport solution that makes as little harm as possible to the people living and working in the areas, as well as historical and cultural values of the city, is thus challenging. This is also why alternative modes of transport, that will simplify and provide a more sustainable alternative to the conventional truck transport is needed.

5.2 The transport decision for excavated mass

An efficient transport system that can remove and dispose the mass in a sustainable way is needed. In order to understand on what grounds the transport decision of excavated mass is made, the extensive planning process of the railway tunnel is presented.

When introducing a new railway system, an extensive planning takes place. The process is dependent on the *Law of building railway and roads* and the *Swedish Environmental Legislation* (Göteborgs Stad, 2013a). The construction and the transport system should make as little to inhabitants, the environment and still fulfil the goals of the roads and railway plan.

First, a pre-study is executed where Trafikverket identifies and analyses possible solutions. In this stage, a public dialogue with stakeholders is needed. For Västlänken, this was performed in 2002. Second, a road and railway investigation is performed. Trafikverket tests, analyses and evaluates the chosen solutions. A description of the consequences for the environment, an MKB, is performed after which the solution needs acceptance from the government. Trafikverket performed the road and railway investigation for Västlänken in 2007 and provided three different solutions that were evaluated. The MKB will however not be finished until 2014. Third, the work- and railway plan is performed. At this stage, Trafikverket decides on the final distance and execution, and what areas and buildings that will be affected by the construction work. A cohesive dialogue and consultation with stakeholders, municipalities, and authorities is important. When the plan is prescribed, the plan can still be appealed for a certain period of time and not until this time has passed, the actual construction work can take place. This is the stage at which Västlänken is today. Trafikverket also have a dialogue with Göteborgs Stad that is developing the local plans for the area[8].

Fourth, a final construction document and the technical documents of the building together with an environmental management plan are developed. When the final documents are

[8] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013.

finished, Trafikverket releases a tender for contractors. In the tender, Trafikverket puts demands and specifications that the contractor needs to fulfil. In the Västlänken project, this is planned for 2015 for the preparatory work, and in 2016 for the construction work. The six kilometres of tunnel will be divided into separate parts, for which different contractors are responsible. Most of the construction parts will require turnkey contractors, where the contractor is responsible for the technical planning, subcontractors and finalization of the project. The turnkey contractor is thus responsible for the procurement of transport, which will impact the choice of transport operator for the excavated mass. However, the type of transport will be specified in the tender and thus decided by Trafikverket[9].

5.3 Investigated Shafts

The three shafts investigated in this thesis are located in the city centre of Gothenburg; two at Rosenlund and one at Skeppsbron, as illustrated in Figure 9. Shaft 1 is planned to be an open shaft, while Shaft 2 and Shaft 3 are planned working tunnels leading in to the main train tunnel. The three shafts examined are all located close to water, why using the waterways for the mass transportation is interesting to investigate.

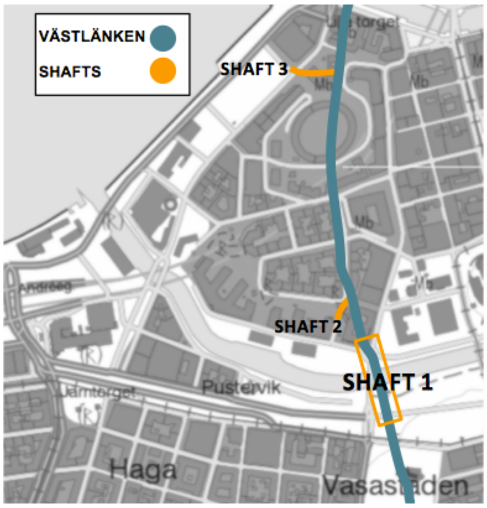

Figure 9. The three shafts investigated.

In order to evaluate if the urban waterways are possible to use, the limitations at the canals need to be investigated. Shaft 1 and Shaft 2 in Rosenlund, are both situated in direct connection with the smaller canal, Vallgraven, that surrounds the city centre of Gothenburg. The closest docking point for a barge transporting the mass from these two shafts would be at Fisketorget. The section of the canal that runs from Fisketorget to Göta älv is presented in Appendix 1. The main issue is that one of the bridges is only 1.5 meters in height. The water depth in this section of the canal varies between 2.9 – 3.9 metres at mean depth of water level and the minimum width is 10.5 metres (VBB Anläggning, 1996). During high tide however the water level increase with approximately 1 meter (Stadsbyggnadskontoret, 2009) and passing under bridges might be hard. Shaft 3 is located close to Skeppsbrokajen with a water

[9] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.

depth of approximately 8.5 meters and with no bridge clearance or width limits in need to consider for barge transport (Port of Gothenburg, 2012). The traffic situation on the river is also limited, and the only potential disturbances would be the shuttle vessels in the area, but if only passing a couple of times each day, this is not regarded a problem[10].

The different shafts consist of different type of mass and also differ in characteristics such as geographical conditions, which will affect the transport decision for the excavated mass. The characteristics of each shaft are presented in Table 4.

Table 4. Characteristics of Shaft 1, Shaft 2 and Shaft 3.

	Shaft 1	Shaft 2	Shaft 3	Reference
Area	Rosenlund	Rosenlund	Skeppsbron	
Type of mass	Gault / CLAY	Granite / ROCK	Granite /ROCK	Trafikverket[11]
Type of excavation	Cut-and-Cover	Drill and Blast	Drill and Blast	Trafikverket[12]
Excavation Rate	300-1000 m3/day	500m3/day	500m3/day	COWI[12]
Total Weight	400 000 tonnes	135 000 tonnes	170 000 tonnes	COWI[13]
Excavation Volume	250 000 m3	50 000m3	65 000 m3	COWI[13]
Contaminated mass	14 000 m3			COWI[13]
Fraction Size		Crushed in tunnel: 0-150mm	Crushed in tunnel: 0-150mm	Trafikverket[12]
Distance to water	300m	300m	120m	Trafikverket[12]
Time for Excavation	2018-2021	2017-2019	2017-2019	Trafikverket[12]
Other aspects	Aqueduct	Working Tunnel	Working Tunnel	Trafikverket[12]

5.3.1 Simultaneous projects in the area of the shafts

Shaft 1 and Shaft 2 are located close to residents and business in the Rosenlund area. The area also holds historical and cultural values. In 2012, Göteborgs Stad, the local trade association Innerstaden Göteborg and property owners invested in a restoring project to make the area safer and more attractive (Göteborgs Stad, 2013b) and in total SEK 50 millions were invested. The feedback on the project has been positive[13, 14] and Wallenstam plans to continue the work.

[10] Emma Hellström (Pilot Planning Manager, Port of Gothenburg) e-mail conversation, October 23, 2013.
[11] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[12] John-Erik Fredriksson (Construction and Project Manager, COWI) interviewed October 16, 2013.

[13] Peder Wahlgren (Sales Manager, Wallenstam) interviewed October 25, 2013.
[14] Roger Wilhelmsson (Responsible for Logistics and Infrastructure, Innerstaden Göteborg) interviewed October 25, 2013.

Having construction sites at this area for many years would risk creating conflict of interest.

Shaft 3 is located at the area called Skeppsbron, and will correlate with a numbers of projects. Previously, this area has been symbolized by heavy traffic but after Götatunneln was completed in 2006 the traffic was reduced. Göteborgs Stad's planning office now has expansive plans for the area in order to re-unite the city with the river, the proposal involves construction of 400 new apartments as well as 30 000 m^2 for office and retail (Söderberg, 2012). Furthermore the plan is to make the waterfront more attractive by building piers. The plan was approved by the city's building committee in 2013, the final decision will however be conducted by the city council. If the plan is approved the construction of Skeppsbron will most likely take place simultaneously as the construction of Västlänken[15].

5.3.2 Landfill locations – point of destination

A serious effort is put on finding areas for re-use and landfill of the excavated mass. As the project of Västlänken still is in planning phase, is it not determined what area of landfill that will get dedicated to the mass, however the most probable destinations are Frihamnen and Port of Gothenburg. In order to avoid disturbance of the market competition between contractors and operators, Trafikverket will specify where the excavated mass should be transported. However in this thesis, the point of destinations are assumed to Frihamnen and Port of Gothenburg. At Frihamnen, the vision is to create a new dense city district and connect Kvillestaden, Backaplan, Lindholmen and Ringön[16]. A first expansion phase of Frihamnen is planned for 2021, and the entire development is planned to take place between 2020 and 2030[17]. The illustration in Figure 10 shows a plan on how the area could possibly develop. The plan would require 1.2Mm^3 of mass, as the ground will be raised to a level of 3.5 meters to meet the rising sea level. This is more than a third of the mass resulting from Västlänken.

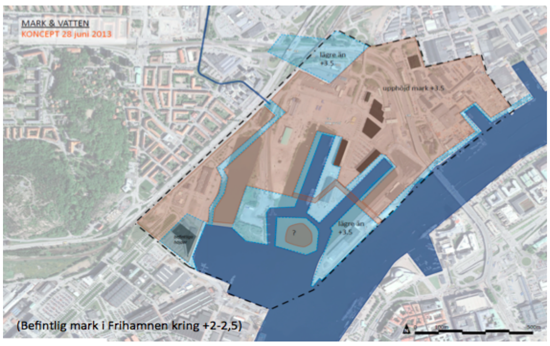

Figure 10. Future Scenario of Frihamnen. (Stadsbyggnadskontoret, 2013)

The other position investigated is Port of Gothenburg, as plans of landfill of Risholmen in connection with the construction of Västlänken are official (Göteborgs Hamn, 2013). How much mass that is needed is not known, but an assumption that all mass from the three shafts investigated is to be used is made in this thesis.

[15] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013
[16] Hanna Areslätt (Project Manager and Planning Architect, Stadsbyggnadskontoret) interviewed October 22, 2013.
[17] IBID

5.4 Rules and legislation

Transportation of people and goods greatly affects the environment and the carbon emissions resulting from road transport contributes to global warming (Transportstyrelsen, 2013). The effects of freight transport are hard to reduce solely through national law, and instead international forums such as the UN agency UN-ECE are used to improve international laws and regulations regarding the effects of transport. On a national level, the work mainly consists of the implementation of international laws and regulations through the undertaking of projects with the purpose of reducing the emissions and noise from the national freight transport.

In the Gothenburg area, it is the environmental zone located in the central part of the city that mainly affects the transport choice. The environmental zone covers an area of $15km^2$ (Trafikkontoret, 2006). The main goal when introducing the environmental zone was to reduce the local environment in terms of emissions, congestion and noise. The regulations include heavy vehicles, with a gross weight of 3.5 tonnes and the main rule is that heavy-duty, diesel-run vehicles over six years are not allowed. Vehicles with Euro 4 are allowed into environmental zones until 2016, and vehicles with Euro 5 are allowed to drive within environmental zones until 2020 (Transportstyrelsen, 2013). What is regulated is also the technology of engines and vehicles should be equipped with a compression ignition engine and not the type of fuel used.

5.4.1 Construction machinery

Regarding construction machinery, the affecting rules and legislation mainly regards type of engine and fuels used (Trafikverket, 2012a). As this case takes place in a dense urban area, the legal requirements are stricter than in rural areas. The common requirements for fuels were established in the EU year 2000 and set certain requirements regarding content such as level of sulphur. Finally, it will not be possible to use dump truck during the construction work, due to that the construction work will go on for several years[18]. It will hence not be possible to get a special permit to use dump truck. Special permits are only possible to apply within shorter construction projects.

5.4.2 Construction trucks

As mentioned above, what mainly affect the type of truck in central Gothenburg area is the rules within the environmental zone. Besides from the environmental zone there are limitations regarding time and emissions, however these limitations should not cause any problems according to Trafikverket[19]. Time restrictions are not an issue if the concstruction work only goes on between 7am to 22 pm. There are also length restrictions in central Gothenburg, as longer vehicles only are allowed to drive between 6am and 8am[20]. This restriction also includes the area of Rosenlund and Otterhällan at Shaft 3. In public procurements conducted after 2014, heavy vehicles should also meet the standards of Euro 5

[18] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.

[19] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.

[20] Christoffer Widegren (CW Logistik) e-mail conversation, 2013

or later (Trafikverket, 2012a). Finally, there are congestion fee in central Gothenburg that will also affect the cost of using construction trucks[21].

5.4.3 Vessels

Regarding the vessels investigated in this thesis, namely barges and the tugboats used to navigate them, there are several affecting rules and costs such as fairway dues, quayage, speed limits, tax, and emission limitations. However, as Västlänken is conducted in interest of the city of Gothenburg, it will most likely not be relevant with quayage or harbour fee when using the barge for mass transport[22]. Transportation classified as inland waterway transport generally implies reduced port and fairway charges as well as decreased insurance expenses compared to seagoing transportation[23]. Furthermore, there is no fairway charge for internal transportations within Västra Götaland[24]. Barge transport is moreover exempt from tax on diesel[25], although this might change if the proposed EU directive 2006/87/EC gets introduced before or during the construction work starts. Regarding emission limitations, the same rules apply to barges as to trucks in the urban environment[26]. For ships, the maximum level of emissions regarding sulphur is 0.1% when still, and when moving 1.0% for both the barge and the tug-boat within the Port of Gothenburg[27].

Another important aspect to consider is the International Ship and Port Facility Security (ISPS), a standard that is adopted by the International Maritime Organization (IMO) (Transportstyrelsen, 2013). IMO is governed by the United Nations, the rules thus apply in ports around the world and aims to create a safe transportation between ports for passengers and cargo. For this case, ISPS implies that if the vessel is manned, supervision by guards will be required[28]. However, when the barge in this case unloads, this will not be a problem, as no berthage in an actual harbour is used. Carlbergs, one of the barge operators interviewed hence do not believe that supervision by guards will be necessary in this case[29].

Within the area of Port of Gothenburg, a maximum speed of eight knots is allowed. This applies within the port's area, hence from its western border at Älvsborgs fortress to the lighthouse Skeppsbron. For vessels below the length of twelve metres, a maximum speed of twelve knots are allowed within the same area. (Sjöfartsverket, 2013)

5.5 Stakeholders

The most important stakeholders when deciding on what transport mode to be used for the excavated mass have been identified and are described in this section. In accordance with the definition of stakeholders in the theoretical chapter, the five most relevant groups of

[21] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[22] Jörgen Wallroth (Port Captain, Port of Gothenburg) interviewed via phone November 7, 2013.
[23] Bertil Arvidsson (Senior Advisor, BACAB) interviewed October 14, 2013.
[24] IBID
[25] Thomas Fritsson (Site Manager, Carlbergs) interviewed November 7, 2013.
[26] Roy Jaan (Project Manager, Sjöfartsverket) interviewed October 11, 2013.
[27] Klas Ljungmark (Marine Engineer, Transportstyrelsen) e-mail conversation.
[28] Lennart Sandinge (Owner, Sandinge Bogsering och Sjötransport) interviewed October 29, 2013.
[29] Peter Burman (CEO, Carlbergs) interviewed November 7, 2013.

stakeholders that will be described are: shippers, transport operators, receivers, public authorities and residents. The main interest of each stakeholder is summarised in Table 5. First, each stakeholder's role in the project is presented, followed the main issues identified for each stakeholder. Last, the stakeholder's opinion on the barge alternative is presented. In general, most stakeholders do have opinions on the transport decision and are all affected by it. The main issues for each stakeholder differ noticeably, and conflicts of interest are likely to emerge when different opinions should be merged to one solution.

Overall, a majority of the stakeholders are positive to the usage of urban waterways. New models of barges can easily be hired if needed and the type of mass excavated does not seem to bring any major problems[30]. An introduction of barge transport might also have effects on the urban transport market in general and even though many transport operators are not directly affected by the transport decision, an introduction of barges will force them to decide how the new market situation should be handled[31].

Table 5. The main stakeholders' main interests and issues in context of Västlänken.

STAKEHOLDER	
SHIPPERS	
Identified stakeholder	The contractor orders the transport of excavated mass, however Trafikverket decides on how the transport should be executed and where the mass should be transported.
Main interest	The tender and transport decision should be fair to the market competition[32]. On-time deliveries and the cost aspect are crucial[33 34 35]. The cost for the transport solution represent 40-70% of the total cost for the excavation, which gives the transport buying decision high priority[36].
Main issues	Transport demands in the tender should not be too detailed, as the most suitable transport alternatives must be possible to use.
Opinion on barge	Usage of barge is not seen as a problem. The contractor might get indirectly affected if their own haulage companies/partners not can provide vessels – new transport relations may be needed[37].
TRANSPORT OPERATORS	
Identified stakeholder in this case	Performs the actual transport. In this case truck operators, construction machine operators and vessel operators.
Main interest	Great interest in the choice of transport mode made by Trafikverket, as it will result in more or less business. Opportunities for small operators[38], fair competition needed.

[30] Lennart Sandinge (Owner, Sandinge Bogsering och Sjötransport) interviewed October 29, 2013.
[31] Ulf Hammarberg (Environmental Affairs, DHL) interviewed October 24, 2013.
[32] Markus Evans (EHSQ Coordinator, PEAB) interviewed October 18, 2013.
[33] IBID
[34] Thomas Fritsson (Site Manager, Carlbergs) interviewed November 7, 2013.
[35] Bengt Johansson (AO Manager, GLC) participated in seminar October 4, 2013.
[36] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[37] Markus Evans (EHSQ Coordinator, PEAB) interviewed October 18, 2013.
[38] Peter Burman (CEO, Carlbergs) interviewed November 7, 2013.

Main issues	The contractors usually have their own transport operator partners. This can be an issue if another mode of transport than conventional is required in the tender. Hence, new transport relations might be needed.
Opinion on barge	The truck operators are promoting conventional transport solutions referring to price, flexibility and less risk, whereas the vessel operators on the other hand promotes the use of barges referring to price, sustainability and safety. The operators regard both modes of transport as feasible.
RECEIVERS	
Identified stakeholder in this case	The receiver is assumed to be Göteborgs Stad, even though no such plans are determined in the time of writing.
Main interest	Time of delivery, deliveries of the right type and fraction of mass. For example it may be important that the deliveries of rock are made before the deliveries of clay.
Main issues	-
Opinion on barge	Göteborgs Stad does not see any problems with using barge transport. Possibilities for benefited cityscape and decreased congestion is in favour of the planned apartment buildings in the area of Frihamnen, as it would benefit the wellbeing of the residents and the visual intrusion in the area while the construction is on-going[39].
PUBLIC AUTHORITIES (LOCAL AND NATIONAL GOVERNMENT)	
Identified stakeholder	The project owners, with the power to specify what mode of transport that will be used and where to direct the transports. Public authorities furthermore regulate under what conditions the transport can be performed, regarding for example noise, emission levels, and time zones. The primary authorities involved at this stage are Göteborgs Stad together with Trafikverket, their areas of responsibility are different but cooperation between the two is seen as crucial from both sides[40 41].
Main interest	Create a transport solution that is seen to be sustainable both from an economic and environmental perspective, and at the same time cause as little inconvenience for the inhabitants and businesses as possible. Important with coordination between functions and projects[42 43].
Main issues	Coordination issues between the different public authorities and various contemporary projects in the city, such as Rosenlund. The various organs are often in different stages of the planning process, which may result in duplication of work and lack of knowledge[44 45].
Opinion on barge	Positive to the use of IWW, as this could be one way to promote Gothenburg as a city with a vivid waterfront[46 47].

[39] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013.
[40] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[41] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013.
[42] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[43] Josefin Larking (Manager Mobility Management Västlänken, Trafikverket) interviewed November 5, 2013.
[44] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013.
[45] Josefin Larking (Manager Mobility Management Västlänken, Trafikverket) interviewed November 5, 2013.
[46] Karin Holmström (Project Manager Västlänken, Stadsbyggnadskontoret) interviewed October 11, 2013.
[47] Hanna Areslätt (Project Manager and Planning Architect, Stadsbyggnadskontoret) interviewed October 22, 2013.

RESIDENTS	
Identified stakeholder	In this case, the residents are represented by the local trade association in Gothenburg's city centre, Innerstaden Göteborg, and the property owner Wallenstam[48] [49].
Main interest	The transport should cause as little inconvenience as possible. Minimize noise, dust, and visual intrusion. The transport solution must ensure that the inhabitants can move freely in order to guarantee normal flows. Limit the mass transport to certain times of day when less people move in the area. Requests a better dialogue with Göteborgs Stad and Trafikverket[48] [49].
Main issues	Mass transport may harm the up-and-coming Rosenlund's development, and increased leveles of dust and noise may complicate the property owner's ability to lease their space and furthermore make the area less attractive. Heavy vehicles should avoid Rosenlundsgatan and instead reach E45 via Nya Allén[48] [49].
Opinion on barge	Very positive to the usage of barge, as it can decrease the transport flow in the area and open up for the possibility of making the canal navigable in the future[48] [49].

[48] Peder Wahlgren (Sales Manager, Wallenstam) interviewed October 25, 2013.
[49] Roger Wilhelmsson (Responsible for Logistics and Infrastructure, Innerstaden Göteborg) interviewed October 25, 2013.

6 Suggested Transport Chain

In this chapter, the reader will gain a technical understanding of the vehicles, construction machines and vessels used as references in this thesis. Second, the different routes from each shaft and for each transport chain are explained. This chapter makes it possible to answer the first research question.

6.1 Technical conditions for transport chain

Two types of transport chains have been identified and evaluated. First, a conventional transport chain where a truck is loaded at the shaft and unloaded at the final destination, see Figure 11 is investigated. Second, a barge transport chain where transhipment is needed at a node between the shaft and the final destination is investigated. Suitable construction machines, vehicles and vessels have been identified and combined in different transport chains. The choice of machines has been conducted in cooperation with specialists in the different areas of transport technology and is described in further detail in this section. First, the main mode of transport is presented and the different aspects of barge and truck are described. Second, the importance of transhipments is stressed and different alternatives for loading and unloading are presented.

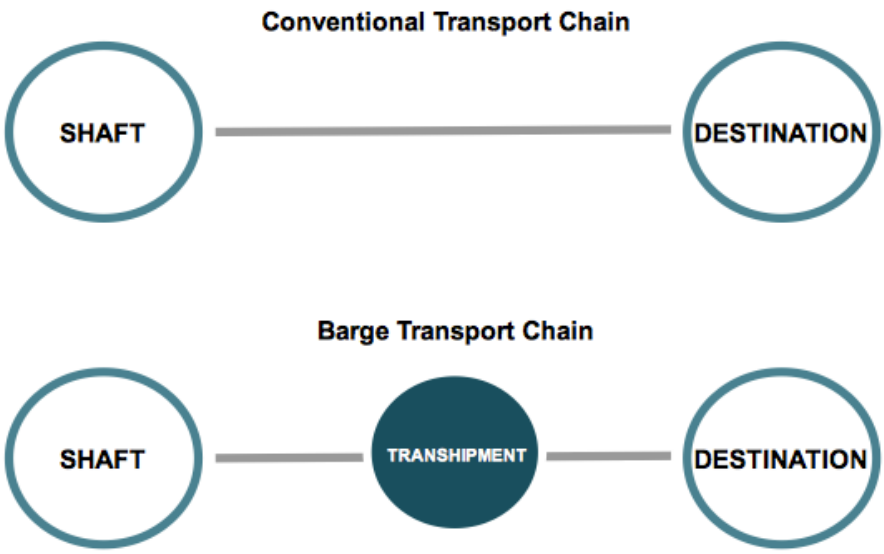

Figure 11. Identified transport chains.

6.1.1 The main mode of transport – construction truck or barge?

The industry has great experience and knowledge of conventional transport chains and construction truck is the conventional solution used for inbound and outbound deliveries to and from construction sites[50]. Different types of vehicles have been examined both in

[50] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.

academia and by executers and the construction truck has proved high level of service, owing to the extended infrastructural road network, which enables flexibility of route choice and door-to-door solutions[51]. Furthermore, many operators, fierce competition, and market pricing characterize the market of road-transport. However, road-transport also has the disadvantages of high-energy consumption, congestion, noise, road accidents, and the requirement of land use.

The choice of construction trucks used for the suggested transport chain is conducted in cooperation with Volvo Technology. Two vehicles are suggested, Truck 1 and Truck 2, and are described in Table 6. For the excavated mass, the weight will be the limiting factor of the capacity, why the volume of the trucks is not of importance. The size of the trucks is similar to the one used in the construction of Citybanan in Stockholm and are both seen as probable trucks in this environment[52,53]. A larger truck with a trailer would result in less congestion, fuel consumption per tonnes, noise and cost, as fewer trips would be necessary[54]. In the dense areas of Gothenburg, the size of the construction trucks is however limited due to lack of space where the construction takes place. Thus, a larger truck combination than the ones chosen are not likely to be used[55,56,57].

Table 6. Vehicle data. (Mean speeds are assumed)

VEHICLES	Truck 1	Truck 2
Model	FMX 6X4	FMX 8X4
Maximum loading weight [tonnes]	12.2	16.5
Fuel consumption empty [l/100km]	25.1	27.1
Fuel consumption full [l/100km]	28.1	31.2
Mean speed for short distances in dense urban environment [km/h]	7	7
Mean speed for longer distances travelling on larger urban roads [km/h]	35	35

In order to find an alternative to the conventional transport chain that would benefit the sustainability in Gothenburg when handling the large amount of mass resulting from Västlänken, the barge alternative is investigated. The vessels used for operating inland waterways are usually not constructed for large oceans and a variety of barges are commonly used (BVB, 2009). A barge is a vessel with a flat keel and is either equipped with its own machinery or needs a tugboat to run. The tugboat is used to tug or push the barge and since the propulsion machinery together with the operating unit accounts for 75-80% of the cost of modern vessels, barges with own propulsion tie up substantially more capital than those with external tugboats (Lumsden, 2012).

Barge transport is suitable for bulk goods such as ores, coal, sand, gravel, and construction materials (Vierth et al., 2012; Konings, 2009) and combines a high transport capacity with low operating cost. Barge is competitive compared to trucks at high frequency and high

[51] Dan Andersson (Senior Lecturer, Chalmers). Lecture in Transport Systems October 31, 2012.
[52] Jesper Mårtensson (HMSQ Manager BanaVäg i Väst, Trafikverket) interviewed October 15, 2013.
[53] Ola Gunnarsson, (Project Development Manager, PEAB). interviewed , October 18, 2013.
[54] Lennart Cider (Project Manager, Volvo Technology). e-mail conversation, 2013.
[55] Ola Gunnarsson, (Project Development Manager, PEAB). interviewed , October 18, 2013.
[56] Markus Evans (EHSQ Coordinator, PEAB) interviewed October 18, 2013.
[57] Per-Inge Söderström, Trafikverket, interviewed October 31, 2013.

loading capacity (Konings, 2009). It is also becoming more competitive when legislations such as lorry traffic bans, regulatory restriction, road toll-systems and increased diesel fuel prices are introduced (Lowe, 2005). On the Swedish transport market, there are very few barge operators available[58], and barge transport is not being used to its full potential[59]. In Central Europe, however, barge transport is much more common and as the directive 2006/87/EC is implemented in Sweden, the barge specialist Arvidsson[60] thinks that the inland waterway market will be more attractive for larger European barge operators. According to both Sjöfartsverket[61] and Arvidsson there are available barges on the European market suitable for mass transportation from Västlänken from all three shafts presented earlier. The possibility of constructing a new barge optimised for the Gothenburg context is also emphasized[62] [63].

Three different barges have been identified in cooperation with three Swedish barge operators, and the barges are referred to as OP1, OP2, and OP3. All operators have performed similar transport assignments with similar type of mass before, and also have experience from performing landfill in docks and harbours. All three barges manage to operate within Göta Älv's limitations and are able to dock at Skeppsbron, however none of them is suitable to use in Vallgraven, close to Shaft 1 and Shaft 2, as the bridge clearance height and water depth is too limited. Thus, transhipment from the three shafts to a barge docked at Skeppsbron will be necessary. Also, as other barge alternatives might be available on the transport market, a theoretical barge adapted to fit in the canal at Shaft 1 and Shaft 2 has been identified after discussions with Björn Södahl and is also used as a reference. This gives a direction on how different barge alternatives affect the fuel consumption and efficiency of the transport chain. For all three barges, the weight of the mass is the limiting fill factor, why the volume loading capacity is not of importance. The four barges, including the non-existing theoretical barge are described in Table 7 and presented in Figure 12.

Table 7. Barge data

BARGES				
	OP1	OP2	OP3	Theoretical
Maximum loading weight [tonnes]	4500	150	1400	290
Maximum draft [m]	4.1	2.0	3.5	2.5
Propulsion method	Tugboat	Tugboat	Self propelled	Pushboat
Speed [knots]	4	4	7.5	4
Fuel consumption [l/h]	80	30	526	30

All barges can be loaded using belt conveyor, wheel loader, or excavator. The unloading processes on the other hand differ for the various barges. The unloading from OP1 is performed directly from the barge by using wheel loader that enters through an integrated ramp. OP2 and the theoretical barge are equipped with hatches in the hull that are opened to

[58] Fredrik Moback (Environmental and Technical Manager, Trafikverket) interviewed via phone October 9, 2013.
[59] Bertil Arvidsson (Senior Advisor, BACAB) interviewed October 14, 2013.
[60] IBID
[61] Roy Jaan (Project Manager, Sjöfartsverket) interviewed October 11, 2013.
[62] Björn Södahl (Research Coordinator Shipping and Maritime Technology, Chalmers) interviewed October 23, 2013.
[63] Roy Jaan (Project Manager, Sjöfartsverket) interviewed October 11, 2013.

unload the mass. OP3 is equipped with an inbuilt belt conveyor situated underneath the loading space, which the mass is released to through hatches in the bottom of the cargo hold and the mass is then unloaded in the barge's fore.

The tugboats, used for OP1 and OP2, are both staffed with one helmsman and three seamen, however no staff is required while the barges are docked. OP3 has the same staff requirements; the theoretical barge on the other hand would only require one helmsman and one seaman, in accordance with the new directive 2006/87/EC[64].

Figure 12. Barge from OP1 (upper-left corner), Barge from OP2 (bottom), and Barge from OP3 (upper-right corner).

6.1.2 Transhipments – construction machines or belt conveyor?

A main issue in a transport chain is the transhipments; both regarding cost, sustainability and space[65]. Excavators and wheel loaders that loads and unloads the truck usually perform the transhipment of excavated mass. How many construction machines and vehicles that are needed and what size they should have depends on the mass characteristics, shaft conditions, conditions of the mass, transport distance, type of roads, road restrictions and destination conditions (Granhage, 2009). However, in the case investigated in this thesis, the loading and

[64] Björn Södahl (Research Coordinator Shipping and Maritime Technology, Chalmers) interviewed October 23, 2013.
[65] Volvo Group Trucks Technology, meeting with Anders Berger (Product area manager) et al. (see Appendix 8), November 14, 2013

unloading of vessels implies other conditions for the transhipment of excavated mass.

The way the transhipment from ships is handled differs, depending on quay facilities and type of mass. A crane, a wheel loader, or a belt conveyor is usually used to tranship dry bulk material (BVB, 2013), such as the excavated earth. A truck can also drop the mass directly onto the ship from a tilting pier. Some inland navigation vessels have their own loading and unloading systems on-board the ship. This however takes up a lot of space and weight, and is not as common. When unloading the ship, similar methods are normally used. However, in this thesis, the mass will be unloaded into water, which makes it possible to use the self-unloading barges with hatches in the hull described earlier.

In order to compare different transport solutions, some typical construction machines and vehicles that are normally used for transhipments have been identified. The most conventional construction machines are the wheel loader, excavator, and dump truck. For areas where this is not possible, due to incline or rough country where temporary roads are hard to use, belt conveyors can be a suitable alternative to move the mass to the barge or truck. The construction truck described earlier is also used for transhipment from the shaft to the barge. Suitable transport machines and vehicle models have been determined in collaboration with Volvo Construction Equipment, Swecon, Volvo Technology, and Kellve. First, the wheel loaders and excavator used as references in this thesis are described in Table 8.

Table 8. Construction machine data (Volvo Construction Equipment, 2009).

CONSTRUCTION MACHINES			
	WL Clay	**WL Rock**	**Excavator**
Model	Volvo L90F	Volvo L90F	Belted Volvo EC160C
Bucket capacity [m3]	2.7	2.2	0.21
Fill rate [%]	110	80	110
Fuel consumption [l/h]	9	13	10
Other	Small platform, suitable for operations in narrow areas and on barges.		A general-purpose-boom of 4.6 metres.

When using this wheel loader in combination with the construction trucks, the larger truck takes 4 scopes to fill and the smaller one 3 scopes to fill. This is however not optimized, and more research is needed in order to find the most efficient bucket size, even though 3-5 scopes is in the range for an ideal flow[66].

Second, the dump truck Volvo A25F is used as a reference. The dump truck is one of the most common machines used for excavation (Herbert and Day, 2005) and is used for transport of construction mass from shafts. Dump trucks are allowed to drive on the road network, and can reach the speed of 50 kilometres per hour on well maintained roads. Volvo A25F has a maximum loading weight of 24 tonnes. The fuel consumption is highly dependent on the road specifics and varies between 15-25 litres per hour (Volvo Construction Equipment, 2009).

[66] Volvo Group Trucks Technology, meeting with Anders Berger (Product area manager) et al. (see Appendix 8), November 14, 2013.

Third, the totally enclosed 1-meter wide Kellve belt conveyor is used as a reference. This is a feasible belt to use, as it can take an 18 degrees incline and is suitable for 0 - 150 millimetres rock material. The incline implies a distance of 12.3 meters to reach a height of 4 meters, which is suitable when crossing a road. In dusty environments, enclosure of the material is needed (Kellve, 2013). The belt will have a width of 1.5 meter when assembled and will be electrically powered by a 30 kW engine. In general, the flexibility and mobility of belt conveyors is low, however it is not dependent on the road network and can be constructed above or underneath congested areas. The amount of mass transported on a belt conveyor depends on the width of the belt, the speed of the belt and the height to which it can be piled. When an increase in production is needed, the most economical way is usually to increase the power and speed, rather than having a wider band. A risk when using belt conveyor is that it runs for long periods without attention. If sudden accidents happen, the results can be costly if their results are not controlled. Also, if the power fails, the belt tends to run backward and the load will get jammed. This is also possible to prevent by locking the band from backsliding (Herbert and Day, 2005). The operator Jehander[67] considers belt conveyor as a safe transhipment method and the only identified safety risk is to drive into the belt conveyor if it is crossing a street.

The location of the transhipment will decide on space and storage possibilities. In the areas investigated in this thesis, the space available is scarce and space efficient methods need to be used. Also, the construction machines used for transhipment are used in an urban environment, which further implies restrictions on noise, vibrations and visual intrusion. The relation between loading equipment and the main mode of transport is important, and most often the transport system has an oversized transport equipment or an oversized loading equipment. The latter is the one to prefer, as it gives the loading unit time to do clean-up work at the site It is also time efficient, as the loading unit is ready with its first load when the transport unit returns empty loaded (Herbert and Day, 2005).

6.2 Transport distances

The transport chains investigated starts at the three chosen shafts and finish at the landfill positions identified at Port of Gothenburg and Frihamnen. Depending on what combination of transport modes that is used for the total transport chain, different routes are identified, as the road network differ from the distances on waterways and for belt conveyors. The route when using the road network is dependent on what roads and bridges that are feasible to use for heavy transport and what other projects that will affect the traffic situation at this time. The main issue is the simultaneous construction of the Central Station, why the road transport is assumed to cross Älvsborgsbron[68], the south bridge crossing the canal. The routes can be identified in Figure 13, and the different transport distances are found in Appendix 2.

[67] Ralf Hansson (Sales Manager, Sand & Grus AB Jehander) interviewed November 4, 2013.
[68] Josefin Larking (Manager Mobility Management Västlänken, Trafikverket) interviewed November 5, 2013.

Figure 13. Transport distances from shafts.

Starting with Shaft 1 when using truck most of the clay will be transported on Norra Allégatan, why this distance is used in the calculations. However, some clay may also be transported on Rosenlundsgatan, but this will not affect the distance noticeable. The truck route will then merge onto E45 and cross Älvsborgsbron, the south bridge crossing the canal. The route will then continue along Lundbyleden to reach Frihamnen. When the destination is Port of Gothenburg the truck will instead merge onto Torslandavägen, which further implies that the truck needs to travel through the Natura 2000 area Torsviken (Naturvårdsverket, 2013). For Shaft 2 the trucks are presumed to run on Rosenlundsgatan, merge onto E45 and then similar as for Shaft 1. For Shaft 3, the route will begin on the street Skeppsbron, and then continue along the same route as for Shaft 1 and 2.

When barge is used as the main mode of transport a belt conveyor or a truck will be used for the transhipments from the shafts. This adds a short distance but in total the sea way allows for shorter distances compared to truck, especially for the destination Frihamnen. Further on truck movement through Torsviken will not be necessary.

7 Results

In this chapter, the results for the feasibility study and the sustainability study are presented and results for both research questions are thus answered. The results are based on the theoretical framework, benchmarking of similar case studies, the case study of Västlänken, the technical framework, and calculations. First, the feasibility results of the first research question are presented and it is concluded what modes of transport that are feasible in the context of Västlänken. Second, the sustainability results for the second research question are presented. The fuel consumption, environmental impact, economical impact, and social impact of the suggested transport chains are described in order to do this.

7.1 Feasibility

Several feasible vehicles and vessels that are available on the Swedish market are identified and examined in this thesis. In addition, a theoretical barge solution is also examined. The different transport solutions are seen as more or less suitable from a feasibility perspective depending on geographical prerequisites, technology, rules and legislation. In this section, the results in the feasibility study are presented.

7.1.1 Complexity of urban freight transport

As stated in the introduction of this thesis, a well-functioning freight transport system is vital for a sustainable economy and society. The transport system can get divided into three layers, as illustrated in Figure 1 in the theoretical framework; a material flow, a transport network, and an infrastructure system (Lumsden, 2012). In this case, the material flow consists of the demand to transport excavated mass from three different shafts to Frihamnen and Port of Gothenburg. The transport network consists of the identified vehicles and vessels; construction trucks, barges, wheel loaders, excavators, belt conveyors and dump trucks that will be further described and analysed in this section. Finally, the infrastructure is a prerequisite for the transport network's existence and consists of all the facilities and equipment included in a road network, waterways, and harbours (Wandel et al, 1992).

7.1.2 Material flow

As stated throughout this thesis, a large amount of excavated mass need to be transported. The large material flow in combination with different requirements on transport for rock and clay, different transport solutions are more or less suitable.

When transporting rock with conventional modes of transport, the loading of the construction truck can either take place within the work tunnel, or just outside depending on area and elevation of the work tunnel. The technique for excavating rock is blasting, which implies that the mass gets divided into smaller pieces before loaded onto the vessel or vehicle. However, if the excavated mass instead were to be transported on a belt conveyor when loading a vessel there would be a need to crush the rock to a fraction of 0-150 mm before it gets loaded on the belt conveyor. The crushing of the rock is necessary no matter what destination the rock has, however the crushing does not necessarily have to take place before the transport if other methods are used for transhipments than belt conveyor. It can however be argued that the there are several other reasons for crushing the stone within the work tunnel, for example the loading can be done directly from the crusher and the noise emissions resulting from the crushing will be reduced as it takes place within the tunnel.

On the other hand, as stated in Chapter 4 one of the reasons for not choosing belt conveyor and barge in the case of Citybanan in Stockholm was that it was seen difficult to store the masses temporarily in connection to the site. Due to the noise and dust related to stone crushing, the Swedish Work Environment Authority also considered it impossible to crush the stone at the construction site. In Gothenburg, it is however not seen as a problem to crush the rock at the construction site. It would on the contrary be preferred to do it within the work tunnel as the noise emissions gets reduced. Furthermore, if the rock should get deposited into the water, as assumed in this thesis, the rock needs to be crushed before loading anyhow.

The transport of clay is more problematic than the transport of rock, as the mass is looser and harder to handle. The clay in Gothenburg, as described in Chapter 5, becomes less viscous the more it gets handled and transhipments and transportation hence results in more mud-like clay. This implies that the transport and handling gets more complicated. There has been an interest from different stakeholders such as Trafikverket and the City of Gothenburg to examine the possibilities to transport the mass on belt conveyors, however when interviewing geologists at Chalmers and stakeholders within the area of construction, it has been argued that it most likely is not possible due to the characteristics of the clay in Gothenburg.

7.1.3 Transport network

The conventional solution used for inbound and outbound deliveries to and from construction sites are trucks, however in this thesis the potential use of urban waterways has also been investigated. The transhipments differ somewhat between a truck and vessel transport solution. For the conventional solution, wheel loader and excavator usually perform the loading and unloading, if the construction truck does not unload itself, which is even more common. For the vessel, a belt conveyor is also an alternative worth to investigate. The feasibility of each mode of transport is analysed below and technology, legislation, and type of mass transported are taken into account. However, all vehicles and vessels identified and analysed in this thesis are more or less feasible, as transport operators and experts took part in choosing the vehicles and vessels.

7.1.3.1 Conventional transport chain

Looking at the distribution between different modes of transport for land based freight transport in Sweden, road represent approximately 65% (Vierth et al., 2012) and is thus regarded the most conventional transport chain used for construction projects like Västlänken. The production manager at Västlänken, Per-Inge Söderström[69], argues that the reason for this is the high service level achieved, door-to-door solutions and the flexibility of route choice.

With regards to rules and legislation, there are several restrictions that are important to consider when choosing a suitable type of truck. The two trucks that have been chosen to be included in this thesis are however possible to use in the urban environment of the shafts and are equipped with modern and efficient technology. However, many operators, fierce competition, and, low margins characterize the road transport market and this opens up for many possibilities for the mass transport, both regarding costs, environment and technology.

[69] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.

Trafikverket thus has a large possibility to direct what transport vehicles to use in the tender process. An important aspect to consider is that construction trucks are limited to the existing infrastructure, which will be further analysed in Chapter 7.1.2.3. This implies that the trucks will need to drive on narrow and congested streets, in order to reach the larger streets and take detours due to wanting infrastructure. Also, the trucks chosen are rather small as this is in accordance with valid rules and legislation. Larger trucks would need special permissions, and would result in less truck trips for the mass each day. When looking at one of the assumed destinations for the mass, Port of Gothenburg, the trucks need to pass through a Natura 2000 area, where only a certain number of trucks are allowed. Hence, a high number of freight vehicles are not regarded as feasible and a combination with barge would be a better solution. In conclusion, the construction trucks are regarded to be feasible for transporting both rock and clay.

7.1.3.2 Barge solution

Barge transport represents a very small fraction of the modal split in Sweden today, and there are few operators available on the Swedish market. In central Europe on the other hand, barge represents a larger share of the modal split and several operators are available and in case of a barge transport decision in Västlänken, it is likely that many types of barges would be possible to choose from. Based on what is available on the Swedish market, the authors have chosen three feasible barges to investigate in this thesis. They are all feasible to navigate on Göta Älv, but have different features; one large barge with a transport ramp used for loading (referred to as OP1), one dredging barge that unload itself by opening its keel (referred to as OP2) and one smaller barge with its own belt conveyor for loading and unloading (referred to as OP3) are investigated. The main technical differences are loading- and unloading, capacity, and propulsion. The theoretical barge is excluded in this part, as it is not available on the transport market today, and thus hard to analyse from a feasibility perspective.

It is assumed that all mass should get tipped into water, and it can be argued that all different unloading techniques are feasible. An important aspect to consider is however that OP2 has a deeper draft, which means that it cannot be used to fill the last part of the dock. The other barges can be moved while unloading, which facilitates filling. OP1 is much larger than the other two vessels, which can affect the loading with regards to depth of water and possible docking location. The length of OP1 could however constitute an issue when docking at Skeppsbron, if the planned expansion of Skeppsbron will overlap with the construction of Västlänken. Thorough coordination in-between the two construction projects will be necessary in order to avoid such issues. Regarding capacity, the quantity of excavated mass will fluctuate during the construction. Due to this, different capacity and size of vessel will be optimal during the different phases. A larger vessel will be more suitable during the first period of excavation, as the excavation rate of gault is higher in the beginning and then decreases for example. As a reference when optimizing capacity, the planned construction project Förbifart Stockholm, mentioned in Chapter 4, will use barges with a capacity of 2000 tonnes.

Finally, the propulsion of the different vessels differs as tugboats move two of them and one has its own propulsion machinery. The main difference from a feasibility perspective is that a tugboat demands more space and possibilities to navigate, however this do not constitute any problem and thus the propulsion of all three vessels are regarded as feasible. The three vessels investigated in this thesis are as mentioned limited to navigate on Göta Älv due to geographical prerequisites and infrastructure, and as two of the examined shafts are located close to Vallgraven, it was interesting to also examine the possibilities for a fourth barge solution adopted to the prerequisites in Vallgraven. It is likely that this type of vessel is available on the market, and if not, it might even be possible for barge operators to modulate a specialized barge for the project.

As the usage of inland waterways is still rather restricted in Sweden, the investigation is limited to the old technology of available barges. However, as the discussed directive 2006/87/EC most likely will get implemented in Sweden, this opens up for possibilities for foreign operators to get established on the Swedish market and hence introduce newer technology. All three investigated vessels are considered as feasible with regards to the rules and legislation discussed in Chapter 5. When taking on a wider perspective and considering the aims of the European Commission, the use of inland waterways are also considered as feasible as an increased modal split for inland waterways is the target.

7.1.3.3 Transhipments

As stated when discussing transhipments in Chapter 6, the main issue in a transport chain is the transhipments, both regarding cost, sustainability and space. There are several feasible ways of conducting the transhipments, and in this thesis conventional constructions machines such as wheel loader, excavator and dump truck has been identified and examined. In addition, belt conveyors have been identified as an alternative method for transhipments to barges.

From a feasibility perspective, an important aspect of the wheel loader and excavator is the type and size of bucket, as it needs to suit the mass transported. Although, as said earlier, the main scope of this thesis is the main modes of transport (construction trucks and vessels) and hence more research could be done in order to find the optimal wheel loader and excavator. However, the transhipments chosen are regarded feasible, as different buckets have been chosen for rock and clay and would be suitable for both vessels and trucks and are also suitable in regards to legislation and technology. The difference between the transport chains is not regarded substantial when it comes to the construction machines, why this is not the main part of the analysis. The third conventional transhipment solution on the other hand, the dump truck, is regarded as less feasible as the construction work will go on for several years and it will be problematic to get special permit for using dump truck.

For barge, the alternative of using belt conveyor was also investigated. First of all, it can be argued that the type of belt conveyor identified and examined in this thesis is not suitable for clay. There are most likely possible solutions with belt conveyors, for example conveyors with built-in baskets and pipelines have been brought up during interviews. However, as the scope of this thesis is the main mode of transport namely construction trucks and vessels, further investigations in this matter has not been made. The authors have however been in contact with a Swiss provider of solutions for belt conveyors that are positive to a future development of a suitable belt conveyor for clay. The belt conveyor discussed in this thesis is powered by electricity, and the only issue from a feasibility perspective regarding propulsion is thus lack of electricity during the construction work, which is rather unlikely.

An important aspect to discuss is the required incline of the belt conveyor, which is necessary in order to cross streets without disturbing the natural flow of people and traffic. From Shaft 2, it is regarded as feasible to use belt conveyor as the stretch allow for having a twelve meter long incline of the belt before reaching the height of four meters, to cross the road at Rosenlundsgatan. It is also regarded as feasible to use belt conveyor for transhipments from Shaft 2 to loading of a vessel in the canal. From Shaft 3 on the other hand, an elevation of 18 degrees is not possible before reaching Stora Badhusgatan. A factor to consider as well is the planned expansion of Skeppsbron, as described in Chapter 5, which for example concerns a planned expansion of the tram network. This further complicates the usage of an elevated belt conveyor in the area and would require other solutions, such as a buried belt conveyor or other routes than the one identified in this thesis.

7.1.4 Infrastructure system

The infrastructure system is a prerequisite for movement of both freight and people in cities, but it also limits the type of vehicles, vessels, and routes that can be utilized. Dablanc (2007) states that space dedicated to logistics activities is disappearing from cities and that specific requirements of freight transport will make it even more complex. For instance, freight transport is dependent on greater areas of space than passenger traffic, as there is a need of loading and unloading of goods, and material handling. As argued in Chapter 6, an efficient transport system and especially methods for transhipments are thus crucial as the space available for storage is scarce in the dense urban area of this case.

Depending on what combination of modes of transport that will be used for the total transport chain, different routes have been identified, as the road network differ from the distances on waterways and for belt conveyors. The route when using the road network is dependent on what roads and bridges that are feasible to use for heavy transport and what other projects that will affect the traffic situation at this time. The main issue is the construction of the Central Station, why the road transport is assumed to cross Älvsborgsbron, the south bridge crossing the canal. In theory inland waterways are often said to be rather limited with regards to the existing waterways, however in this case it is rather on the contrary as trucks need to drive a long detour in order to reach the destination whereas the vessels just need to cross Göta Älv. The long detour that the trucks need to take is in line with Dablanc (2007), who states that goods movement are largely indifferent to the internal structure of cities.

7.1.5 Concluding remarks

In conclusion, all transhipment methods investigated are feasible for rock and clay, except from belt conveyor that is only feasible for rock from Shaft 2. All barges and construction trucks investigated are suitable from all shafts and for all types of mass, however the available barges do not fit in the canal close to Shaft 1 and Shaft 2, why transhipments to Göta Älv are needed. It is however likely that a smaller barge that does fit in the canal is available on the European market, why a theoretical barge that do fit is also investigated in the next section. A summary of the feasible vehicles and vessels is presented in Figure 14. It is also concluded that the infrastructure of Gothenburg plays a significant role when choosing transport mode. The seaways open up for shorter transport distances and the possibility of adjusting the infrastructure for the purpose of the barge transport is also emphasized.

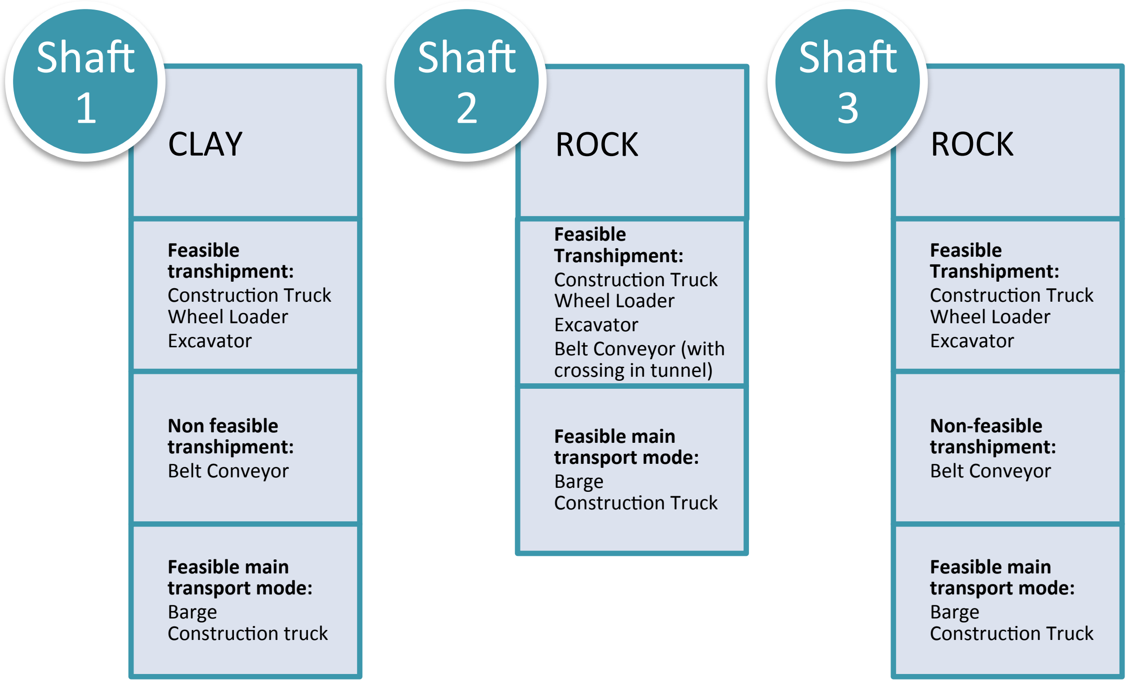

Figure 14. Fesibility of transhipments and main transport modes for the different shafts.

7.2 Sustainability

In this section, a conventional transport chain is compared to barge alternatives from a sustainability aspect. The different transport chains are described and some main conclusions are drawn, as a base for the rest of this section.

For the conventional transport chain, the transport chain starts at the orifice of the shafts, where a wheel loader loads the construction truck that travels loaded between the shaft and the point of destination, where the truck manoeuvres and a wheel loader or an excavator dumps the material, before the construction truck drives back unloaded to the shaft again, as illustrated in Figure 15.

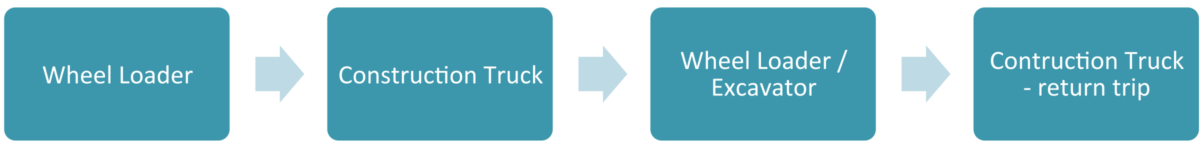

Figure 15. Conventional transport chain.

The results for the distances from Shaft 2 to Port of Gothenburg and Frihamnen when transporting rock are presented in Table 9. It is clear that the larger Truck 2, is most efficient from an environmental and cost aspect and the wheel loader is also more efficient than the excavator. In the rest of this section, this is the conventional transport chain used as a reference. The transport chain from Shaft 1 shows slightly higher values, as the distance from Shaft 1 is longer than from Shaft 2. For Shaft 3, the difference in distance is negligible, why the same results are observed. However, all shafts show that the larger truck in combination with wheel loader is the most efficient transport chain.

Table 9. Fuel consumption, environmental impact and cost impact for transport chain from Shaft 2.

Transport Chain Shaft 2 – Port of Gothenburg	Fuel Consumption [L/tonne]	External Costs [EUR/tonne]	Total Cost [SEK/tonne]
Wheel Loader - Truck 1 - Wheel Loader - Truck 1	0.52	0.05	32.9
Wheel Loader - Truck 2 - Wheel Loader - Truck 2	**0.44**	**0.04**	**26.1**
Wheel Loader - Truck 1 - Excavator - Truck 1	0.66	0.06	40.0
Wheel Loader - Truck 2 - Excavator - Truck 2	0.58	0.05	33.1
Transport Chain Shaft 2 - Frihamnen	**Fuel Consumption [L/tonne]**	**External Costs [EUR/tonne]**	**Total Cost [SEK/tonne]**
Wheel Loader - Truck 1 - Wheel Loader - Truck 1	0.63	0.06	39.5
Wheel Loader - Truck 2 - Wheel Loader - Truck 2	**0.52**	**0.05**	**31.0**
Wheel Loader - Truck 1 - Excavator - Truck 1	0.77	0.07	46.6
Wheel Loader - Truck 2 - Excavator - Truck 2	0.66	0.06	38.1

Several barge alternatives are developed in order to find suitable transport chains for rock and clay. The first one is a transport chain where a belt conveyor is used to load the barge. The transport chain for this alternative is illustrated in Figure 16, and shows that a wheel loads the belt conveyor that loads the barge. Depending on what barge that is used, it either unloads itself (OP2 and OP3) or needs wheel loaders to unload (OP1). The belt conveyor is only used for rock material, and according to the feasibility study, it is only possible to use from Shaft 2.

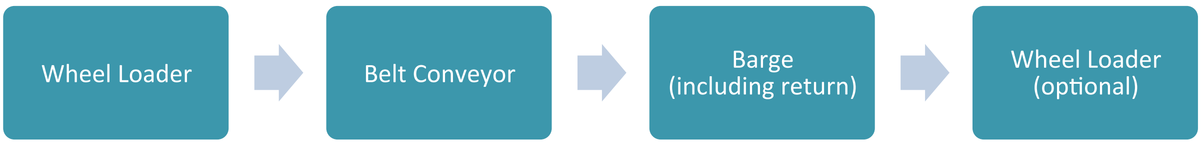

Figure 16. Barge transport chain with belt conveyor.

The second barge alternative is a transport chain where a construction truck is used to move the mass to the barge. The transport chain is illustrated in Figure 17 and shows that a wheel loader loads a truck that drives to the barge at Skeppsbron where a wheel loader loads the barge. Similar to the first solution, depending on what barge that is used, it either unloads itself (OP2 and OP3) or needs wheel loaders to unload (OP1). Truck 2 for transhipment can be used from all three shafts investigated.

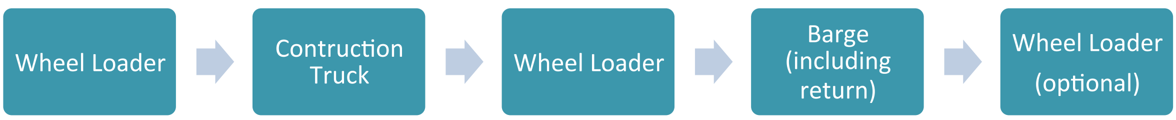

Figure 17. Barge transport chain with construction truck.

The third barge alternative is a transport chain where a theoretical barge that is adapted to the geographical prerequisites in the canal at Shaft 1 and Shaft 2 is used. The transport chain includes less transhipments, as seen in Figure 18, as the barge is located just by the shafts.

The barge itself is also cost-efficient, as it does not require as much staff as the larger barges due to the use of push barges[70].

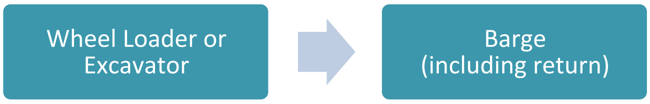

Figure 18. Barge transport chain with theoretical barge

As summarized in Table 10, the large barge from OP1 is the most efficient one both regarding environmental impact and cost. Even though OP1 in combination with belt conveyor is preeminent, OP1 also shows good results when Truck 2 is used for transhipment. OP2 and OP3 show substantially higher environmental impact and higher cost than OP1, especially for the longer distance to Port of Gothenburg. The theoretical barge also shows to be less efficient than OP1.

Table 10. Fuel consumption, environmental impact and cost impact of transport chain from Shaft 2.

Transport Chain Shaft 2 – Port of Gothenburg	Fuel Consumption [L/tonne]	External Costs [EUR/tonne]	Total Cost [SEK/tonne]
Wheel Loader - Belt - Barge OP1 - Wheel Loader	**0.14**	**0.014**	**8.0**
Wheel Loader - Belt - Barge OP2	0.52	0.076	38.5
Wheel Loader - Belt - Barge OP3	0.55	0.081	
Wheel Loader - Truck 2 - WL - Barge OP1 - Wheel Loader	0.21	0.019	17.34
Wheel Loader - Truck 2 - Wheel Loader - Barge OP2	0.59	0.081	45.83
Wheel Loader - Truck 2 - Wheel Loader - Barge OP3	0.62	0.086	
Wheel Loader - Barge that fits in Vallgraven	0.32	0.029	18.33
Transport Chain Shaft 2 - Frihamnen	**Fuel Consumption [L/tonne]**	**External Costs [EUR/tonne]**	**Total Cost [SEK/tonne]**
Wheel Loader - Belt - Barge OP1 - Wheel Loader	**0.11**	**0.008**	**7.2**
Wheel Loader - Belt - Barge OP2	0.12	0.015	18.0
Wheel Loader - Belt - Barge OP3	0.21	0.029	
Wheel Loader - Truck 2 - WL - Barge OP1 - Wheel Loader	0.18	0.014	16.51
Wheel Loader - Truck 2 - Wheel Loader - Barge OP2	0.19	0.02	25.31
Wheel Loader - Truck 2 - Wheel Loader - Barge OP3	0.28	0.034	
Wheel Loader - Barge that fits in Vallgraven	0.10	0.009	10.47

In the coming sections, belt conveyor is assumed for transhipments from Shaft 2 and Truck 2 for transhipments from Shaft 1 and Shaft 3, in accordance with the results above. First, the

70 Björn Södahl (Research Coordinator Shipping and Maritime Technology, Chalmers) meeting with the authors October 23, 2013.

fuel consumption of the transport chains is presented. In order to understand the impact on the three sustainability aspects of the transport choice, the environmental impact, the cost impact and the social impact will then follow.

7.2.1 Fuel Consumption

Fuel is the main operating cost for vehicles[71], and increased fuel tax (Lowe, 2005) also leads to an increased attention to fuel consumption. At the same time, fuel is also closely connected to air pollution (Trafikverket, 2012b) and Richardson (2005) identifies fuel consumption as one out of five indicators of sustainability for transportation. It is thus clear that fuel consumption impact the economy as well as the environment.

When comparing the different transport chains, it can be seen that for the distance to Frihamnen, all barge alternatives outclass the conventional transport chain when it comes to fuel consumption per tonne, as seen in Figure 19. This is partly due to that the sea distance is significantly shorter than the road distance. For Port of Gothenburg, the results are thus not as distinct as the road and sea distances are more similar. However, the large barge from OP1 is still showing significantly lower fuel consumption than the other transport alternatives. The rest of the results can be found in Appendix 2.

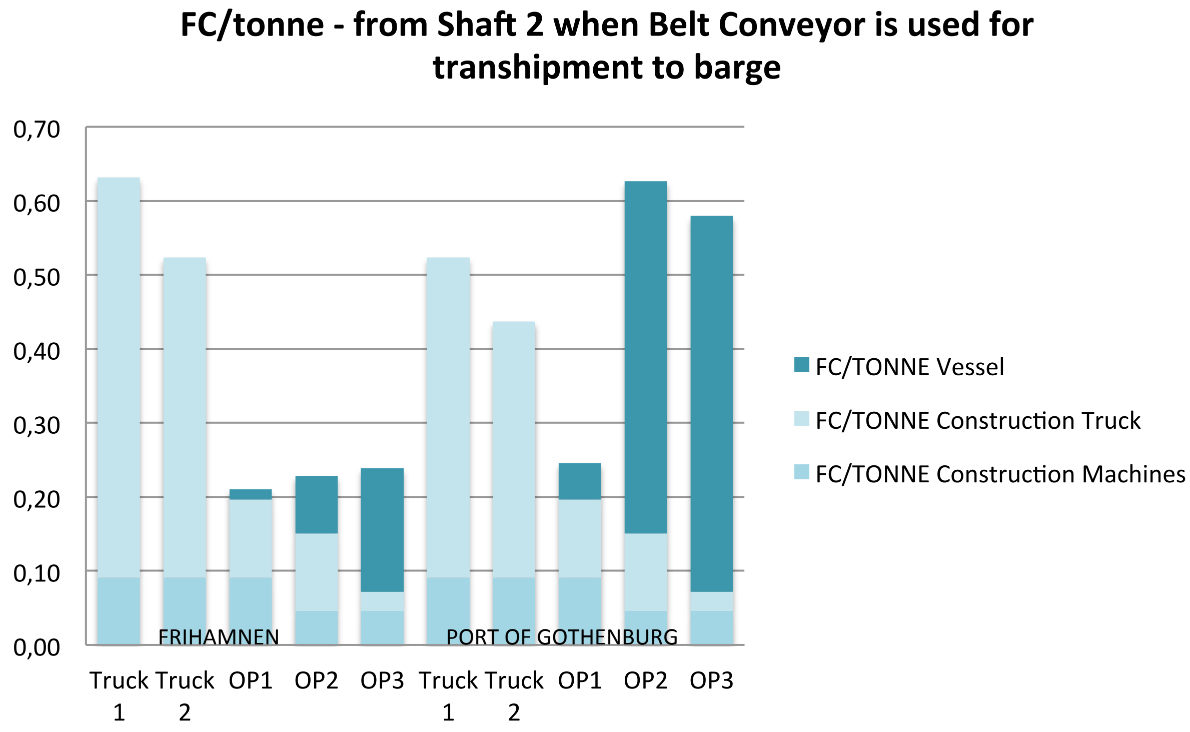

Figure 19. Fuel Consumption per tonne from Shaft 2 when belt conveyor is used to barge.

If only concentrating on the different barge alternatives, the load capacity seem to be an important factor and the large barge from OP1 shows much lower results than the smaller vessels from OP2 and OP3. For the shorter distance, the advantage of OP1 is not as evident,

[71] Linda Styhre (Researcher and Project Manager, VTI) interview October 21, 2010.

as the vessel only stands for a small part of the total fuel consumption. When looking at the longer distance, the difference between the barges is however clear, and OP1 is prevalent due to its loading capacity that allows for less fuel consumption per tonne.

If looking at the share of fuel consumption resulting from each mode of transport, it is clear that transhipments are an important source of fuel consumption in the investigated transport chains, see Figure 20. In the barge transport chains to Frihamnen, the construction machinery stands for a significant part of the total fuel consumption. For Port of Gothenburg, the vessel takes up a higher share, as the sea distance is longer. The larger barge from OP1 is much more efficient than the others, why its share is smaller than for OP2 and OP3. This is mainly due to the larger amount of loading capacity of OP1, which is already mentioned. The reason why OP3 shows a higher share of fuel consumption than OP2 is because it is equipped with own propulsion, which requires more fuel per hour than the tugboats used for OP1 and OP2.

For the conventional transport chain, the transhipments result in a smaller share of fuel consumption. For the trucks, the speed is an important factor, as driving below 30 kilometres per hour results in an increase in fuel consumption (McKinnon, 2010). The mean speed in the city centre is assumed to be seven kilometres per hour, compared to a mean speed of 35 kilometres per hour at larger urban roads[72], which is one reason behind the split in fuel consumption for the conventional transport chain.

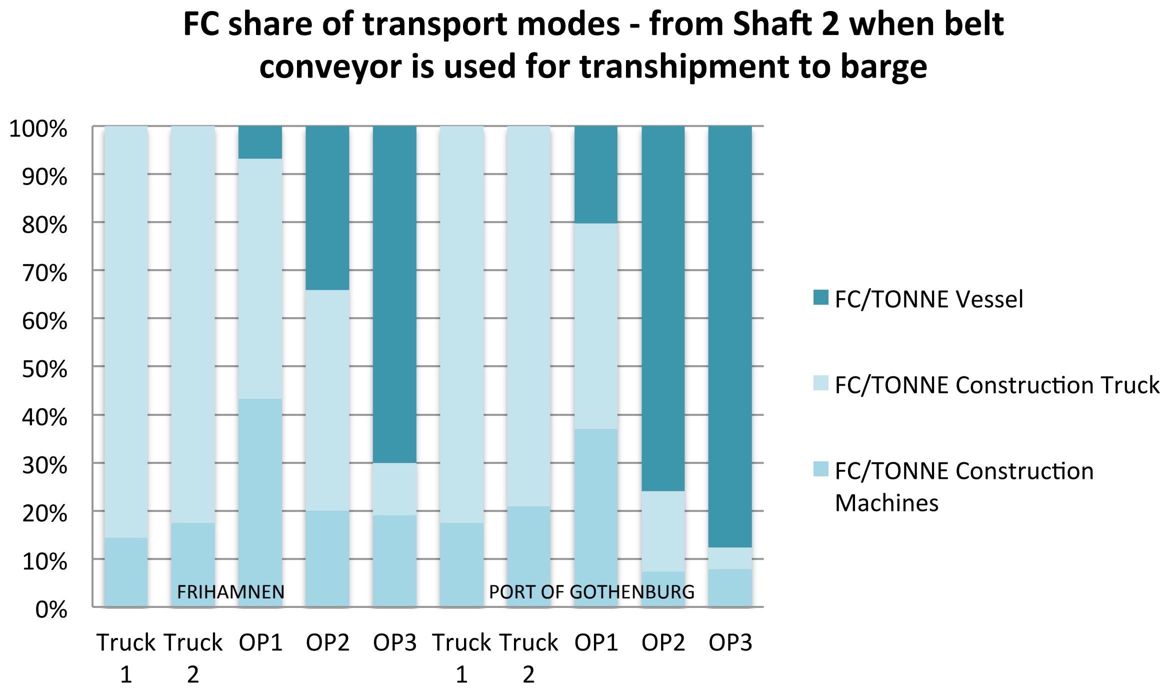

Figure 20. FC share for each transport mode from Shaft 2.

For the case investigated in this thesis, barge shows to be an efficient alternative to conventional transport. Furthermore, as the sea distance is shorter than the road distance, this was not surprising. However, in order to make a general conclusion, the fuel consumption for

[72] Volvo Group Trucks Technology, meeting with Anders Berger (Product area manager) et al. (see Appendix 8), November 14, 2013.

the different transport solutions is also compared for similar distances. The fuel consumption per tonne kilometre is illustrated in Figure 21.

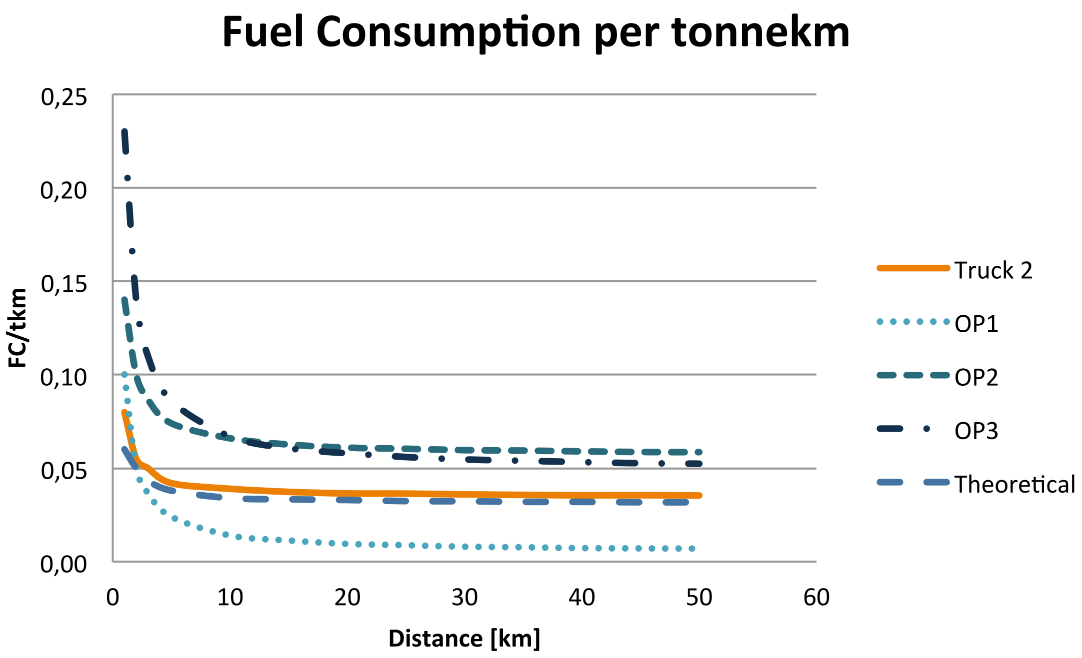

Figure 21. FC per tonne kilometre.

Even now, the barge from OP1 shows to be more fuel-efficient than the conventional transport chain. In this chart, the results from the theoretical barge that would fit in the canal next to Shaft 1 and Shaft 2, is also presented. This barge is more fuel-efficient than the conventional transport for all distances, in spite of its small loading capacity of 290 tonnes. OP1 is however still more efficient for distances above two kilometres. In conclusion, it can be said that barge can be more fuel-efficient than truck, however the load capacity and transhipments are significant parameters to take into account when comparing transport chains.

7.2.2 Environmental Impact

As mentioned, UFT results in air pollution and has negative effects on the environment on a local, regional and global level. McKinnon (2010) states that the focus within logistics has historically been to minimize the cost and maximize the efficiency and effectiveness. However, it can be argued that change is slowly approaching, and based on the development with legislation and rising interest within the area of sustainable logistics it is likely that a change is on its way. This change is necessary in order to come close the goal of no CO_2 emission from UFT in 2030, set by the European Commission (2011). To make sure improvements are implemented, the environmental impact from UFT needs to be quantified, and this is when external costs is useful.

As seen in the theoretical framework, the most important external cost drivers differ between road and inland waterways. For road, the emission standards of the vehicle are the main driver and it furthermore depends on vehicle speed, fuel type, and the combustion technology (IMPACT, 2007). For inland waterways on the other hand, the main external cost drivers are engine- and vessel type, fuel quality, operation mode and if driving upstream or downstream. It is important to note that the trucks used as reference in this thesis are modern vehicles, with up-to-date technology, while the vessels investigated are older models. According to Dablanc (2007), older types of vehicles are often used in cities and it is thus likely that the calculations for construction trucks are too wishful. The Euro level used in the calculations is however Euro 5, which is in accordance with todays requirements. This could possibly be changed until the project starts and improvements are thus also to be expected for both transport modes.

In order to analyse the external costs resulting from the suggested transport chains in this thesis, an impact assessment is necessary. The impact categories included in this analysis are air pollution and climate change, as illustrated in Figure 22.

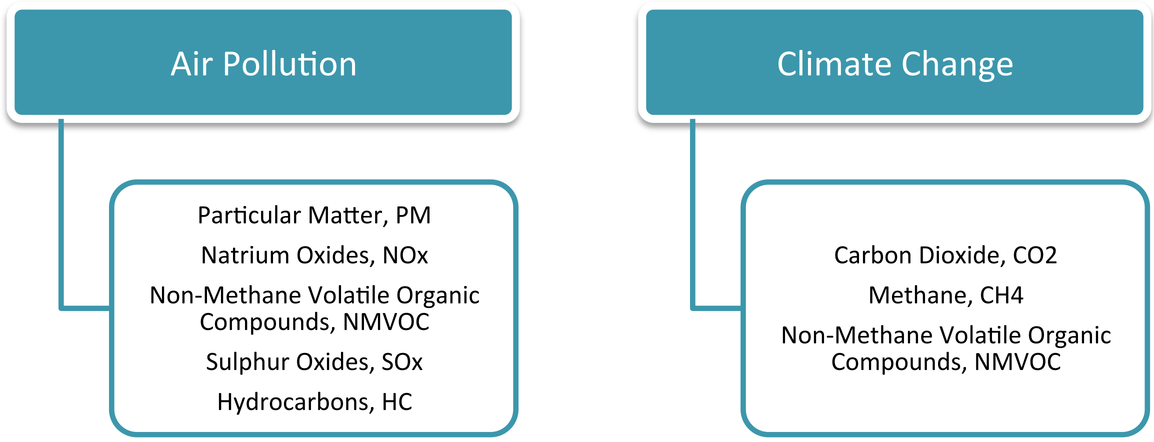

Figure 22. Impact categories included in the analysis.

In accordance with the introduction to this chapter, the suggested transport chains from Shaft 2 to Port of Gothenburg and Frihamnen are presented. The results for Shaft 1 and Shaft 3 are to find in Appendix 3. Starting with the distance to Port of Gothenburg, illustrated in Figure 23, eight different transport chains are compared. The dominating emission factors for all chains are PM, NO_X and CO_2, which implies that both of the impact categories are affected. Comparing the different transport chains, the share of PM differs between the conventional transport chains and the barge alternatives. The level of PM for construction machines and belt conveyor is much lower than for the other vehicles and vessels. The larger share of vessel and construction truck of the total fuel consumption, the larger is thus the share of PM per tonnes of fuel. The share of each vehicle and vessel were further clarified in Chapter 7.2.1. The emissions observed in the transport chains follows the emission factors used in the calculations and are thus in accordance with theory, where emissions of PM, CO_2 and NO_X are typical for road transport, although the amount of emissions largely depends upon the type of fuel and vehicle or vessel used.

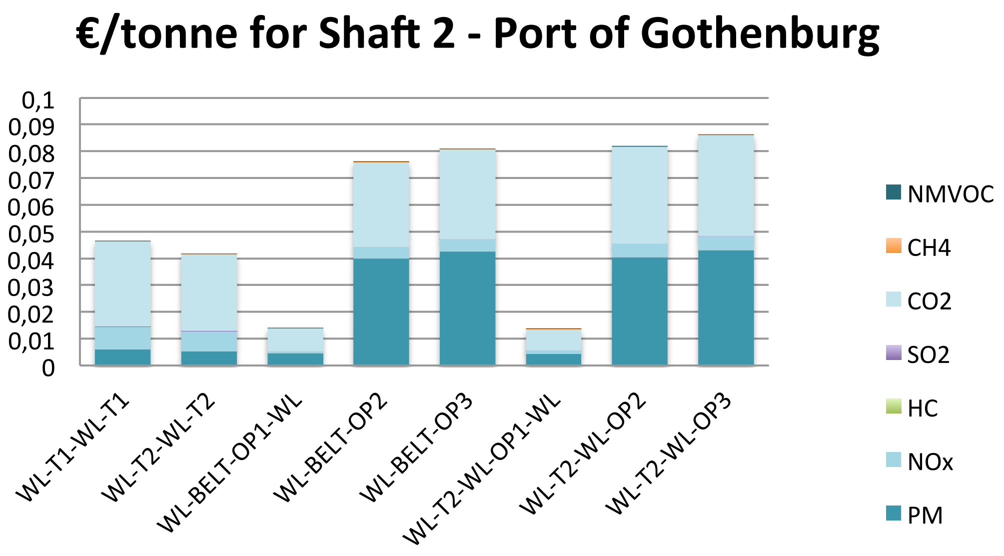

Figure 23. The external costs resulting from eight suggested transport chains from Shaft 2 towards Port of Gothenburg. The external costs on the Y-axis are given in Euro/tonne.

In the second chart, see Figure 24, the shorter stretch from Shaft 2 to Frihamnen is illustrated for the same eight transport chains as earlier. Similar to the earlier distance, PM, NO_X and CO_2 are dominant, which implies that both of the impact categories are affected also in this case. The main difference between the distances is however the level of PM for the barge alternatives, which is smaller as the share of fuel consumption of vessels decreases when the distance is shorter. This follows the same logic as described earlier, as vessels and trucks result in more PM/tonne than construction machines and belt conveyor.

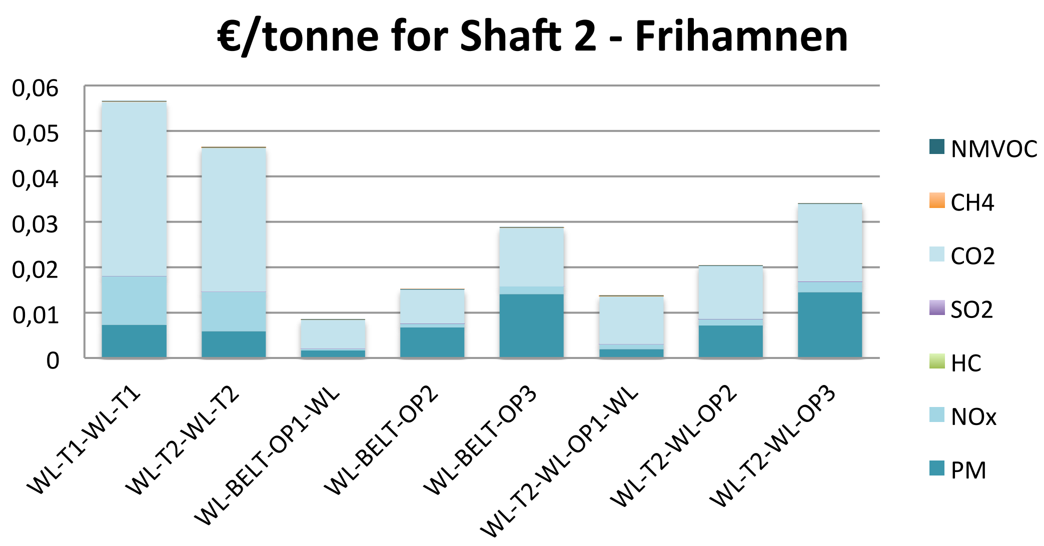

Figure 24. The external costs resulting from eight suggested transport chains from Shaft 2 towards Frihamnen. The external costs on the Y-axis are given in Euro/tonne.

When comparing the two distances, it can be seen that the best transport solutions from an environmental perspective is the ones where the large barge from OP1 is used. Furthermore, it can be seen that on the short distance the two transport chains including Truck 1 and Truck 2 has the highest environmental impact, whereas on the longer distance the transport chains including OP2 and OP3 shows the highest environmental impact. The reason to why the smaller barges show higher environmental impact on the longer distance is their increased share of fuel consumption. For the short distance, the impact of the small barges is not as large. Shaft 1 and Shaft 3 follows the same logic, even though the alternatives including belt conveyor are not regarded feasible. In conclusion, the load capacity and the split between different modes in the transport chain have a great impact on the emission-levels per tonne.

Finally, when looking at Figure 25 below, in which the external costs per tonne-kilometre is illustrated, it can also be seen that OP1 still is best from an environmental perspective, but only slightly better than Truck 2 and the Theoretical Barge. It can also be seen that the longer the distance, the closer Truck 2 gets towards being equal to OP1 and the Theoretical Barge.

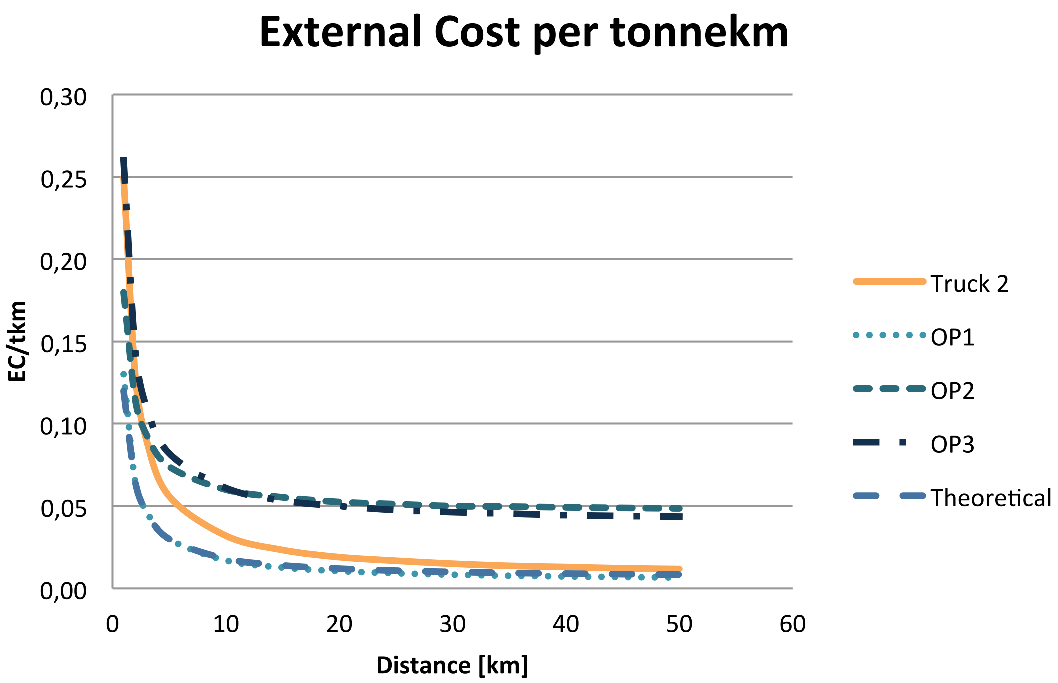

Figure 25. External cost per tonne-kilometre.

7.2.3 Economic Impact

In this section, the cost impact of the discussed transport chains is presented. First, the external cost of congestion in urban areas is discussed, followed by a cost analysis of the different transport chains.

7.2.3.1 Congestion

Limited and overexploited road networks in medium and large European cities leads to decreased speeds, increased travel times, and less reliability for road transport (IMPACT, 2007; McKinnon, 2010; MDS, 2012). The issue with congestion reach even higher importance in today’s society as a result of the shipper’s increasing demands on on-time deliveries (Lammgård et al., 2013), a fact that is further stressed by the interviewed shippers in this thesis[73].

Congestion is a reality in the city of Gothenburg and there is a high risk that the level of congestion and its related problems will increase even more in Gothenburg in the coming years. As said throughout the report, there will be an increased future demand of mass transport due to several major infrastructure projects, and as more people and businesses move to the city. As presented in Appendix 5, congestion calculations, the potential use of vehicles for mass transport from the three examined shafts may result in external costs of approximately €2000 per day if trucks similar to Truck 1 are used for all shipments. If instead Truck 2 is used there is a possibility to reduce the congestion related external costs with 25%. Another possible solution to reduce the impact to a minimum can be to perform the mass transport during hours when there is less congestion, however this may result in problems at the working site or at the destination. First, it will require larger intermediate storages of mass at the shafts. Second, it can create congestion at the site and at the destination as the same number of trucks needs to be loaded and unloaded in a shorter limit of time. Third, it may create bottleneck situations for the transport operator, as more construction trucks will be demanded during certain hours.

When instead looking at the other proposed mass transport solution, i.e. to use urban navigation the congested related problems can be reduced dramatically as the waterways enables congestion free transport (European Commission, 2011). This regards especially for the transport chains where a belt conveyor can be used for the intermediate distances, but also when trucks are used for this distance as the number of road kilometres is reduced to a minimum. The congested related problems will with this option be limited to the Rosenlund and Skeppsbron areas, which will have negative impact for the concerned residents. However, the other proposed option i.e. to only use truck, will affect the same and even more areas in the city and with this more residents.

7.2.3.2 Cost analysis

It is clear that the cost aspect is one of the most, or the most important criteria when shippers procure transport solutions[74,75,76,77] (Lammgård et al., 2013). Of course this will have implications when making transport decisions in the case of Västlänken. In this case, the cost parameter may even receive even higher priority from the shipper's side, due to the large share that the transport represent out of the total cost for excavation.

Both truck- and inland vessel operators refer to price as one of their main competitive strengths. However, it is argued that the transport conditions that apply for the mass transport from Västlänken, i.e. high volumes of bulk, is optimal for barge from a cost perspective (Konings, 2009; Vierth et al., 2012). The benchmark study has however shown that barge transport has been turned down in transport planning processes, as it has been considered to be a costly and an uneconomical solution[78] (Trafikverket, 2009). On the other hand, in the

[73] Markus Evans (EHSQ Coordinator, PEAB) interviewed October 18, 2013.
[74] Thomas Fritsson (Site Manager, Carlbergs) interviewed via phone November 14, 2013.
[75] Per-Inge Söderström (Production Manager Västlänken, Trafikverket) interviewed October 3 and October 31, 2013.
[76] Bengt Johansson (AO Manager, GLC) seminar October 4, 2013.
[77] Jesper Mårtensson (HMSQ Manager BanaVäg i Väst, Trafikverket) interviewed October 15, 2013.
[78] Klas Nydahl (Senior Advisor, Malmö Stad Gatukontoret) interviewed via phone October 3, 2013.

case of BanaVäg i Väst where water transport was used, it proved to be very favourable compared to the road alternative.

Figure 26 presents cost relations for the evaluated transport solutions from Shaft 2 but the correlation can be seen as representative for all three shafts examined. The results for the other shafts are presented in Appendix 4. OP1 clearly stands out in the competition, much owing to its ability to transport up to 4500 tonnes per shipment. The high capacity of the large barge from OP1 results in low operating and personnel costs per tonne. Depending on the transhipment method the cost level varies, and it can be seen that the belt conveyor alternative represent the lowest cost per transported ton. The second barge alternative considered, OP2, shows favourable cost figures for the destination Frihamnen, but when the destination is changed to Port of Gothenburg, OP2 shows a high cost level compared to the other transport options. The reason to this is that OP2 in the first case has a clear advantage compared to road due to the much shorter distance travelled. When the distance approach the same as for road the operating and personnel cost for the required tugboat will have a major impact, which results in a high cost per tonne. This is also in line with Lumsden's (2012) argumentation saying that the propulsion machinery unit, i.e. the tugboat accounts for a major part of the costs for barge transport. The reason to why this not has a major affect to OP1 is once again due to its high carrier size. That the carrier size has a clear connection to the cost level is also seen when comparing the two road options. Even if the larger Truck 2 has both higher hourly and fuel consumption cost, the increase in transport work per shipment lowers the total cost per tonne compared to Truck 1.

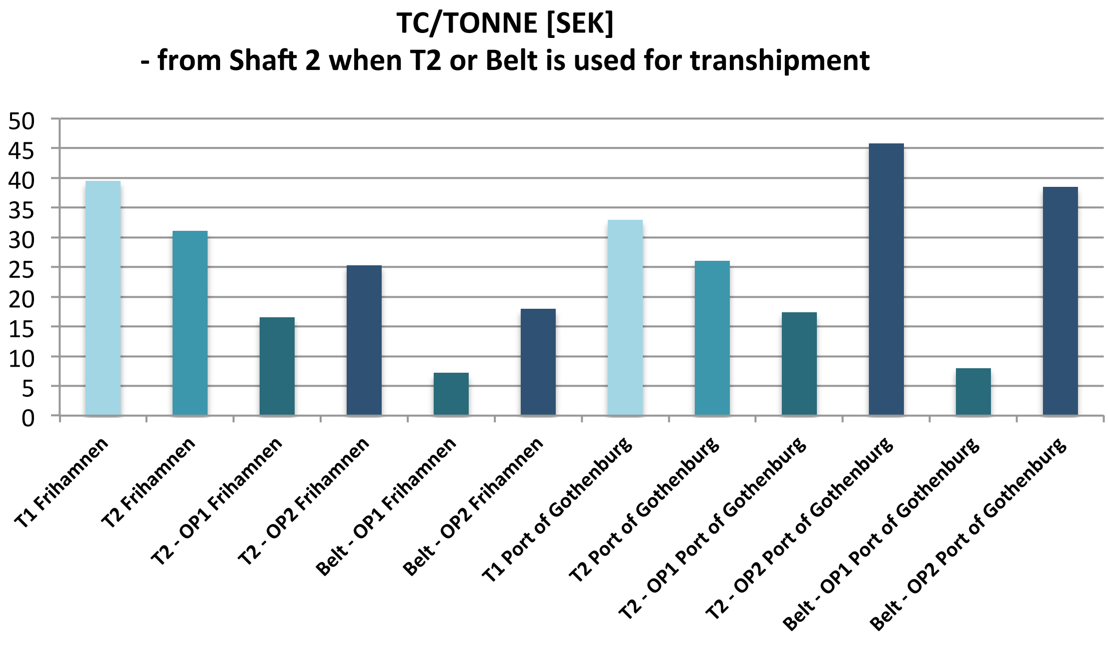

Figure 26. Total cost per tonne from Shaft 2.

From a total cost perspective there is a major difference for when the cost arise for the various solutions. In Figure 27 it can be seen that for OP1 the actual voyage including the time required for unloading represent less than 10% of the total cost per tonne, while for OP2 and the theoretical barge about 50% of the cost arise during transit. For OP1 most of the costs, 75%, instead arise in the transhipment processes, and 15% of the costs can be referred to when the barge is docked. This has the implication that a reduction of costs related to the trucks and construction machines used for transhipment would actually have more positive impact for OP1 than the inland waterway directive 2006/87/EC, as this will only affect less than 10% of the total cost. For OP2 and the theoretical barge, the directive will however have greater significance, as this transport solution requires more labour intensive processes per transported tonne. For the truck alternative the transit cost represents approximately 90% of the total cost per tonne, thus a decrease of cost related to personnel would have the largest impact as this constitute the largest share of costs related to the truck, as seen in Appendix 4. The cost related to transhipment for barge transport is generally a negative aspect discussed in qualitative assessments for using barge[79,80]. A conclusion can however be made, that even if this is the case the total transport cost for barge can still be lower compared to road i.e. more quantitative assessments of various kinds of transport solutions in transport planning processes might show results in contradiction to qualitative ones.

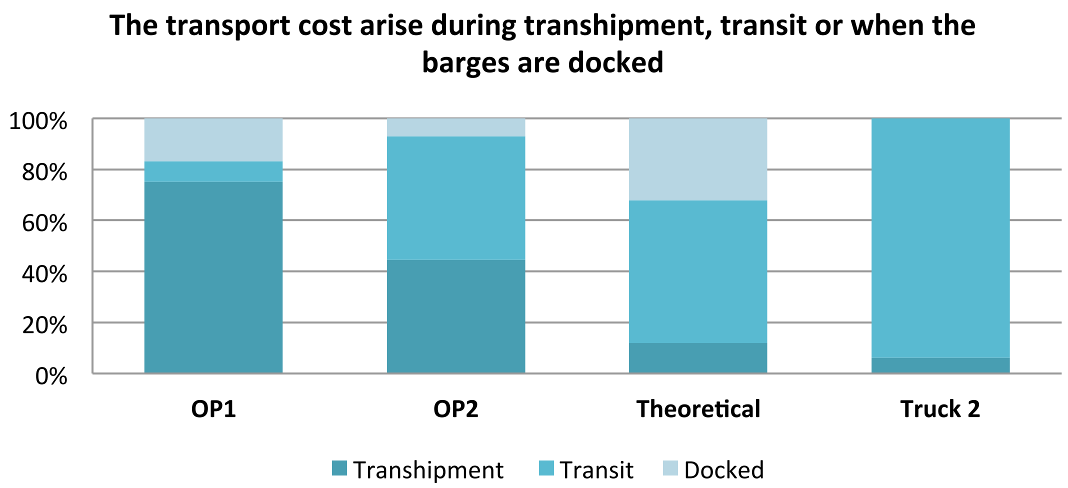

Figure 27. The transport cost arise during transhipment, transit or when the barges are docked.

Figure 28 presents the total cost per tonne kilometre. The validity of the figures is also strengthened by the fact that the total cost per tonne kilometre, both for truck and OP1, end up very close to the numbers presented in the case of BanaVäg i Väst. As seen in the graph Truck 2 together with the theoretical barge in Vallgraven represents the lowest cost per tonne-kilometre for really short distances. Thus, if there had been available infrastructure for road transport connecting Rosenlund and Frihamnen resulting in the same distance, or a somewhat longer distance than the distance travelled by the vessels, truck would have been a very good alternative from a cost perspective. However, today's limitations in the road infrastructure network requires that the trucks need to travel a much longer distance to reach the destination, which leads to a higher total cost per tonne. The chart also entails that for longer distances OP1 would have been even more outstanding from a cost perspective compared to the other options. As seen OP2 shows a much higher cost level than the theoretical Barge in Vallgraven even though their technical specifications are quite similar. This mainly depends on the fact that the personnel cost for Barge in Vallgraven is almost half the personnel cost for OP2.

[79] Fredrik Moback (Environmental and Technical Manager, Trafikverket) interviewed via phone October 9, 2013.
[80] Bo Franzon (Product Manager, Volvo Technology) interviewed November 14, 2013.

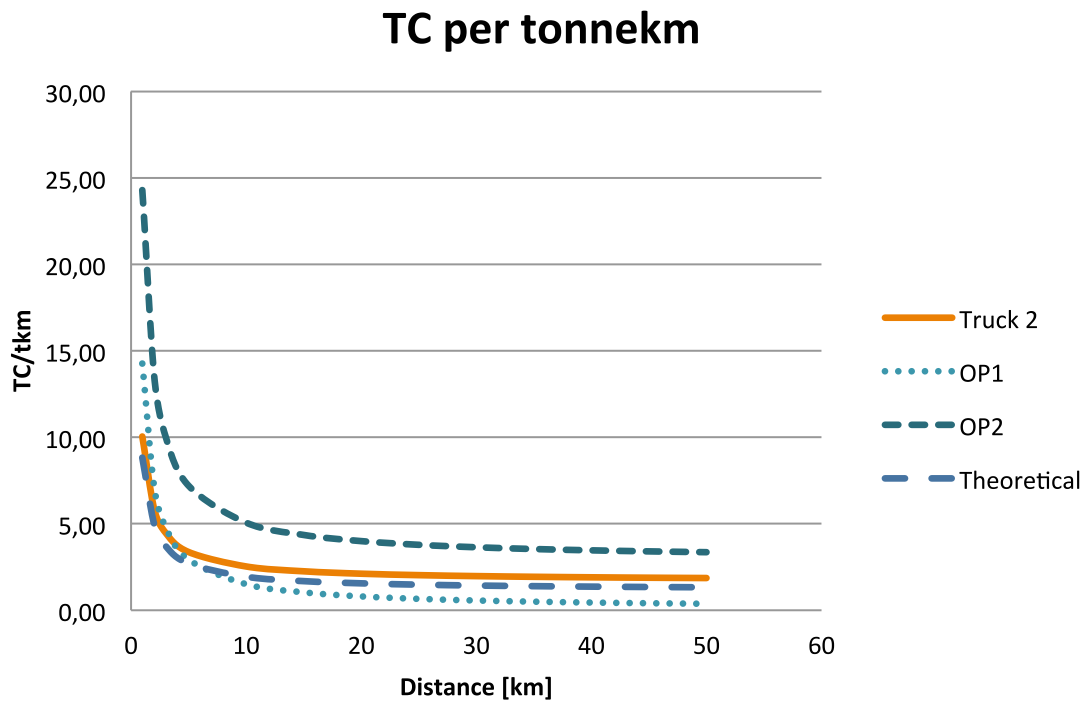

Figure 28. Total cost per tonne kilometre.

7.2.4 Social Impact

As mentioned in Chapter 2, the theoretical framework, the social impact of UFT is harder to measure than the environmental and economical impact, as the social impact is subjective. In order to examine the social impact (safety, noise and visual intrusion) a comprehensive stakeholder analysis has been conducted and this part of the analysis will hence be done through a qualitative discussion.

7.2.4.1 Stakeholder Analysis

According to the theoretical framework, the transport decision mainly affects the shippers, receivers, transport operators, authorities and residents, who are the main actors of the transport decision (Ballantyne et al., 2013). In accordance with theory, these stakeholders all have important roles when it comes to the transport of excavated mass and are all affected by the transport decision in the project of Västlänken. In accordance with Rogerson (2012) Trafikverket however plays a significant role, as it is the final decision-maker of how the mass transport should be defined in the tender of the project. This is when the decision of using barge or not will be determined, which will have consequences for all the other stakeholder groups. This is also supported by the benchmarking of similar projects in Europe and Sweden, where it is showed that barge has only been used when a political demand has been formulated to do so. What makes the decision further complex is the law of transparency connected to public procurement (van Weele, 2010). The decision needs to be made in consultations of the other stakeholders and the role of the construction buyer described in theory is thus extended.

Trafikverket's role thus differs from industrial transport buyers, which is further emphasised when looking at the major parameters in the transport decision; Swedish shippers ranked price and on-time delivery as the main aspects when choosing transport mode (Lammgård et al., 2013). Trafikverket however prioritize sustainability and environmental criteria high, as a part of their public responsibilities, which would emphasise the use of barge as an alternative to conventional road transport, as the environmental emissions has been showed to be significantly lower for a barge transport chain, than for a conventional transport chain. Cost is however still an important aspect, and according to the cost analysis performed in this thesis, Truck 2 together with the theoretical Barge in Vallgraven represents the lowest cost per tonne-kilometre for really short distances and OP1 is the most outstanding alternative for longer distances compared to the other alternatives.

The *shippers* are normally concerned of delivery and collection of goods at the lowest price, at the same time as meeting the need of their customer (Ballantyne et al., 2013). When talking to contractors, the main concern when it comes to the mass transport in this project is that the tender should be fair to the market competition. The importance of finding a price-efficient and reliable transport is valid, however the tender and transport decision will serve as the base of finding a competitive offer. If barge is chosen as the main mode of transport, the contractors will find transport operators that offer these services and as long as the contractors have the same conditions and compete on the same prerequisites, a barge decision is not seen as a problem.

The *transport operators* are normally concerned of low cost and high quality transport operations and that the shipper and receiver are satisfied with the transport (Ballantyne et al., 2013). When talking to transport operators, fair competition seems to be their main concern regarding the project of Västlänken. The transport operators usually work in close cooperation with contractors, thus who will perform the transport is dependent on what contractor that is chosen. The transport choice will affect the operators a lot, as it will either be a new business opportunity or not. Barge transport would open up for new operators entering the Swedish market, which can possibly have affects on the transport market as a whole. If barge transport are implemented for a long-term project is could be possible for other contractors and shippers to use the same transport solutions. The truck operators would however be negatively affected, as they would loose business.

The *receivers* are normally concerned of the on-time delivery and short lead-time of the products transported (Ballantyne et al., 2013). In accordance with theory, Göteborg Stad, who would be the receiver of the goods, defines the main issue as the timing of excavated mass with the planned construction work at the receiving locations. The type and quality of the mass is also of concern, as rock deliveries are needed before the deliveries of clay for instance. These aspects would however not be affected by the use of barge transport, as the transport is reliable and efficient (Lowe, 2005; Konings, 2009). In case of unforeseen circumstances, such as weather conditions where barge is not possible to use, conventional transport is also available and can be used as a back-up solution or in combination with barge transport. Barge transport would simplify the unloading of the excavated mass at its destinations and would possibly benefit the cityscape, both regarding congestion and visual intrusion for the residents, tourists and business of the city.

For *public authorities* on a national level, theory claims that the main concern is that the transport should result in a minimum of externalities, while maximising economic efficiency and effectiveness. International rules and legislations also apply in Sweden and EU's White

Paper of transport is usually used as a reference for transport goals. In the White Paper of 2011 the European Commission states that there is a need of shifting the balance between different modes and that the integration of inland waterways into the transport system should be stimulated. In the White Paper the goal of CO_2 free UFT by 2030 is also stated. The transport decision will affect the sustainable impact, and as shown, the environment will benefit from a barge transport solution. As congestion is also a major problem in urban areas of European and Swedish cities, barges would also free space on the roads. Truck is however a conventional transport solution, and cities also have to adjust demands and legislations to improve the externalities resulting from trucks.

The public authorities have a significant role in the decision of transport mode for the excavated mass. Theory claims that local authorities emphasise an attractive city for inhabitants and tourists, with minimum inconvenience from freight transport. It is however important to have an effective and efficient transport system. When talking to Stadsbyggnadskontoret, the cityscape and long term planning of the city is its main concern. Even though a lot of effort is put on where to locate the different train stations and how the city as a whole will be affected, not much effort is put on the actual transport decision. This is where Trafikkontoret and Trafikverket take on an important role of making sure that the traffic flow will be continuous in the construction phase. Congestion in the city centre is seen as a major problem, why a barge alternative to more trucks on the roads seems promising. If trucks are used, specific routes will have to be determined, as many construction projects will be on going simultaneously.

Also, the local environmental zone in Gothenburg will also put demands on congestion, noise and emissions of the transport modes and even though the same demands are put on barges as on trucks regarding emissions, the barges will not lead to congested roads. To conclude, the local authorities will have to take the transport decision into account when planning construction works and developing the cityscape. The transport decision will as mentioned be made of Trafikverket who wants a cost efficient, reliable and sustainable mode of transport, which makes the use of barges interesting, as it is showed in the environmental analysis that barges has less negative impact than transport chains where truck is the main mode of transport.

The *residents* and business in the city are also affected by the transport decision, even though they are sometimes neglected by theory. More businesses and residents are moving to cities (MDS Transmodal, 2012) and the urbanization rate of 0.6 % shows a steady increase. In coastal areas, like Gothenburg, the rate is even higher (EEA, 2013). The more people that move into urban areas, the larger amount of freight transport is needed, and the higher the level of traffic congestion, noise, emissions, and accidents becomes (Taniguchi and Thompson, 2003).

When looking at the shafts in the Rosenlund area, the area is heavy populated and businesses together with local authorities have put effort on improving the area. When the large amount of excavated mass from the two shafts should be transported, the residents and businesses in the area will be greatly affected and when talking to businesses in the area, this is seen as a major problem. As mentioned in Chapter 5, the residents interviewed in this thesis emphasize that the transport solution must meet the requirements regarding noise, dust, safety, visual intrusion, and the ability to move freely in the area. Noise is caused by freight vehicles, and in urban areas, this can be an issue during night-time (MDS Transmodal Limited, 2012). The construction work and mass transport is however not planned to go on more than 22 pm at night. Dust and visual intrusion are also important aspects, as businesses and residents will be affected by it. The organizations and estate-owners in the area stress the importance of minimizing the negative aspects of the transport in the area. They need goods to be transported to the businesses in the area and tourists to walk on the roads. The interviewed residents prefer the use of urban waterways as it can reduce the number of trucks in the area of Rosenlund and hence reduce the potential safety risk. Both organizations talked to welcomes the use of water transport, as this can reduce the use of construction trucks from the roads in the area and they also think it is in favour for the cityscape.

To conclude, the amount of mass that needs to be transported is large, and the stakeholders affected are many. The main actor is Trafikverket, who defines the transport decision in its tender to the contractors. The shippers, transport operators, receivers, authorities and residents are all affected by the decision, but in general a barge solution has a positive impact on most stakeholder groups. The only group that is negatively oriented towards a barge alternative is the truck operators, who will lose business if not entering the barge market. The contractors will also be affected, as they might have to change transport operators for the barge transport, but does not see this as a major issue. Over all, barge transport would lead to less congested roads, less emission and about the same amount of noise as conventional transport and is also seen to have a positive impact on the cityscape. Residents, authorities and receivers are all sympathetic towards using barge transport. The different opinions of the stakeholders are illustrated in Figure 29.

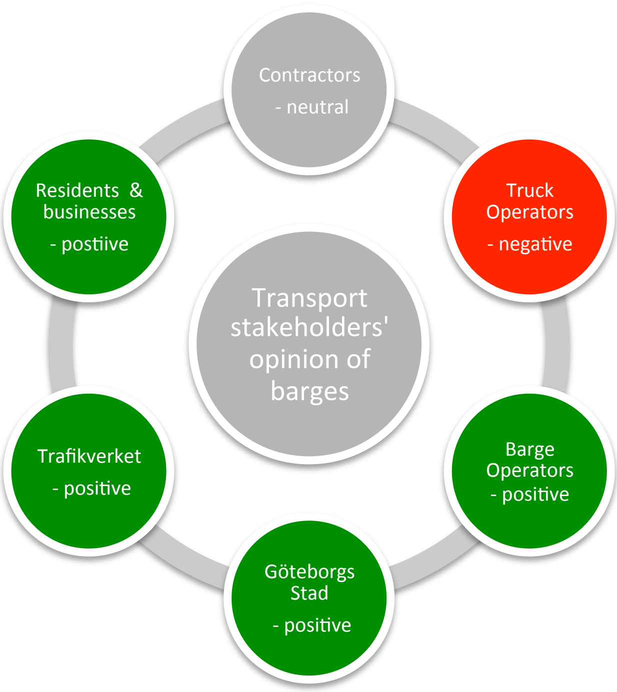

Figure 29. Transport stakeholders' opinion of using barges for mass transport.

7.2.4.2 Safety

Safety and the increased risk for accidents due to urban freight movement is a great concern, frequently mentioned both in the theory and during interviews. As mentioned in the theoretical framework, a majority of road accidents and one in three fatal accidents occur in urban areas. When deciding mode of transport, Arnäs (2012) provides an important model that estimates transport quality by multiplying security, safety, reliability and sustainability, divided by cost. It is clear that cost plays a crucial role when choosing mode of transport and is usually the determining factor, however in urban areas where the statistics shows that freight movement can result in fatal accidents and road accidents, safety as well becomes a crucial and potentially determining factor. This is also why inland waterways becomes interesting in this matter, as barge transport is known to provide a high level of safety (Lowe, 2005; Koning, 2009). As argued by McKinnon (2010) safety has been a highlighted aspect of logistics in recent years and tightening controls and enforcements in order to reduce the number of accidents due to road transport has been implemented. As a part of this, it can be argued that a stepwise increased usage of other modes of transport, with a determined higher level of safety, would be the natural evolvement.

The safety risks are generally considered to be higher with truck, although it is important to consider the evolving technology regarding safety aspects connected to trucks. For example within a few years there will likely be legislation requiring automatic brakes for all trucks[81]. As stated in the theoretical framework, some of the most important cost drivers for external costs related to safety are vehicle speed, type of road, drivers characteristics, time of day, traffic speed and volume, and technological development. The trucks referred to in this thesis are modern, which should imply reduced external costs from safety. However, as stated by Dablanc (2007) older vehicles are often used within urban freight, which thus would imply higher external costs. Regarding vehicle speed, the trucks will drive slowly with an average speed of 7 km/h in the dense urban area, which can be argued will decrease the safety risk. On the main streets on the other hand the trucks drives with an average speed of 35 km/h.

The construction of Västlänken will give rise to an increased transport need in Gothenburg, an already congested dense urban area. The focus in this thesis is as known three shafts in the area of Rosenlund, an up and coming area of the city where large investments has been made in late years in order to increase the movement of people in the area. When interviewing stakeholders involved in the area of Rosenlund, it became clear that a great concern is that the future mass transport may harm the future development of Rosenlund. The safety aspect is a part of this concern, as the combination of movement of people and trucks carrying mass constitute a safety risk.

The transhipments, loading and un-loading of the truck or vessel, is also important to consider when deciding transport chain in this case. From a safety perspective, using truck when loading the barge would constitute the same safety risk as for trucks in general. If the loading instead were done with a belt conveyor, the transport would be lifted away from the streets and a couple of metres up in the air. When meeting with Jehanders, who use belt conveyors daily in their work, it was stated that belt conveyors do not constitute any large safety issues for the people who are moving in the surrounding areas, besides the risk of driving into the belt if it is crossing the road[82]. On the other hand in the case of Citybanan in Stockholm, one of the main reasons for not using barge was that it was considered too high of a safety risk to let conveyors cross the busy streets in order to load the barges. It can be concluded that as belt conveyor is a rather untried transhipment method in urban areas, further investigations and pilot tests would be required in order to determine the potential safety risk.

[81] Volvo Group Trucks, meeting with Anders Berger (Product area manager) et al. (see Appendix 8), November 14, 2013.
[82] Ralf Hansson (Sales Manager, Sand & Grus AB Jehander) interviewed November 4, 2013.

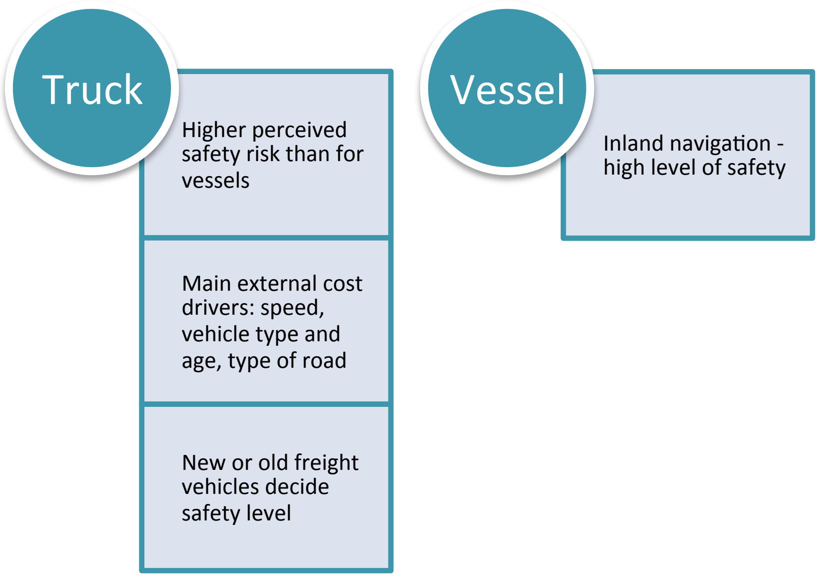

Figure 30. The main aspects affecting the safety risk for the two main modes of transport.

In conclusion, safety is a crucial aspect when determining mode of transport in urban areas as summarised in Figure 30. From a safety perspective, barge is considered as the preeminent freight vehicle.

7.2.4.3 Noise

When living and moving in urban areas, people get used to constant noise from cars, buses, construction sites, and freight vehicles. As stated in the theoretical framework, noise is especially regarded to bother the residents during night-time and the emissions are restricted to the actual time of emission. When implementing the environmental zone in central Gothenburg, and by that limit the usage of heavy vehicles, the main goal was to reduce emissions, noise and congestion. This means that the city has taken a stand and deliberately implemented rules in order to reduce, among other things, the noise emissions. The construction work will most likely go on between 7am and 10pm during the construction of Västlänken, hence the noise emissions will not disturb any residents during night-time. The noise resulting from the construction work and the mass transport will disturb stakeholders such as restaurants, businesses, shops, inhabitants and visitors as the construction work will go on for several years, and it is thus important to take on actions in order to reduce the noise emissions. As stated in Chapter 5, the predicted increase of noise due to the mass transport may complicate the property owner's ability to lease their space and furthermore make the area less attractive. As mentioned, large investments have been made in the area of Rosenlund lately in order to increase the neighbourhood's status and street life and too much noise emissions could easily damage the future development of new restaurants and businesses for example.

As mentioned in the theoretical framework, noise emissions from shipping mainly consists of the noise generated when loading the vessel, which is easier to address and reduce than noise from for example road and air freight as it has a different nature. By using for example quieter ramps, the loading of the vessel can be made with less noise emissions. In the case of Förbifart Stockholm, described in Chapter 4, a proposed solution for the transport from excavation site to the vessel that will transport the mass to the location for land-fill a belt conveyor belt will be used. When the mass leaves the belt conveyor it will get released through a dust and noise-dampening cone to the vessel's hold, which could be a suitable solution for the case of Västlänken as well when evaluating belt conveyors as a possible loading solution. However, when planning for the construction of Citybanan in Stockholm as well the use of belt conveyors were seen to harm the local environment due to noise and dust. During interviews made by the authors it has on the other hand been stated that noise and dust from belt conveyors easily can get reduced or even eliminated through full cover and isolation. In the other discussed transport solution, when using truck for the entire stretch, the noise emissions due to transhipments will be reduced, as there only will be one loading occasion and one un-loading occasion. As the loading of the truck most likely will be made within the work tunnel however, the noise emissions in the urban area from loading will be much lower for truck than for barge. On the other hand, other factors included in the noise emissions from trucks will increase. As said, the main emissions resulting from trucks depend on propulsion and the sound of rolling, and depend of the vehicle speed. Also type of vehicle and tyre, age of the vehicle and level of maintenance will affect the noise emissions. Hence, coherently with Chapter 8.2.2 above, the external costs from noise are very dependent upon how old vehicle fleet that will be used during the construction and increase/decrease with the vehicle speed.

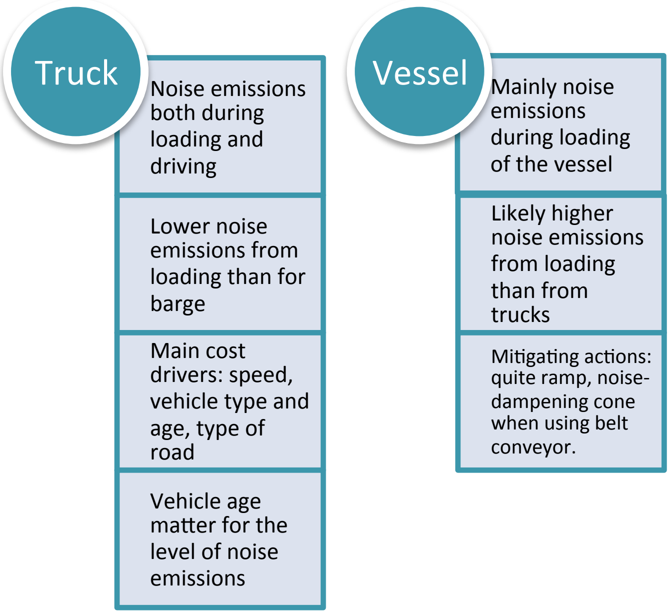

Figure 31. The main aspects affecting the noise emissions from the two main modes of transport.

In conclusion, no matter what mode of transport that is used noise emissions will be a fact, but they arise at different points of the transport chains depending on mode of transport as summarised in Figure 31. For barge, most noise emissions will arise during loading. For truck, the noise emissions from loading will be lower as the loading will take place within the work tunnel but on the other hand more noise emissions will result from the propulsion of the vehicle during the transport.

7.2.4.4 Visual Intrusion

Visual intrusion implies that the presence or vision of freight vehicles spoil the surrounding areas as stated in the theoretical framework, and becomes especially interesting in this case as the construction and thus movement of construction machines and trucks will go on for several years. During the stakeholder interviews, it became clear that the main stakeholders affected or familiar with the matter of visual intrusion are residents and authorities such as Stadsbyggnadskontoret and Trafikverket. As mentioned earlier, the main interest from the residents is that as little inconvenience as possible is caused with regard to noise, visual intrusion and dust. Trafikverket tries to minimize the inconvenience caused by the construction work by for example taking on mobility management actions in order to maintain the flow of traffic and people and make sure that people are able to go from one point to another. The aim with this is that people shall not feel displaced or be scared by the freight vehicles. Trucks can be argued to result in a higher level of visual intrusion than barge in this matter, as they will block the way for people and vehicles and by that also spoil the surrounding areas. When constructing Citybanan in Stockholm, as described in Chapter 4, as small trucks as possible were used and it can be argued that a contributing factor was to minimize the visual intrusion for the people living and acting in central Stockholm. This could be one way of minimizing these effects in Gothenburg as well. There is however a trade-off between smaller trucks in order to reduce the visual intrusion and increased emissions, as more trucks will be needed when using smaller vehicles. Stadsbyggnadskontoret furthermore argues that it is possible to take on other actions in order to minimize the visual intrusion during the construction work, such as using the belt conveyors for displaying information to the citizens. They furthermore emphasize the usage of vessels instead of trucks in order to utilize the waterways in Gothenburg and hence bring out the vivid water in the city in order to reduce visual intrusion.

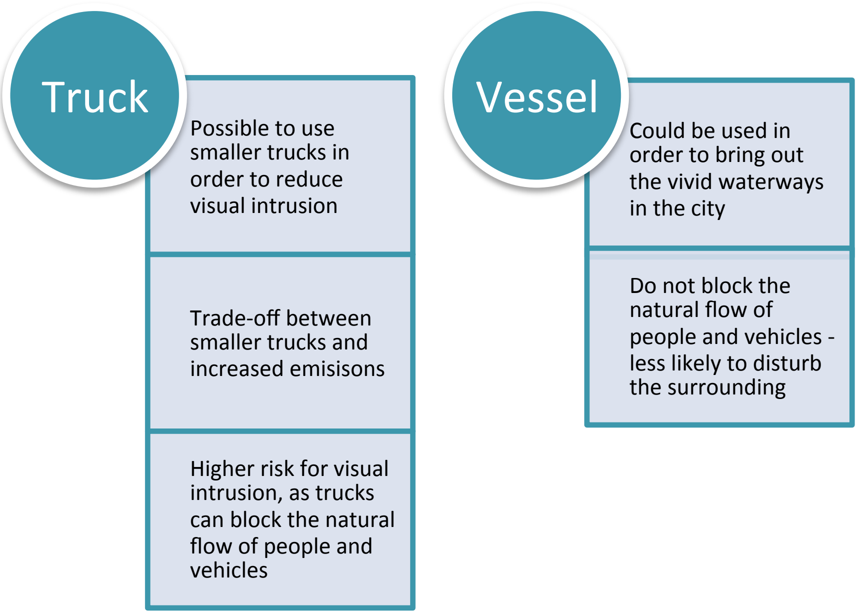

Figure 32. The perceived visual intrusion resulting from the two main modes of transport.

In conclusion, visual intrusion is a highly subjective aspect of sustainability and differs from one citizen to another. However, barge can be argued to be better from a visual intrusion perspective as it does not block the way for people and vehicles and by that do not disturb the surroundings in the same way as truck can be perceived to do as summarised in Figure 32.

7.3 Summary of results

To summarize the results presented it can be concluded that when considering both the feasibility aspects related to the various transport solutions and examined shafts, as well as the sustainability dimensions a preeminent solution for each shaft has been found. As seen in

Figure 33 the main transport mode for all three transport chains is OP1 while the transhipment method varies depending on the shaft.

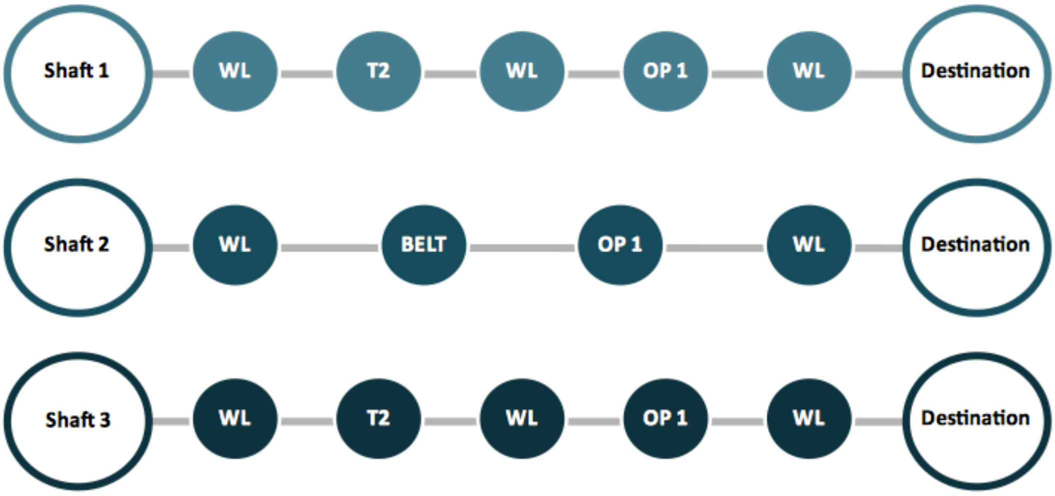

Figure 33. Feasible and sustainable transport chains from all three shafts.

8 Analysis

In this chapter, the results for both research questions are further analysed. First, a general analysis of the result is presented, followed by a system analysis where the results are put into a larger context. Third, a risk analysis is presented, followed by a last summary and a recommendation. In the end of the chapter, contributions to academia, areas of future research and reflections of the results are presented.

8.1 Changed prerequisites

A large barge has been seen to provide the most efficient transport solution. It is however important to consider the impact of the location of the barge. It has been shown that a location close to Shaft 1 and Shaft 2 does not make up for a smaller sized barge, even though it has shown to be a viable alternative to conventional transport. It can be concluded, that in the specific case investigated, the large barge is unbeatable, however each geographical location brings specific conditions to the transport chain, which aggravates the transferability of the results gained in one case to another (Lindholm, 2012a) and in accordance to Browne et al. (2011) the transport infrastructure, traffic levels and regulations differ between cities. Thus, to apply these results on a more general level, actual distances and vessels need to be compared to actual road distances and vehicles in order to see what mode that is most fuel efficient in each specific case, but as seen in this thesis, barge is an important transport mode to take into account when searching for fuel efficient alternatives to conventional solutions.

In order to understand the results on a more general level, the transport alternatives have also been compared per tonne-kilometre, and the existing infrastructure of Gothenburg is in this case excluded. The existing infrastructure investigated implied shorter distances when using barge, however the results show that barge is competitive also when the same distances for barge and truck are compared to each other. This is an important result, as cities are in continuous change and routes and distances are likely to change. This thesis shows that even though the distances would change on behalf of the conventional transport chain, a large barge is still a more efficient transport solution. It is also important to realize the opportunity to adjust the infrastructure in order to be able to utilize more suitable transport solutions. Some transport alternatives, such as using belt conveyor to the barge from Shaft 3 has been excluded due to limitations of infrastructure. If adaptions of roads or routes would be made, the barge alternatives would however show even better results in combination with belt conveyor. The long timeframe of the project also make grounds for temporary changes of the infrastructure, which implies that the results of the barge transports in this thesis can be further improved.

Another aspect that is relevant when analysing the results is the receiver of the mass, in this case, Göteborgs Stad. A barge solution would imply rare deliveries, rather than continuous truck deliveries. This requires a certain capacity at the receiver, however in landfill projects of the harbour this is not seen as a major problem, and the barge solution might even be a more efficient way of receiving mass. This is something that needs to be further investigated before implementing a transport solution. As both rock and clay will be used for the filling, the amount and the timeframe for the different material will also be a relevant aspect. What type of mass that is needed and at what time, should thus be investigated. To this point of the thesis, it has been assumed that the vessels only load one type of mass at the time. However, it might be that the receiver wants mixed loads. This would imply an increased efficiency for the barge alternatives, which will be further discussed in the system view analysis. To conclude, the capacity and the requirements of the receiver will play a crucial role in the transport decision, however it is evident that a barge alternative implies less unloading of mass and is flexible regarding mixed or separate loads of mass.

When different transport chains have been compared in this thesis, the technology available on the Swedish transport market today has been assumed. This has however led to different conditions for the barge alternatives and the conventional transport chain. The barges available on the Swedish market are equipped with old machinery, whereas the trucks investigated are new-releases. If barge transports were to be used, more alternatives would be available on the transport market as a wider market than the Swedish market could be explored, and the possibility of using more modern and fuel efficient machinery is evident. This would have implications on the calculations, and would benefit the barge alternatives. Also, if rules and regulations would change, or certain permits that allow larger trucks to be used would be implemented, the conventional transport solution can also be improved. It has been shown in this thesis that larger trucks result in a higher efficiency than smaller ones. However, it is then important to understand the trade-off between the visual intrusion of the city and the cost and environmental impact of the transport solution, as larger trucks are often viewed as negative for the visual intrusion of a city.

An interesting aspect to address when analysing the cost aspects of the different transport solutions is the personnel cost, as it constitutes the largest share of the average cost per hour for the conventional transport as well as for two of the barges investigated. A decrease of personnel cost would imply substantial reductions of the average cost per hour for these transport alternatives. As this project will go on for many years and no local knowledge of the road network is needed, the likelihood of using a foreign work force is large. However, the authorities do have an ethical responsibility and the social and equity aspect will thus be an important factor when the personnel cost is decided. This might however result in substantially lower costs for the conventional transport chain. The barge alternatives will also be affected, as the transhipments stands for such a large part of the cycle times. This is however not assumed to affect the internal comparison of the transport chains, and the large barge would still be more cost efficient.

Also, one of the main problems with the increased level of transport resulting from the construction work is congestion. The European Commission (2011) states that when a city as Gothenburg suffers from congestion, a high risk of affecting the city's economic growth negatively is apparent. In order for Gothenburg to keep its competitiveness, transport decisions should thus aim for decreased levels of congestion. A barge alternative would make use of the non-utilized waterways and would only lead to congestion in limited areas, were transhipment takes place. Congestion is one major factor to consider when making the transport decision, and barge transport would be in favour of the city in this aspect.

In conclusion, it can be said that presuming the prerequisites of this thesis, the large barge alternative from OP1 seem to be a more efficient mode of transport than the conventional transport chain. However, in order to fully understand the implications of an alternative transport chain, a system view analysis and a risk analysis are also performed.

8.2 System View

In this section, the total material flow from the three shafts is investigated in order to understand the entire system in which each mode of transport operates within. The system view is based on the results gained in both the feasibility and sustainability study. In total, the three shafts will give rise to 700 000 tonnes of mass that need to be transported[83]. For a conventional transport chain, this implies 60 000 shipments if using the smaller Truck 1 for all transport assignments and 45 000 shipments if using the larger Truck 2. This can be compared to the 160 shipments necessary for the largest barge from OP1 and 2500 shipments for the theoretical barge. This difference will be noticeable when looking at the congestion in Gothenburg and will also have effects on the transport system as a whole.

If using a conventional solution, the number of vehicles in the system is important, as it will decide how many vehicles that are taking up space on the roads simultaneously, thus affecting the congestion. The number of vehicles differs depending on what type of truck that is used, what type of mass that is transported, the excavation rate of this mass and for what distance it is transported. The excavation flow for rock is assumed to be quite smooth throughout the process, resulting in an excavation rate of approximately 80 tonnes per hour from Shaft 2 and 80 tonnes per hour from Shaft 3. The flow of clay will however vary through the excavation process with a maximum rate at 100 tonnes per hour and with a minimum rate of 30 tonnes per hour. The number of vehicles necessary is listed in Table 11 and range between nine and twenty vehicles in total for all three shafts. For Shaft 1, the number of vehicles varying during the excavation process, which is not seen as a major problem, as the availability of construction trucks are usually flexible with many operators available[84]. If the larger Truck 2 is used for the transports, fewer vehicles are needed, as each carrier will load more mass each trip. This results in that no more than eight vehicles will be used simultaneously for rock and no more than six for clay.

Table 11. Trucks needed in the system simultaneously

Trucks in the system		
Distance	**Truck 1**	**Truck 2**
Shaft 1 - Frihamnen	2-8	2-6
Shaft 1 - Port of Gothenburg	2-6	1-5
Shaft 2 - Frihamnen	6	4
Shaft 2 - Port of Gothenburg	5	4
Shaft 3 - Frihamnen	6	4
Shaft 3 - Port of Gothenburg	5	4

For the barge alternative, the system is however more sensitive to fluctuations in demand, and if the excavation suddenly stops, the barge will have to be docked for a longer time. Unlike truck, the barge cannot be used for other services while waiting and will result in an additional cost to the project. The urban context of this case also implies limited possibilities for intermediate storage. This is not a problem for the conventional solution, as the frequent flow only needs small storage. However, for the barge alternative this is a major problem and in a transport system with two large barges that load one type of mass each, a huge amount of

[83]John-Erik Fredriksson (Construction and Project Manager, COWI) interviewed October 16, 2013.
[84] Dan Andersson (Senior Lecturer, Chalmers). Lecture in Transport Systems October 31, 2012.

mass will have to be stored while the barges are unloading, as seen in Table 12. The table also shows the amount of storage necessary if one large barge with the ability to load mixed types of mass is used. As seen the storage needed varies depending on the cycle time of the barge transport chain and the excavation rate, and varies between 107 and 1719 tonnes.

Table 12. Intermediate storage needed for OP1.

Intermediate storage needed for OP1		
Distance	**Cycle time [h]**	**Intermediate storage [t]**
Skeppsbron - Frihamnen CLAY (Shaft 1)	3,6	107-357
Skeppsbron - Port of Gothenburg CLAY (Shaft 1)	5,5	164-546
Skeppsbron - Frihamnen ROCK (Shaft 2 & 3)	5,3	863
Skeppsbron - Port of Gothenburg ROCK (Shaft 2 & 3)	7,2	1173
Skeppsbron - Frihamnen MIX (Shaft 1,2 & 3)	5,0	970-1220
Skeppsbron - Port of Gothenburg MIX (Shaft 1,2 & 3)	6,9	1337-1719

As the storage possibilities are scarce this type of storage is not regarded as feasible, which is why alternative transport combinations need to be investigated. An alternative would be to use four large barges for the transports. However, this would result in increased cost due to dock-time and would also imply difficulties when all four barges need to be docked simultaneously. This reasoning is based on the assumption that the different mass types must be treated separately, however the barge's cargo space could also be divided into sections; one used for clay and one used for rock. This solution would make the time necessary for fill-up of the barge decreased, as mass from the three shafts would be loaded concurrently and would also decrease the storage needed. The ability to carry different kind of mass in the same shipment would also contribute to an increased flexibility and make the transport system less sensitive to unexpected excavation stops as all three flows are merged into one flow. However, if an excavation stop becomes reality this will, as mentioned, result in increased docking time and cost. Figure 34 presents how the total cost per transported tonne varies with the docking time for OP1. As seen an excavation stop that lasts for two weeks, resulting in a 336 hours increased docking time, would still result in a transport cost per ton about the same to that for truck. The figures presented are valid for a one barge system, however in conclusion, it is regarded feasible and efficient to use two large barges, similar to the one from OP1 that are able to load mixed typed of mass. However, if separate types of mass should be loaded, a conventional transport chain need to be used in combination with the barge alternative, in order to mitigate the limited space for storage.

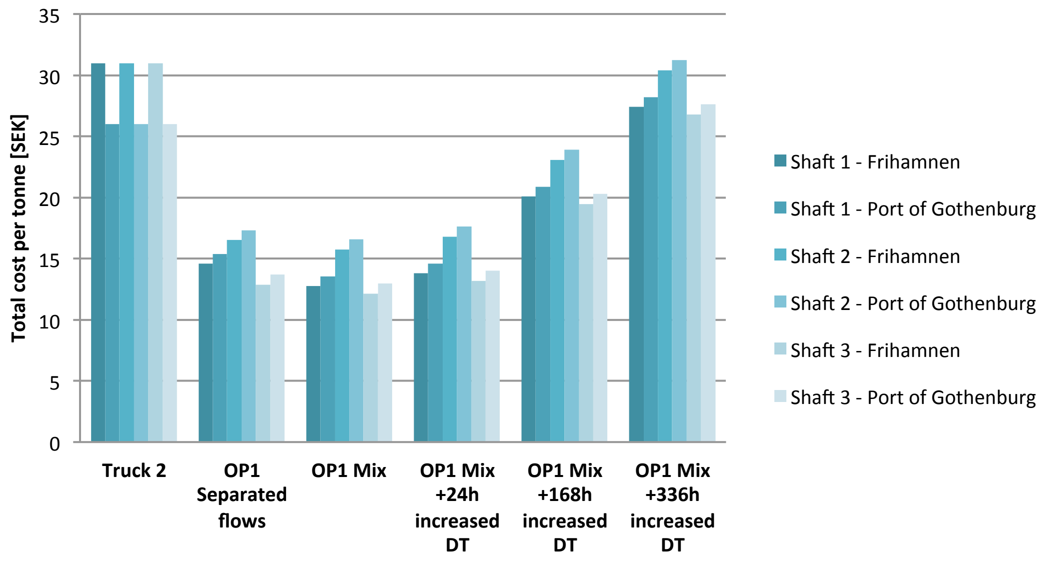

Figure 34. The total cost per transported tonne varies with the docking time (DT) for OP1 when T2 is used for transhipment from all shafts.

When investigating the theoretical barge that fits in the canal next to Shaft 1 and Shaft 2, similar storage issues are apparent. Also here, the use of more than one barge is necessary to avoid the storage. The storage needed varies between 42 tonnes to 624 tonnes, and even though this is less than for the large barge from OP1, the space is even more limited at these shafts and this is regarded as a major problem. The storage needed for each shaft and cycle times is presented in Table 13.

Table 13. Intermediate storage needed for Barge in Vallgraven.

Intermediate storage needed for Barge in Vallgraven		
Distance	**Cycle time [h]**	**Intermediate storage [t]**
Rosenlund - Frihamnen CLAY (Shaft 1)	1,4	42-143
Rosenlund - Port of Gothenburg CLAY (Shaft 1)	3,4	103-343
Rosenlund - Frihamnen ROCK (Shaft 2)	1,4	117
Rosenlund - Port of Gothenburg ROCK (Shaft 2)	3,4	281
Rosenlund - Frihamnen MIX (Shaft 1 & 2)	1,4	160-260
Rosenlund - Port of Gothenburg MIX (Shaft 1 & 2)	3,4	384-624

By using two barges when the destination is Frihamnen or three barges when the destination is Port of Gothenburg, the amount of storage would be regarded as feasible. However, it is also important to keep in mind, that if using a barge in the small canal, the material flow to the barge in Göta Älv will only consist of rock from Shaft 3, which will affect the system as a whole. It can be said that this separation of material flow would lead to a higher total cost as well as a higher environmental impact, and can thus not be recommended from a system view perspective. However, if there of some unknown reason will be impossible to dock a large barge at Skeppsbron, the theoretical barge is a good alternative to truck, especially thanks to the environmental benefits that can be achieved but also from a cost perspective as proved earlier. The theoretical barge is however more sensitive to excavation stops than OP1, as seen in Figure 35 an excavation stop lasting for only 24 hours would imply that the theoretical barge reach the same cost level as the truck alternative. With more than one barge in the system this time becomes even shorter as it is assumed to be a time cost for all barges even when they are not in use. Thus it is recommended, to investigate the risk for excavation stops further before deciding if this alternative is economic sustainable and if so how many barges that would be optimal to use.

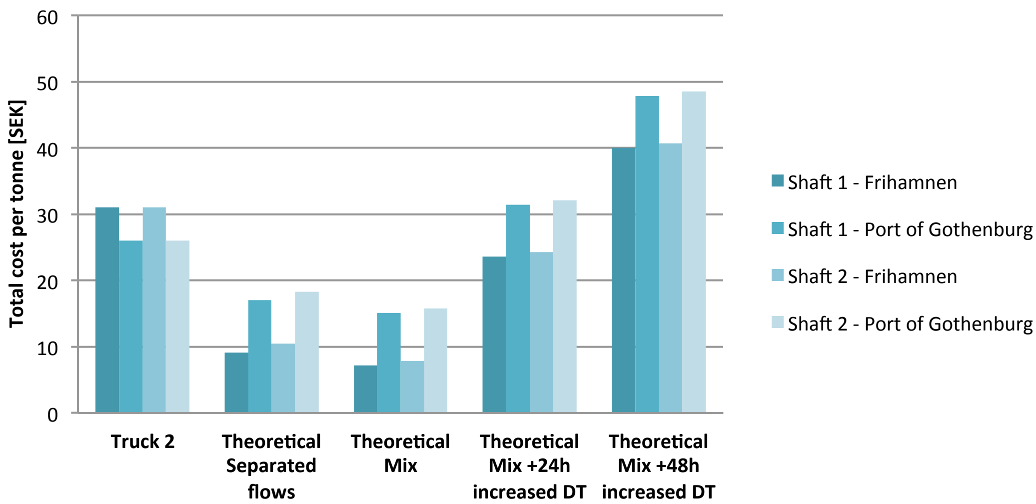

Figure 35. The total cost per transported tonne varies with the docking time (DT) for the Theoretical barge.

In conclusion, if using two large barges similar to the one from OP1, able to handle a mix of the two types of mass, an efficient and feasible transport chain would be achieved. However, if the mass is not possible to be mixed, the barge solution needs to be combined with a conventional transport solution. The alternative of using small barges in the canal at Shaft 1 and Shaft 2 would affect the total material flow negatively, as the material flow from the three shafts would be separated, and thus this is only recommended if OP1 cannot be used. If this is the case the risk for excavation stops must be further evaluated before deciding if this option is economically justifiable, however from an environmental perspective both OP1 and the theoretical barge beats the truck alternative.

8.3 Risk Analysis

The choice of transport chain implies risks on the economic impact, the environmental impact, the social impact and the feasibility of the transport alternatives. In this section, a risk analysis is performed based on the model described in the theoretical framework, see Figure 3, where the most important risks are identified and analysed. In the risk evaluation, mitigation actions are then proposed.

8.3.1 Feasibility risk

Both the barge solutions and the conventional transport solution are regarded feasible. However, *risks when implementing a new transport mode*, that has not been used in the area before is obvious. Transhipment aspects for the barges might need to be adapted to the specific conditions in other ways than those that have been calculated for. The risk of space limitations at the shafts might also lead to risks of difficulties for transhipments to both truck and barge. This risk is especially important if barge is used as the only transport alternative. However, the risk is mitigated if barge is used combination with truck as truck is a well-established mode of transport and risks are known from earlier experiences.

The need of intermediate storage is identified as a large risk when using barge, due to the scarce space in the dense urban area surrounding the shafts. This is only a risk when using separate barges for each type of mass.

The risk of coincide with other projects in the area is impending, and all transport solutions will be affected in some way or another. However, the conventional transport solution is more flexible, and can change its routes more easily. The loading of the barge is limited to a few positions along the quay, which makes it more dependent on other projects in the area. Coinciding projects might lead to increased costs for adjusting belt conveyor or other transhipment in order to pass congested areas.

8.3.2 Environmental risk

The risk of an increased impact on the environment is mainly related to the fuel consumption. It is shown that the capacity of both trucks and vessels is significant for the total fuel consumption, and if regulations and permissions would restrict the size of the vessels and trucks to the extent where the vehicles calculated for are not feasible, the fuel consumption will increase. This risk is higher for trucks, as they will use the public road network and the consequences for the environment are evident. The difference in fuel consumption when using the smaller truck compared to the larger one in this thesis, is more than 20%. This is directly related to the environmental impact. For the barge this risk of occurrence for size limitations is low, as vessels are not regulated in size to the same extent as trucks.

Barges also imply the *risk of impact the water environment*, as the vessels are coated with bottom paint that is contaminating the water. This is not accounted for in the environmental analysis, as the environmental impact is limited to an emission audit. Also, in this thesis a modern truck fleet is compared to old barges. More efficient barges that are more optimal would reduce the risk of increased environmental impact for the barge transport solution, and the risk of using an old vehicle fleet of trucks would increase the environmental impact.

8.3.3 Cost risks

The *risk of costs resulting from congestion* is major when looking at the conventional transport chain, where truck is used as the main mode of transport. More than 300 trucks a day will add to the already congested city centre of Gothenburg and lead to increased delays and more fuel consumption. If decreasing the speed of the truck to half of the speed that is calculated for, the total cost per hour increases by 70%, mainly due to increased labour time. In conclusion, the risk of occurrence and the consequence of congestion are high for truck transport chains.

Costs resulting from fluctuations in transport demand are likely to occur, as production stops are hard to foresee. For barge transport chains, the consequences are higher than for conventional transport chains, as the barge will have to wait empty, whereas the truck is more flexible, and can perform other services while waiting. When looking at the results from OP1, a twice as long work cycle leads to an increase in total cost of 20% for clay and 10% for rock.

In conclusion, the barge alternative implies a higher risk on costs due to demand fluctuations than the conventional transports.

The *costs for transhipment* represent a substantial part of the cost for both transport alternatives. However, belt conveyor implies risks that the other construction machines do not. If the belt breaks, it will stop the transport chain if trucks are not available. Also, the investment cost and the cost of montage are also to consider, as the belt is adjusted to the specific location and hard to reuse without montage and new adjustments. The transhipment space is also a major risk factor when it comes to the barge solution, as storage is needed while the barge is unloading the mass. In conclusion, the barge implies more risks for transhipments and truck is more flexible and can replace each other in a more smooth transport flow.

Other risks identified are *the risk of increased fuel price, costs due to unexpected weather conditions and infrastructure costs* that will only have minor effects on both of the transport solutions. If the fuel tax for barge were increased to the same levels as for truck transports, it would only result in an increase of 0.3% in total cost. For truck, a 20% increase of fuel cost would result in a 4%-increase in total cost. The barge solution is more sensitive to changed weather conditions, and would imply waiting times for the transport. However, if using truck in combination with barge this risk is mitigated. Infrastructure cost occurs for both modes of transport. For barge, the main issue is costs for adjustments of quays and for truck the main issue regards usage of the road network and wear of infrastructure. In conclusion, the risks are regarded as minor and are similar between the two modes of transport.

8.3.4 Social risks

The *safety risk* is higher when using truck than barge. An increase of more than 300 trucks from the shafts investigated each day will substantially increase the risk of accidents, and a rising number of serious accidents involving freight vehicles are already observed to increase (MDS, 2012). This can be compared to the barge solution that is claimed to be one of the safest modes of transport (Lowe, 2005), even though a belt conveyor solution would imply risks when crossing roads and located close to residents. When looking at the risk of leakage of contaminated mass, both transport modes implies risks. The difference is where the leakage will occur; either in the water or in the urban road network. In conclusion, the conventional transport solution implies a higher safety risk, mainly due to the risk of accidents. When it comes to leakage both modes result in a risk of damage on health and the environment.

The *risk of visual intrusion* concern all modes of transport, however trucks are often associated with a negative impact on visual intrusion for residents and businesses in the city, as businesses and estate owners might be affected by decreased revenue due to heavy trafficked roads and construction areas that are blocking views. The barge alternative would imply less risk, and is also not as negatively associated with visual intrusion, even though this is highly subjective. In conclusion, the risk of decreased revenue for stakeholders is higher for a conventional transport chain than for barge transport.

The *risk of noise* is evident for all transport modes investigated, and when transporting rock it is hard to bypass. When comparing barge and truck, the barge alternative implies a larger noise for transhipment and the conventional transport solution results in more noise when driving in urban areas. If belt conveyor is used in combination with barge, the noise for transhipments will however decrease.

The transport decision also implies risks for Trafikverket, as they will be responsible for the decisions made. Also, the mass transport is already reported in media, and it is likely that any problem occurring will be followed up and highlighted. A barge transport chain will likely be more questioned, as it has not been used in the Gothenburg area the latter decades. The risks of the conventional transport chain are experienced and easier to foresee. However, it is possible that a proactive and sustainable transport solution of using barge transport chains will give positive feedback in media.

8.3.5 Risk evaluation – mitigating actions

In this section, mitigating actions for the proposed risks are suggested. Actions for feasibility, environment, cost and social aspects are presented in Figure 36 accordingly.

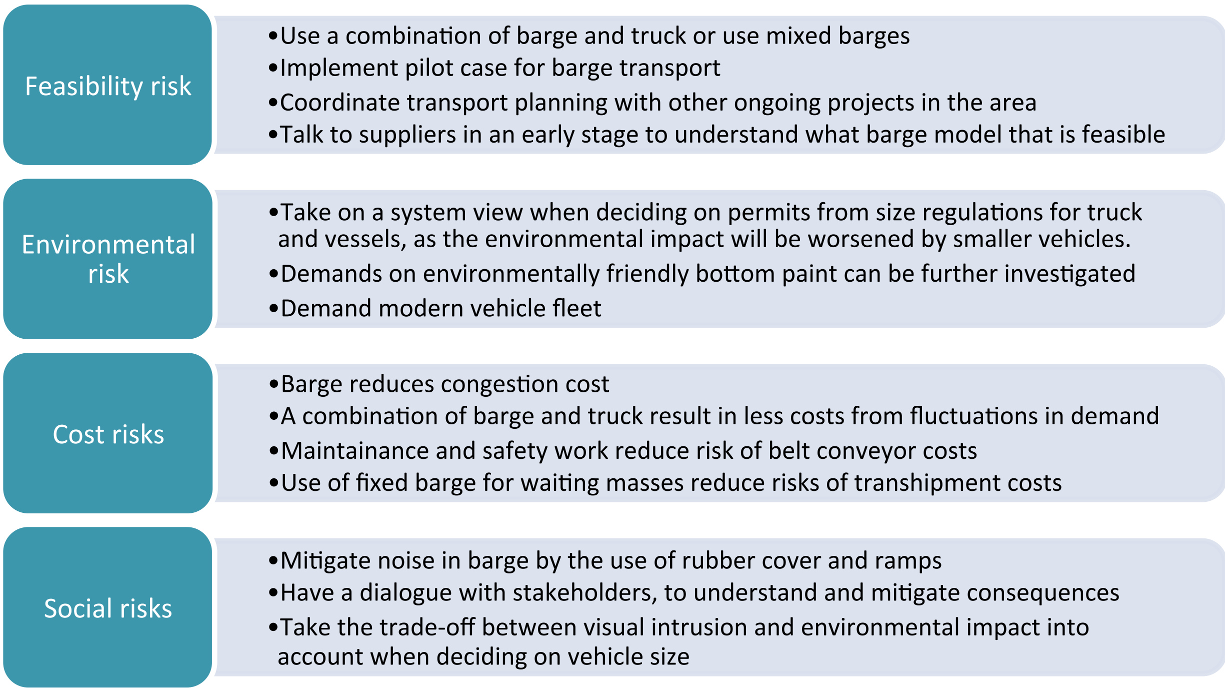

Figure 36. Mitigating actions for proposed risks.

8.4 Recommendation

In conclusion, the large barge from OP1 outclasses all other transport solutions both regarding feasibility and sustainability. When taking on a system view perspective, it is shown that two large barges with mixed types of mass is the most efficient combination for the total flow of mass from the three shafts investigated. The mass flow from all shafts would then merge to a combined barge transport, as illustrated in Figure 37.

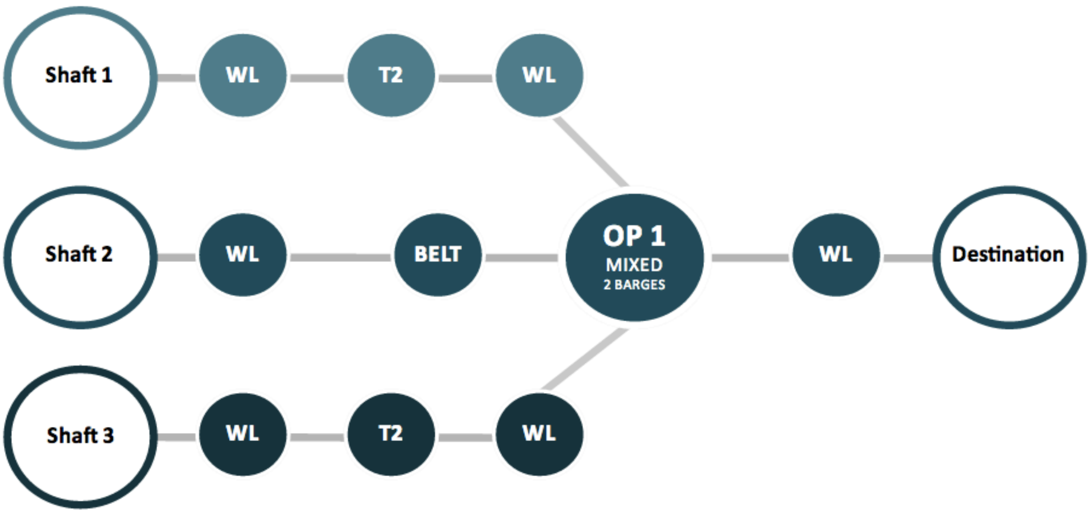

Figure 37. Recommended transport chain.

The solution would lead to less congestion and decrease the safety risk, which are two of the main concerns with the increased levels of transport in the project of Västlänken and in urban logistics. A barge alternative is also in accordance with the stakeholder analysis and would at the same time decrease the impact of noise and visual intrusion for residents and business in the area.

If mixed loads for some reason would not be feasible, an alternative of having two barges, one for each type of mass, in combination with conventional transport is recommended. This solution would not be as efficient as the first alternative, but would serve as a second best alternative that mitigates the risks of flexibility of the system.

Finally, if it is not possible to transfer the mass to Skeppsbron, where the large barge is located, the theoretical barge in Vallgraven needs further investigation. Even though this alternative does not come close to the results and efficiency of the large barge from OP1 with the given values of fuel consumption and cost, it would still decrease the environmental impact and decrease congestion, safety risk and visual intrusion in the city centre. Thus, this alternative deserves attention for further research and an "optimal barge solution" could probably also lead to improved results.

The risk of uncertainties when introducing new modes of transport is always a fact, but the risk also needs to be compared to the perceived benefits of the solution. The result of the barge alternative is outstanding, why effort to mitigate risks is motivated. Mitigating actions and further research is thus recommended before implementation.

8.5 Reflections

In this section some reflections when taking on a wider perspective than the scope of this thesis is discussed. Also, future areas of research and the contributions to academia made by this thesis is presented.

When taking on a wider perspective, and considering the transport market as a whole it can be argued that barges and trucks compete on different terms. Both modes of transport compete on the same market, as defined by Lumsden (2012) however, as there are few barge operators available in Sweden, the level of competition is considerably lower between barge operators than between truck operators. This might affect the costs of barge transport and a more competitive market would probably push prices. Small margins and operators that cut on costs, for example by hiring foreign personnel, characterize the competitive truck market. Similar actions might be the future of the undeveloped barge market.

Also, an important aspect to address with regards to the transport market for vessels is the currently unclear market for IWW in the year of 2018-2028 when the construction of Västlänken is planned to take place. If the discussed EU directive regarding inland waterways gets implemented, this would open up the market for foreign operators and could imply the availability of more modern fleets and a market characterised with more competition than today. Some of the vessels analysed in this thesis are old, and this could hence affect the presented results positively. As mentioned, an increased competition would probably also push prices and make the operators cut on costs.

As discussed in the thesis, truck is the conventional mode of transport in construction contexts. It is interesting to reflect upon the fact that this does not change despite the fact that barges has proven to be a better alternative, both with regards to price and environmental impact in theory. It could be argued that there is a resistance against change on the market and as trucks are reliable and well tried, it is the easiest option when buying transport services. The project of Västlänken has also received much media attention right from the start, and has been subject for several debates. This means that any minor slip might attain attention in media, which could be one reason why a fear of trying new transport solutions exists. However, it is important to emphasize the possibility for the city of Gothenburg to position itself as a sustainable city at the forefront of sustainable UFT. The use of urban waterways could also imply further opportunities, such as open up for a vivid waterfront and increase the ability of the city as a port town.

Also, the mass transport from different construction projects in the city are normally performed separately. Small volumes that could have been merged are often not enough for one contractor to buy barge transport services. In a large project like Västlänken, that will involve the entire city of Gothenburg, it is however important to take on a holistic mind-set. This thesis has only focused on three shafts of the project, and the entire stretch of Västlänken will give rise to millions cubic metres of mass. As Trafikverket are the project owners and regulate under what conditions the transport can be performed, the project of Västlänken provides an excellent opportunity to take on a holistic view and try new, sustainable transport solutions.

Finally, the use of barges in the city centre also brings opportunities for the city logistics of Gothenburg. This is seen in other parts of Europe, where barges are frequently used for the transport of goods, waste and also serves as tourist attractions. The use of barges for other type of transport would also increase the flexibility, decrease cost and develop the barge transport market. Sustainable city logistics is a hot topic in Gothenburg, and besides the on-going project of city deliveries, 'Stadsleveransen', where deliveries are made with small electrified vehicles, barge transport can be a next ground-breaking step. To reach the goal set by the European Commission of CO_2–free city logistics by 2030, radical changes are needed and using the city's waterways is one way of reducing the CO_2 emissions from city logistics.

8.4.1 Contributions to the area of urban freight transport

The research within the area of inland waterways is rather limited, which is why this thesis makes a great contribution in proving the sustainability of inland waterways in an urban freight context. The thesis provides a comparative study of barges and the conventional transport chain and shows that barge has both cost- and environmental benefits based on the condition of a relatively large flow of mass or bulky products in a city environment closely located to waterways. This thesis concludes that barge is a competitive and sustainable mode of transport and also opens up for future possibilities of improved barge solutions in city environments.

Also, this thesis contributes to academia through a comprehensive stakeholder analysis where a majority of authorities, transport operators, shippers, receivers and residents are interviewed and are shown to be positive towards the use of urban waterways in construction projects. Even though this study has been conducted focusing on the case study of Västlänken in Gothenburg, the results are transferable to similar projects in Gothenburg and also to other cities, if adapted to its context. This thesis highlights the importance and benefits of using barges in urban freight transport, which highlights the need of further research within the area.

8.4.2 Future areas of research

This study has attained a broad logistical perspective, investigating several feasible transport chains for the excavated mass but has mainly focused on the main modes of transport, construction trucks and vessels. The broad approach has definitely contributed to strengthening the result of this study. However, due to the broad character of the research, the possibility to probe deeper within specific areas, and investigating each factor more thorough, were limited.

Transhipments have proven to be crucial in order to have efficient and effective transport chains for the excavated mass and an important future area of research is thus the optimization of transhipments within the total flow. As a part of this, possibilities for the transport of clay on belt conveyors have been identified when the authors have been in contact with suppliers of belt conveyors, which further create possibilities for future research. A visualization of an optimized flow including different kinds of transhipments would provide further reliability to the results.

Furthermore, in this thesis a geographical limitation has been set, starting at the top of the shafts and ending at the assumed landfill positions at Frihamnen and Port of Gothenburg. If the distance for the transport chains including truck and barge with truck as transhipment method instead were to start from within the tunnel, which is more likely, this would affect the results, as the impact on both cost and the environment would increase. However, the increase would be similar for the two main modes analysed and would thus not change the outcome of the study. For the transport chains including belt conveyor or the theoretical vessel solution, extra transhipments will possibly be necessary due to the geographical limit set at the entrance to the tunnel, which also can affect the result. However, as this thesis is written from an UFT perspective, it is the transport that is taking place in the urban area that affects the conclusions and not the transport within the work tunnel or shaft. If taking another perspective, such as construction logistics, the most efficient transport within the work tunnel or shaft would be a very interesting area to investigate further.

Finally, it is important to note that the theoretical barge solution that has been discussed and could be developed is described as a theoretical example in this thesis. A future area of research could further improve and optimize the suggested conceivable and sustainable vessel solution, adapted to the conditions in Vallgraven and include new technologies e.g. for energy transfer and propulsion. As discussed the development of such a vessel could have further aims, in addition to mass transport similar vessel solutions could for example also be used for city logistics and freight deliveries in the city centre of Gothenburg.

9 Conclusion

In this chapter, the purpose is addressed and conclusions are drawn based on the theoretical framework, the benchmarking of cases from other cities, the case study of Gothenburg and Västlänken, and the analysis of feasibility and sustainability in order to answer the research questions.

The aim of this thesis was to investigate and analyse the use of urban waterways for mass transport, and the purpose of the thesis was *'to evaluate the feasibility and sustainability of urban waterways when transporting mass in urban areas in connection with the construction of Västlänken in Gothenburg'*.

The first research question addressed the feasibility of urban waterways for mass transport from the construction of Västlänken. This thesis shows that it is feasible to use urban waterways from all shafts and for both types of mass investigated. However, a barge alternative implies a higher risk than the conventional transport chain due to uncertainty and its lower flexibility, as the barges have to wait unloaded at fluctuations of transport demand.

The most feasible transport solution would be to use two large barges that are able to handle mixed mass. This barge would be located in Göta Älv and would handle mass from all shafts simultaneously. If the barge cannot handle mixed types of mass, it needs to be combined with a conventional transport chain in order to avoid large storage. A theoretical barge that fits in the canal at Shaft 1 and Shaft 2 has also been investigated, but is not regarded feasible when analysing the total transport flow, as it would separate the material flow from the three shafts, and thus decrease the economy of scale and scope. Finally, when investigating the feasibility of transport modes, the results are highly dependent on the infrastructure system and thus differ between cities and countries. The result of the first research question is thus specific for the area of Gothenburg and the specific shafts investigated.

The second research question addressed was whether the usage of urban waterways is a sustainable alternative to conventional road transport. This thesis concludes that the fuel efficiency for the different transport chains is significant for the results of environmental impact and total cost. Barge has shown to be more fuel-efficient than truck for specific barge alternatives, however the load capacity and transhipments are shown to be significant parameters to take into account when comparing transport chains. Barges with a large load capacity and barges that offer locations with less transhipment are shown to be the most fuel-efficient modes of transport for large mass flows.

From an environmental perspective it can be concluded that the dominating emission factors resulting from mass transport are PM, NO_X and CO_2, which implies that the main impact categories affected are air pollution, PM and NO_X, and climate change, CO_2. The transport chain that shows lowest environmental impact are the ones where a large barge is used, and where the theoretical barge that would fit in the canal close to Shaft 1 and Shaft 2 are used. This follows the same logic as for the fuel consumption. It is thus shown that barge is an environmentally friendly transport mode also in the case of Gothenburg. However, truck shows lower emissions than the less efficient barges, and it is thus important to take the loading capacity, transhipments, and man-hours needed into account when comparing the environmental impact of transport modes.

From an economic perspective, barge transport chains show to be more cost efficient than conventional transport chains for barges with large loading capacity and for smaller barges located closely to the construction sites, similar to the environmental analysis. The main cost parameter for vehicles and vessels is labour cost, and man-hours need to be used efficiently. The load capacity is thus an important factor as less man-hour is then used for each tonne transported, both for vessels and trucks. Barge has in the other cases investigated showed to be an expensive alternative to conventional transports, however this thesis shows that barge ought to have a fair chance in the tender processes, as it is much likely to be more cost-efficient than other transport modes due to its large loading capacity and its efficient use of man-hours.

From a social perspective, barge shows clear benefits regarding safety, noise and visual intrusion. Safety has been identified as a critical aspect of UFT, and an increased number of heavy vehicles in the urban environment would affect the already rising number of accidents. The stakeholder analysis also shows that all stakeholders except from truck operators are in favour of the use of barge transport. Trafikverket is considered to be the most important actor and is the transport decision maker in Västlänken. One of the main conclusions drawn in this thesis is that Trafikverket needs to have a continuous dialogue with other stakeholders to mitigate the consequences of increased mass transports in the urban environment. A combination of barge and truck transports would be one way to mitigate the consequences for the resident and businesses located at the affected areas, and would decrease visual intrusion, safety risks, noise and improve air quality, delays, and costs due to congestion in urban areas. As concluded from the study of similar cases in Sweden, a demand on barge transport needs to be formulated in order for stakeholders to change old habits and business relations. A demand on barge transport is thus invited in order for barge transport to be implemented in the project of Västlänken.

In conclusion, barge has a great potential on environmental impact, social impact and economic impact for large flows of mass transport and is also considered a feasible alternative to conventional transport when transporting excavated earth in the area of Gothenburg. The infrastructure of Gothenburg allows for efficient barge transport flows and the short distances gained when using the seaways result in sustainable transport solutions. A well working transport system is a precondition for economic growth of cities and the urbanisation of Gothenburg requires mitigation actions in order to handle the congestion. Barge transport is an efficient way of making the transport system in Gothenburg more sustainable and would also facilitate the need of more frequent and efficient deliveries in the city centre, as it would relieve the road network.

Each geographical location brings specific conditions, which complicates the transferability of the results gained in one case to another (Lindholm, 2012a). However, the results gained in this thesis shows that barge should definitely not be excluded from the discussions of sustainable UFT. Urban waterways have had and will play an important role in the development of cities and economies and Adam Smith's words from the late 1700 are valid to this day:

'As by means of water-carriage a more extensive market is opened to every sort of industry than what land-carriage alone can afford, so it is upon the sea-coast, and along the banks of navigable rivers, that industry of every kind naturally begins to subdivide and improve itself…'

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Appendix 1 - Vallgraven

The geographical prerequisites for Vallgraven can be seen in the map below (Figure A1). The width and height limitations are both found at section 9-9617-87, and have been taken into account when specifying the conditions for the theoretical barge.

Figure A1. Vallgraven (VBB Anläggning, 1996).

Appendix 2 - Fuel Consumption

The fuel consumption for the different transport chains was calculated and served as a base for the rest of the calculations. Data of fuel consumption for each mode of transport was collected and is presented in Table A1 and Table A2. In combination with the distances and split of each mode, the total fuel consumption was calculated for each transport chain, as described later. The distances vary depending on what type of infrastructure that is used and what shafts and end positions that are investigated, as the seaways allow for shorter distances than the road network. The distances are presented in Table A1.

Table A1. Distances from shafts, dependent on type of transport mode.

Table A1: Distances	
Conventional Transport Chain	[km]
Shaft 1 - Frihamnen	13,5
Shaft 1 - Port of Gothenburg	11
Shaft 2 - Frihamnen	12,5
Shaft 2 - Port of Gothenburg	10
Shaft 3 - Frihamnen	12,5
Shaft 3 - Port of Gothenburg	10
Barge Transport Chain	[km]
Shaft 1 – Skeppsbron (Belt and Truck)	0,7
Shaft 2 – Skeppsbron (Belt and Truck)	0,7
Shaft 3 - Skeppsbron (Belt)	0,1
Shaft 3 - Skeppsbron (Truck)	0,2
Skeppsbron - Frihamnen	1
Skeppsbron - Port of Gothenburg	8
Theoretical Barge at Shaft 1 and 2 [km]	
Transhipment at Shaft 1 and Shaft 2	0,3
Rosenlund - Frihamnen	1,5
Rossenlund - Port of Gothenburg	8,5

In order to calculate the fuel consumption, data of the specific vehicles has been collected. Fuel consumption has been given for all vehicles and cycle times have been calculated from given data of mean speed, as presented in Table A2.

Table A2. Vehicle data.

Vehicles F=Frihamnen, PoG= Port of Gothenburg UM= Urban Motorway UD=Urban District	Reference	Volume [tonnes]	FC full [l/h]	FC empty [l/h]	Cycle Time
Transhipment					[s]
Dump Truck - Volvo A25F	Volvo Construction Equipment	24	23	-	-
Excavator - Volvo EC160C	Volvo Construction Equipment	0.21	10	-	14_{clay} 17_{rock}
Wheel Loader - Volvo L90F	Volvo Construction Equipment	6.7	9	-	36_{clay}
Wheel Loader - Volvo L90F	Volvo Construction Equipment	4.7	13	-	41_{rock}
Consruction Truck					[h]
TRUCK1 – GVW 26t	Volvo Trucks Technology	12	10_{UM}, 2_{UD}	8_{UM}, 1.5_{UD}	0.9_{F} 0.7_{PoG}
TRUCK2 – GVW32t	Volvo Trucks Technology	17	11_{UM}, 2.2_{UD}	8_{UM}, 1.6_{UD}	0.9_{F} 0.7_{PoG}
Barges					[h]
OP1 – Open$_{CLAY}$	Sandinge	4500	80	80	3.6_{F}, 5.6_{PoG}
OP1 - Open$_{ROCK}$	Sandinge	4500	80	80	5.2_{F}, 7.2_{PoG}
OP2 - Dreding	Carlbergs	150	30	30	1.3_{F}, 3.3_{PoG}

OP3 - Belt	Jehanders	1400	526	420	$1.1_F, 2.1_{PoG}$
Theoretical Barge	Björn Södahl, Chalmers	290	30	30	$1.4_F, 3.4_{PoG}$

The total fuel consumption per ton is the sum of the fuel consumption per ton for each type of vehicle. The fuel consumption for each vehicle was calculated accordingly:

$$\frac{Mean\ Fuel\ Consumption \times Cycle\ Time}{Vehicle\ Load\ Capacity} = \frac{Fuel\ Consumption}{Tonne}$$

Where the mean fuel consumption was calculated accordingly:

$$Mean\ Fuel\ Consumption = \frac{Fuel\ Consumption\ Full + Fuel\ Consumption\ Empty}{2}$$

And the Cycle Time calculated as:

$$Cycle\ Time = Speed \times Total\ Distance\ (including\ return\ trip)$$

For the transhipment vehicles, the cycle time was instead based on cycle times for each bucket load, and a total cycle time for filling each truck and barge was calculated. The dump truck was not used in the calculations, as it was not regarded feasible.

Assumptions:

- Fill rates of 110% for buckets and 95% for trucks and barges have been used as a reference.
- For wheel loaders, the bucket load capacity was given in volume, why a re-calculating to tonnes was necessary.
- For wheel loaders and excavators, the fuel consumption when fully loaded has been used for all distances, as they do not have any return trip.
- For the barges, the unloading time of 1 hour is assumed for OP2, OP3 and the theoretical barge. This is based on information from the barge operators.
- For OP1, it is however assumed that three wheel loaders are used to unload the barge, and is thus the base for the cycle time.
- The belt conveyor is assumed to have enough capacity to handle the total mass flow, in accordance with Kellve (2013). As it is electrical powered, it does not have any fuel consumption.

The results are presented for each shaft separately. Results for Shaft 2 are to be found in Chapter 7. The difference for each transport chain is compared and the total fuel consumption per tonne is presented in Figure A2 and Figure A3. The fuel consumption split for each transport chain is presented in Figure A4 and Figure A5. All figures follow the same logic as Chapter 7.

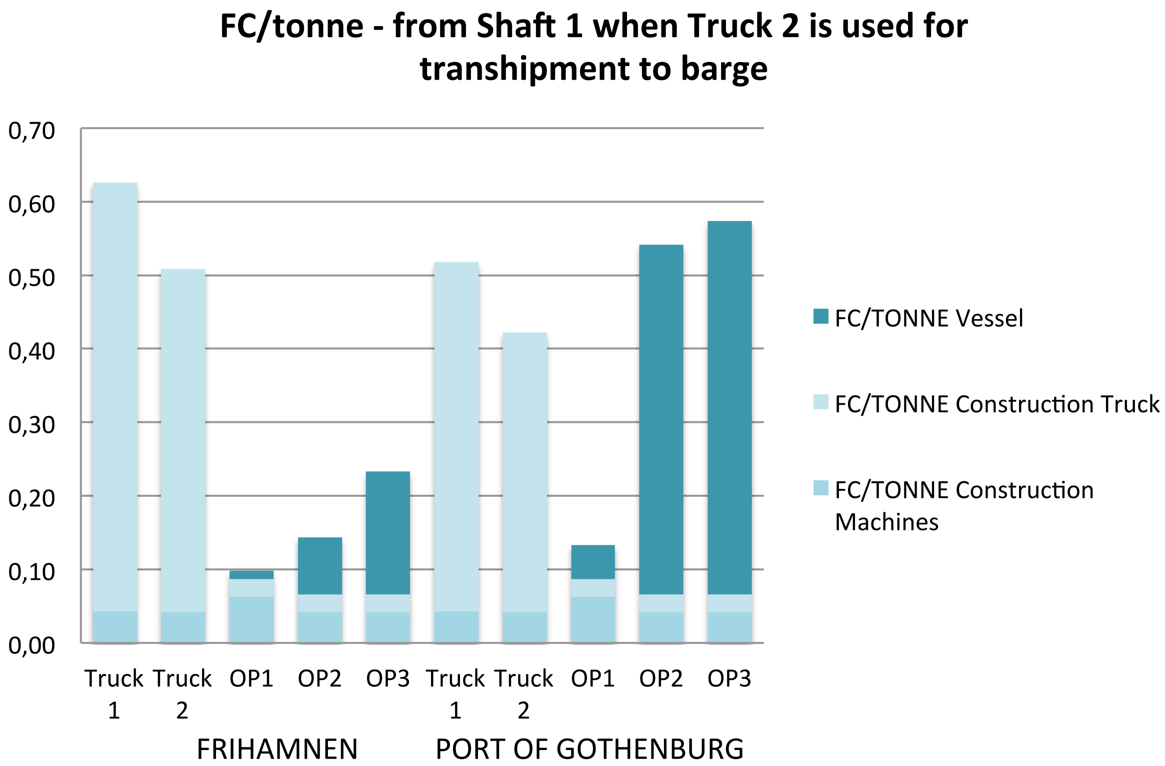

Figure A2. Fuel Consumption for transport chains from Shaft 1 when Truck 2 is used for transhipment to barge.

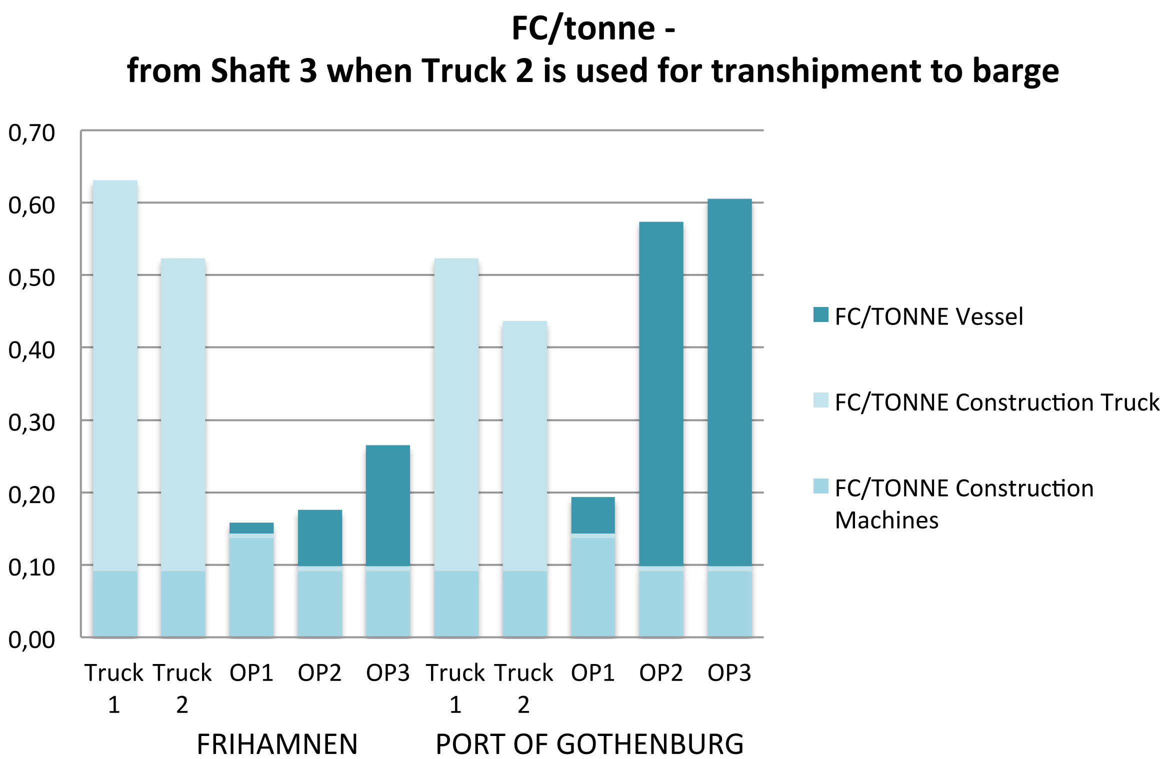

Figure A3. Fuel consumption for transport chains from Shaft 3 when Truck 2 is used for transhipment.

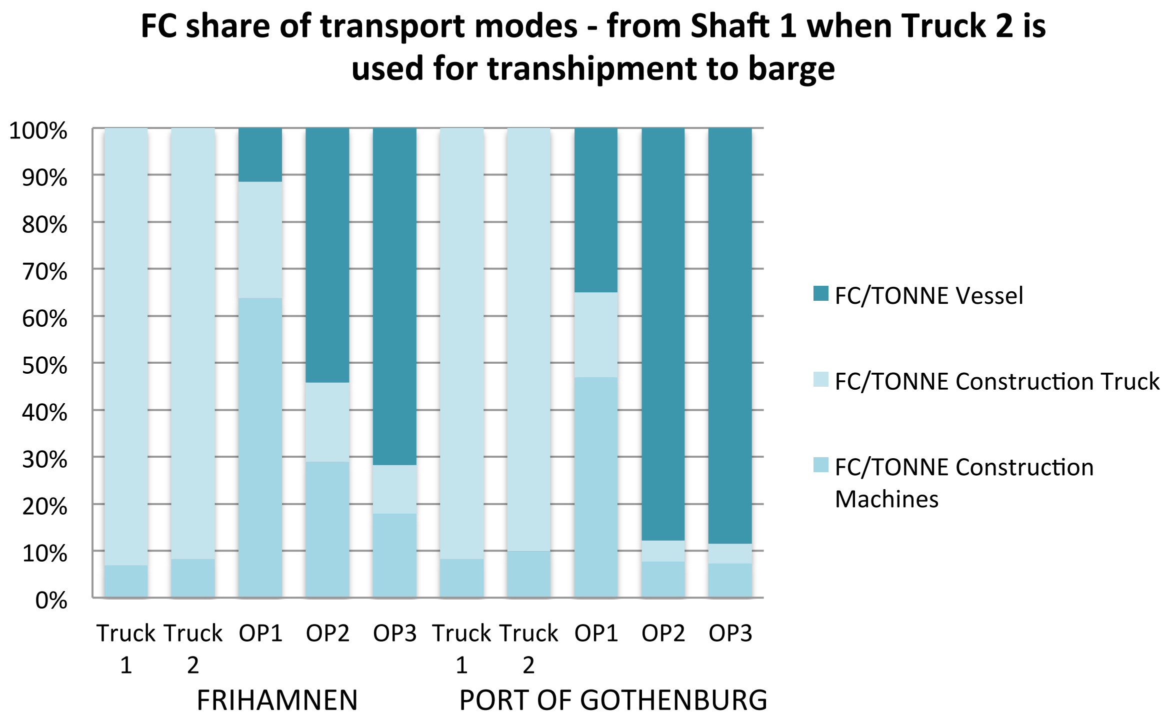

Figure A4. Fuel consumption share divided on each transport mode.

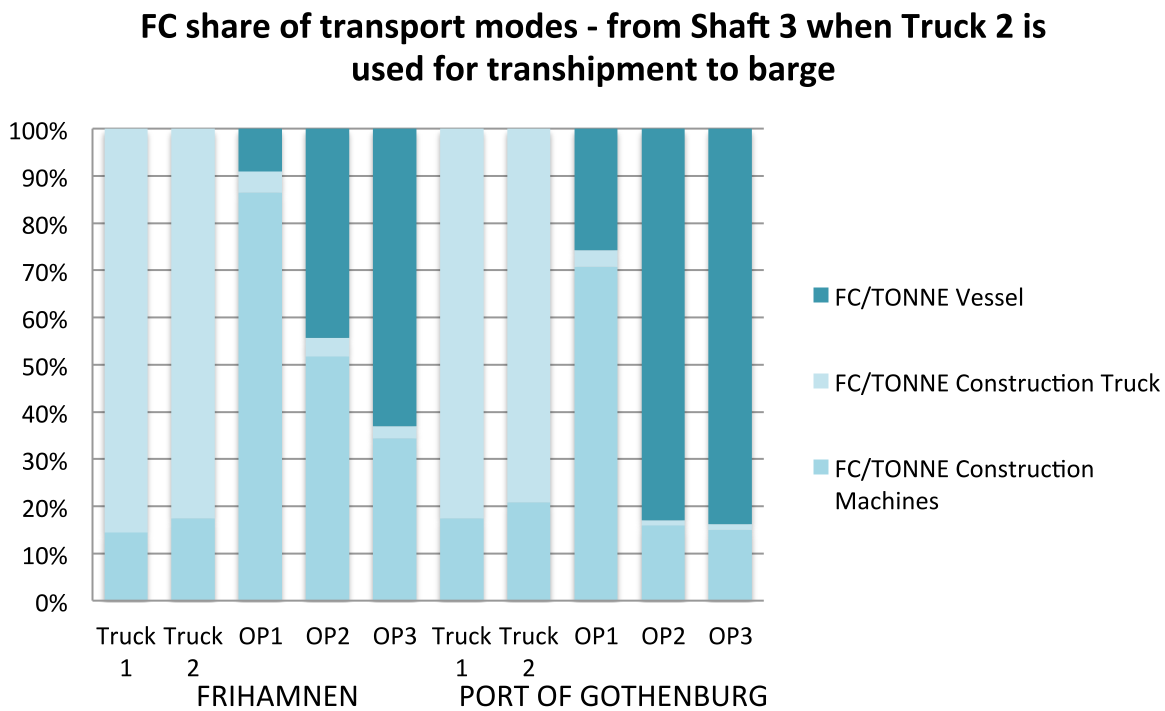

Figure A5. Fuel consumption share divided on each transport mode.

Appendix 3 – Emission Audit

The external costs for each transport chain was calculated in two steps. First of all, data of emissions factors for each mode of transport was collected as can be seen in Table A3. The emission factors for each mode of transport was collected from different sources; for construction trucks IMPACT (2007) was used, for construction machines Erik Fridell at IVL contributed with the data needed, for belt conveyor Gode et al (2011) was used and finally for the vessels Cooper and Gustafsson (2004) was used to collect the emission factors. For the belt conveyor the unit is different than for the others, as the belt conveyor is powered by electricity unlike the other modes of transport that are powered by diesel.

Table A3. Emission factors

Emission factors							
	PM	NOx	HC	SO2	CO2	CH4	NMVOC
Construction Machines [g/l]	2,86E-02	1,47E+00	7,02E-01	3,25E-03	2,43E+03	1,63E-01	5,39E-01
Construction Trucks [g/l]	1,15E-01	8,76E+00	7,69E-02	3,25E-03	2,43E+03	1,54E-03	7,54E-02
Belt Conveyor [g/kWh]	7,50E-03	7,10E-03	0,00E+00	6,30E-03	5,70E+00	4,00E-03	5,50E-04
Vessels [g/l]	7,35E-01	4,08E+00	9,80E-01	3,25E-03	2,43E+03	1,63E-01	8,17E-01

Based on this and the external cost factors, as can be seen in Table A4, the total external costs for each transport chain could be calculated in Euro/tonne. The data regarding external cost factors are collected from IMPACT (2007).

Table A4. External cost factors for emissions (IMPACT, 2007).

External cost factors emissions							
External unit costs	PM-Urban	NOx	HC	SO2	CO2	CH4	NMVOC
[€/g]	0,1134	0,0022	8,75E-10	0,0028	0,000025	0,000575	0,0003

In Table A5 below, the external costs calculated for one of the transport chains is showed as an example. This table provides the basis for the charts used to illustrate the external costs in Chapter 7. The transport chain illustrated is for clay, and consists of Wheel Loader, Truck 1, Wheel Loader and finally Truck 1 again.

Table A5. Total external costs for a conventional transport chain, including Wheel Loader and Truck 1.

Conventional Transport Chain - CLAY								
WLC - TRUCK 1 - WLC - TRUCK 1								
Distance	**PM**	**NOx**	**HC**	**SO2**	**CO2**	**CH4**	**NMVOC**	**TOTAL External cost [€]**
Shaft 1 - Frihamnen	0,008	0,011	0,000	0,000	0,038	0,000	0,000	0,057
Shaft 1 - Port of Gothenburg	0,006	0,009	0,000	0,000	0,031	0,000	0,000	0,047

Finally, in the report only the chart showing the external costs resulting from the transport from Shaft 2 is illustrated. Below, the charts illustrating the external costs resulting from the transport from both Shaft 1 (Figure A6 and Figure A7) and Shaft 3 (Figure A8 and Figure A9) is illustrated.

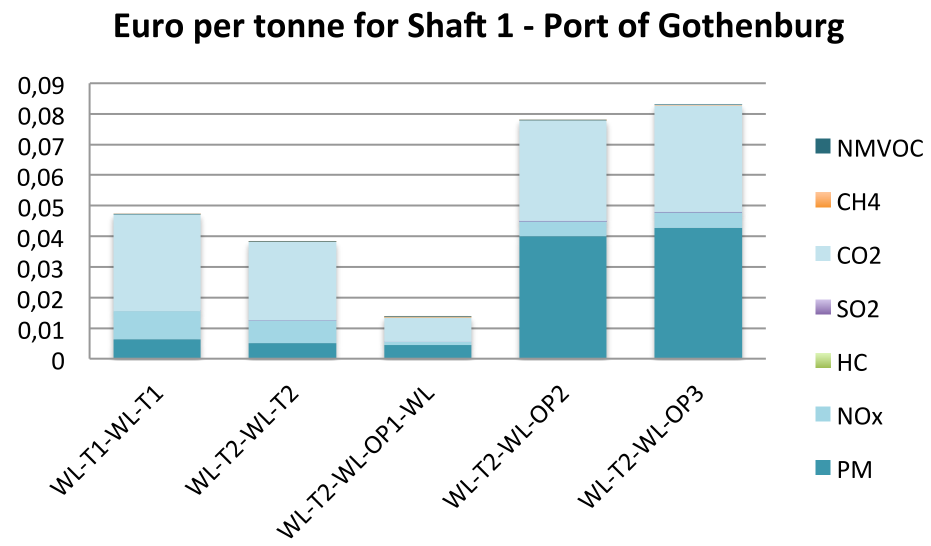

Figure A6. The external costs resulting from eight suggested transport chains from Shaft 1 towards Port of Gothenburg. The external costs on the Y-axis are given in Euro/tonne.

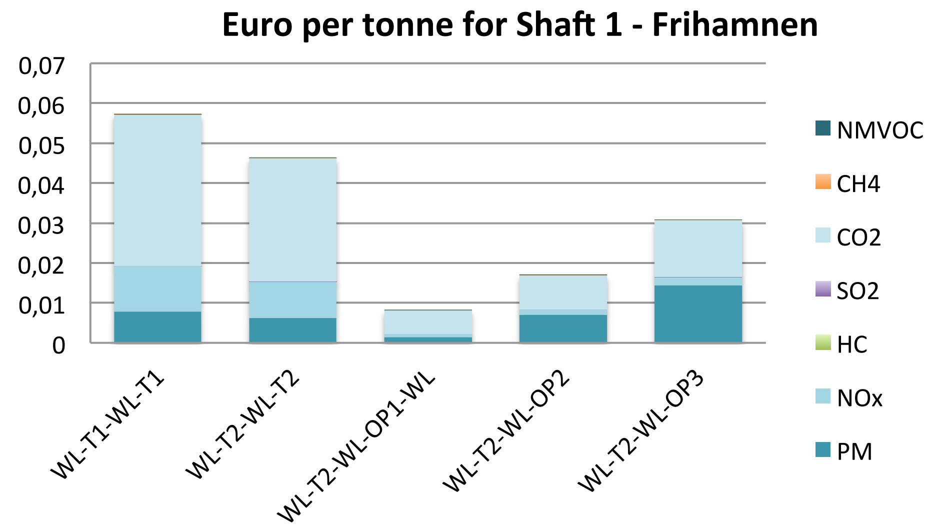

Figure A7. The external costs resulting from eight suggested transport chains from Shaft 1 towards Frihamnen. The external costs on the Y-axis are given in Euro/tonne.

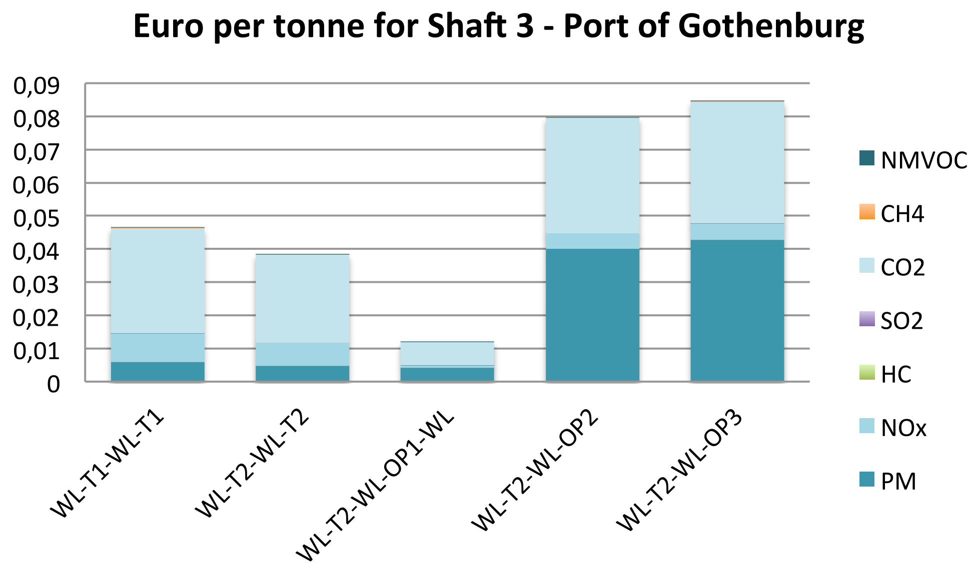

Figure A8. The external costs resulting from eight suggested transport chains from Shaft 3 to Port of Gothenburg.

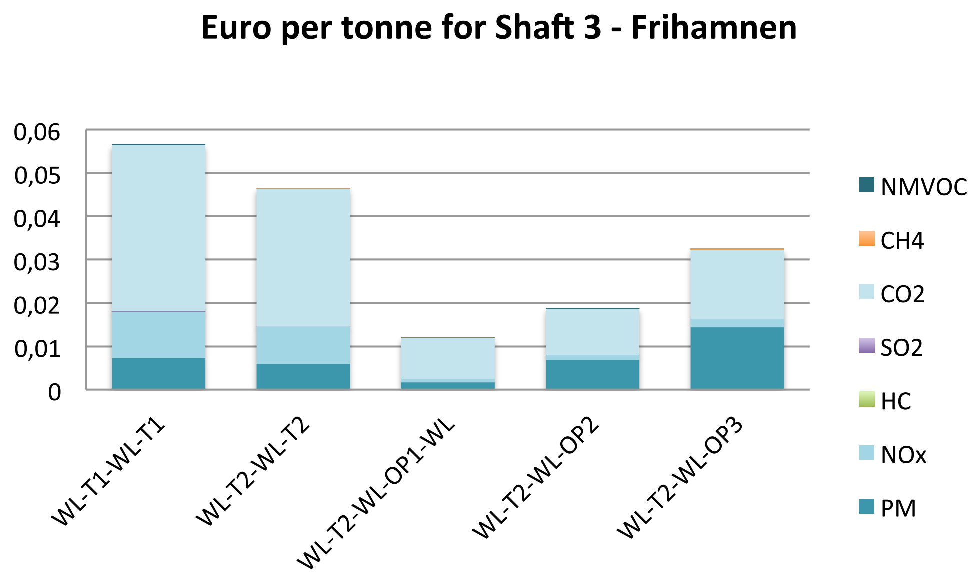

Figure A9. The external costs resulting from eight suggested transport chains from Shaft 3 towards Frihamnen. The external costs on the Y-axis are given in Euro/tonne.

Appendix 4 - Cost analysis

The cost analysis was performed in accordance with the method presented by Styhre[85]. According to the method the costs for each transport leg was divided into five groups. The cost categories for each mode of transport were based on collected data however not all cost categories are present for all modes, see Table A6. Further on the cost for transhipment for each main mode consists of the cost elements that occur in the loading and unloading process performed by other modes.

Table A6. Collected cost data for each mode.

CONSTRUCTION MACHINES	Excavator	Wheel loader		Reference
OPERATING COSTS [SEK/L]				
Average cost diesel fuel (incl. TAX)	10.76	10.76		Svenska Petroleum & Biodrivmedel Institutet (2013)
PERSONNEL COSTS [SEK/H]				
Average personnel costs 06:00-22:00	247	247		Transportarbetarförbundet (2013); Byggnads (2013)
INFRASTRUCTURE COSTS [SEK/H]				
National vehicle tax	0.33	0.33		Skatteverket (2013)
VEHICLE COSTS [SEK/H]				
Insurance	3	3		Erik Lindskog (2013)
Service contract	22	22,5		Håkan Bergdal (2013)
Depreciation - Income from residual value	78	53		Erik Lindskog (2013)
Interest	12	11		Erik Lindskog (2013)
TRUCK	Truck 1	Truck 2		Reference
OPERATING COSTS [SEK/L]				
Average cost diesel fuel (incl. TAX)	10.76	10.76		Svenska Petroleum & Biodrivmedel Institutet (2013)
PERSONNEL COSTS [SEK/H]				
Average personnel costs 06:00-22:00	250	250		Sveriges Åkeriföretag (2013); Transportarbetarförbundet (2013)
INFRASTRUCTURE COSTS [SEK/H]				
National road tax	2.1	3.5		Skatteverket (2013)
National vehicle tax	6.7	6.7		Skatteverket (2013)
Gothenburg road toll	4.4	4.4		Transportstyrelsen (2013)
VEHICLE COSTS				
Maintenance and Tires [SEK/KM]	2.3	2.3		Lars Aspholmer (2013); Sveriges Åkeriföretag (2013);
Interest rate, depreciation, tax, insurance, wash, and installations [SEK/H]	95.3	99.1		Lars Aspholmer (2013); Sveriges Åkeriföretag (2013);
BELT CONVEYOR	1m Covered Belt			Reference
OPERATING COSTS [SEK/kWh]				
Average cost electricity	0.608			Svenska Petroleum & Biodrivmedel Institutet (2013)
INFRASTRUCTURE COSTS [SEK/H/M]				

85 Linda Styhre (Researcher and Project Manager, VTI) interview October 21, 2010.

Assembly cost	0.23			Emil Ceder (2013)
VEHICLE COSTS [SEK/H/M]				
Insurance	0.021			Emil Ceder (2013)
Maintenance	0.017			Ralf Hansson (2013)
Depreciation - Income from Residual value	0.58			Emil Ceder (2013)
Average Interest	0.083			Emil Ceder (2013)
BARGES	Barge OP1	Barge OP2	Theoretical	Reference
VEHICLE COSTS [SEK/H]				
Insurance	18	10	18	Lennart Sandinge (2013); Bengt Sandinge (2013); Björn Södahl (2013)
Maintenance	21	21	21	Lennart Sandinge (2013); Bengt Sandinge (2013); Björn Södahl (2013)
Depreciation - Income from residual value	83	50	83	Lennart Sandinge (2013); Bengt Sandinge (2013); Björn Södahl (2013)
Interest	67	40	67	Lennart Sandinge (2013); Bengt Sandinge (2013); Björn Södahl (2013)
TUGBOATS	Tugboat	Pushboat		Reference
OPERATING COSTS [SEK/L]				
Average cost diesel fuel	5,24	5,24		Svenska Petroleum & Biodrivmedel Institutet (2013)
PERSONNEL COSTS [SEK/H]				
Mate	342	342		Sjöbefälsföreningen (2013); SCB (2013)
Deckhand	250	250		Sjöbefälsföreningen (2013); SCB (2013)
VEHICLE COSTS				
Insurance	12	12		Lennart Sandinge (2013); Björn Södahl (2013)
Maintenance	63	63		Lennart Sandinge (2013)
Depreciation - Income from residual value	58	58		Lennart Sandinge (2013); Björn Södahl (2013)
Interest	47	47		Lennart Sandinge (2013); Björn Södahl (2013)

The operating costs for all modes are based on the current cost situation for fuel and electricity in Sweden, November 2013. The personnel cost are based on information from labour unions, and thus assumes that the transport operators follow the collective agreements. The infrastructure costs are based on annual tax figures from Skatteverket and the assumption that the utilization rate is 3000 hours per year, which is a probable utilization time for machinery and vehicles used in a project with two shift's work[86]. The vehicle costs for the truck are based on figures given by the truck trade organisation Sveriges Åkeriföretag and thus not necessarily represent the specific trucks used in this thesis. For the other modes the vehicle costs have been calculated and are based on collected data from manufacturers and operators, see Table A7.

TableA7. Input data.

INPUT DATA						
Model	Investment [SEK]	Economic depreciation time [YR]	Residual value after depreciation time [%]	Interest rate [%]	Utilization/ year [h]	Assembly cost [SEK/m]
Excavator	1 800 000	5	35	4	3000	
Wheel loader	1 600 000	5	50	4	3000	
Belt Conveyor	12 500 (/meter)	5	30	4	3000	1300

[86] Håkan Bergdal (Market Support, Swecon) interviewed via phone November 5, 2013.

Barge OP1	10 000 000	20	50	4	3000	
Barge OP2	6 000 000	20	50	4	3000	
Barge in Vallgraven	10 000 000	20	50	4	3000	
Tugboat	7 000 000	20	50	4	3000	
Pushboat	7 000 000	20	50	4	3000	

To simplify it have been assumed that the entire investment cost is subject for interest, and that the instalments are even for the entire amortizing period, which is assumed to be equal to the economic depreciation time. The interest for each year was calculated as follows:

$$\frac{Size\ of\ loan_{YEAR\ x} \times Interest\ rate + \left(Size\ of\ loan_{YEAR\ x} - \frac{Investment\ cost}{Economic\ depreciation\ time}\right) \times Interest\ rate}{2}$$

The average interest cost for the entire amortizing period was then calculated and divided with the annual utilization time in order to receive an interest cost per hour.

The maintenance and service costs were given and divided with the annual utilization time in order to receive a maintenance cost per hour.

The insurance cost was given to 1% of the economic vehicle value, and was calculated as follows:

$$Vehicle\ value_{YEAR\ x} \times Insurance\ rate$$

The average insurance cost for the entire period was then calculated and divided with the annual utilization time in order to receive an insurance cost per hour.

The depreciation was assumed to be even for the entire economic depreciation time and was divided with the annual utilization time in order to receive a depreciation cost per hour. This cost was then subtracted with the hourly income from the rest value, which was calculated as follows:

$$\frac{Residual\ value\ after\ depreciation\ time}{Economic\ depreciation\ time \times Annual\ utilization}$$

When all cost categories were calculated they were added to form a total cost per hour for each mode, see Table A8.

TableA8. Cost per hour and fuel.

COST PER HOUR AND FUEL		
Excavator		
Cost per hour	362,80	[SEK/H]
Cost per liter fuel	10,76	[SEK/L]
Wheel Loader		
Cost per hour	337,30	[SEK/H]
Cost per liter fuel	10,76	[SEK/L]
Belt Conveyor		

Cost per hour	0,93	[SEK/H/M]
Cost per kWh	0,61	[SEK/kWh]
Truck 1		
Cost per hour	358,15	[SEK/H]
Cost per liter fuel	10,76	[SEK/L]
Cost per km driven	2,3	[SEK/KM]
Truck 2		
Cost per hour	363,38	[SEK/H]
Cost per liter fuel	10,76	[SEK/L]
Cost per km driven	2,3	[SEK/KM]
Barge OP1		
Cost per hour	188	[SEK/H]
Barge OP2		
Cost per hour	120	[SEK/H]
Barge in Vallgraven		
Cost per hour	188	[SEK/H]
Tugboat		
Cost per hour	1270	[SEK/H]
Cost per liter fuel	5,24	[SEK/L]
Pushboat		
Cost per hour	772	[SEK/H]
Cost per liter fuel	5,24	[SEK/L]

The total cost for each transport chain were then calculated by first calculating the total time cost, the total fuel cost, and the total kilometre cost for each chain. The time cost was calculated as follows: (where TCT: Total Cycle Time; CPH: Cost Per Hour; TUT: Total Unloading Time; TDT: Total Docked Time).

$$TCT_{Wheel\ Loader} \times CPH_{Wheel\ Loader} + TCT_{Excavator} \times CPH_{Excavator} + TCT_{Belt\ Conveyor} \times Distance_{Belt\ Conveyor} \times CPH_{Belt\ Conveyor} + (TCT_{Truck} + TUT_{Truck}) \times CPH_{Truck} + TDT_{Barge} \times CPH_{Barge} + (TCT_{Transit\ Barge} \times TUT_{Barge}) \times (CPH_{Barge} + CPH_{Tugboat})$$

The fuel cost as follows: (where TFC: Total Fuel Consumption; CF: Cost per litre Fuel; CE: Cost per kWh).

$$TFC_{Wheel\ Loader} \times CF_{Wheel\ Loader} + TFC_{Excavator} \times CF_{Excavator} + TCT_{Belt\ Conveyor} \times Engine\ Power_{Belt\ Conveyor} \times CE_{Belt\ Conveyor} + TFC_{Truck} \times CF_{Truck} + (TFC_{Transit\ Barge} + TFC_{Unloading\ Barge}) \times CF_{Tugboat}$$

The kilometre cost as follows: (where TTK: Total Travelled Kilometres; CPK: Cost Per Kilometre).

$$TTK_{Truck} \times CPK_{Truck}$$

The results are presented for each shaft separately. The difference for each transport chain is compared and the total cost per tonne is presented in Figure A10, Figure A11, and Figure A12.

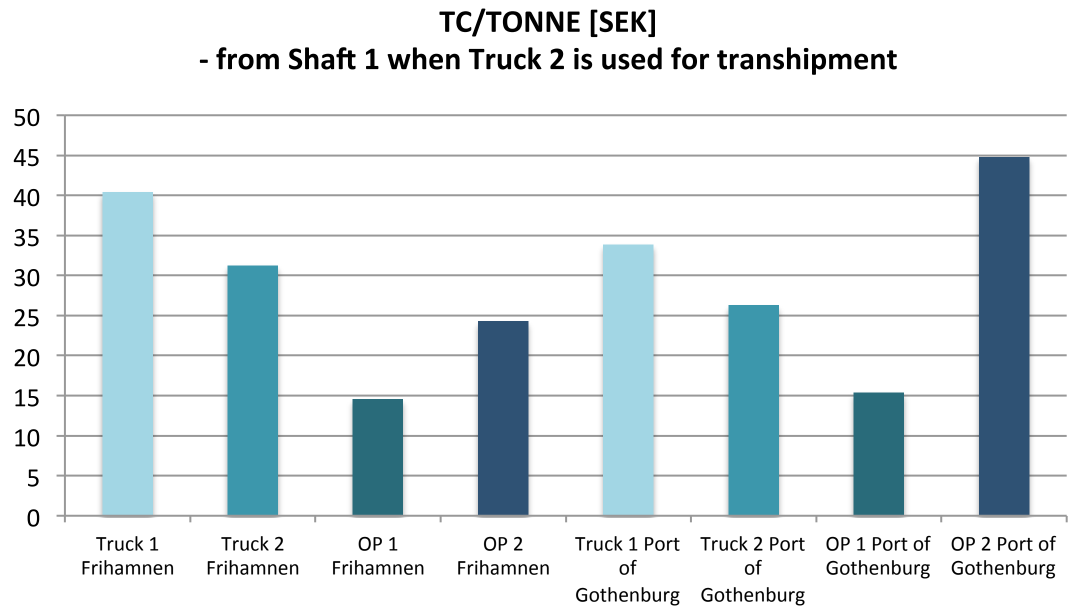

Figure A10. Total cost per tonne from Shaft 1.

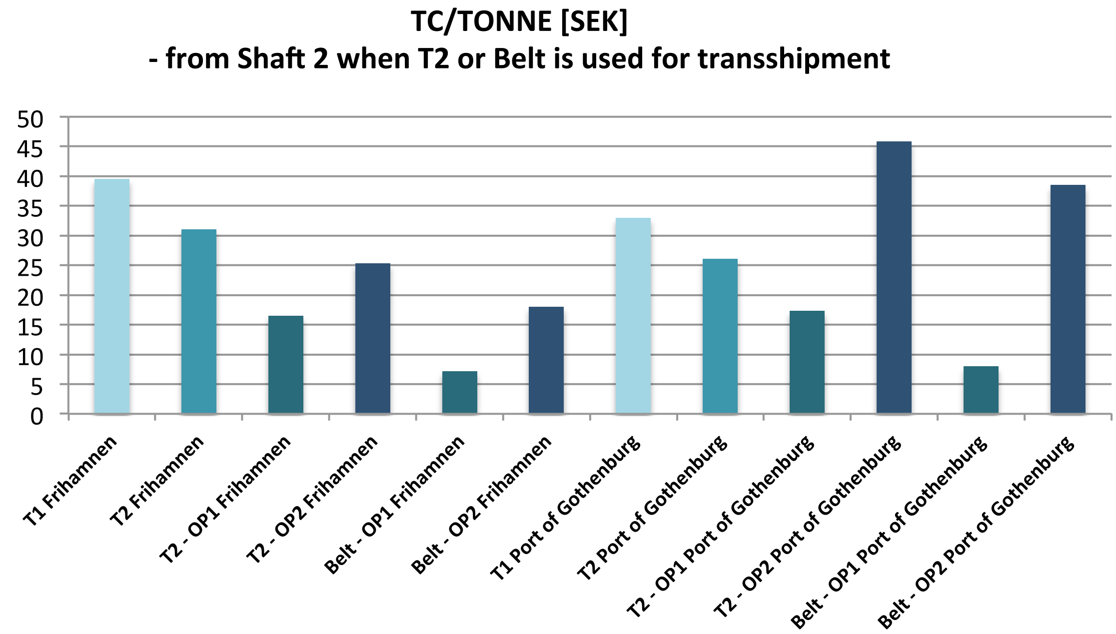

Figure A11. Total cost per tonne from Shaft 2.

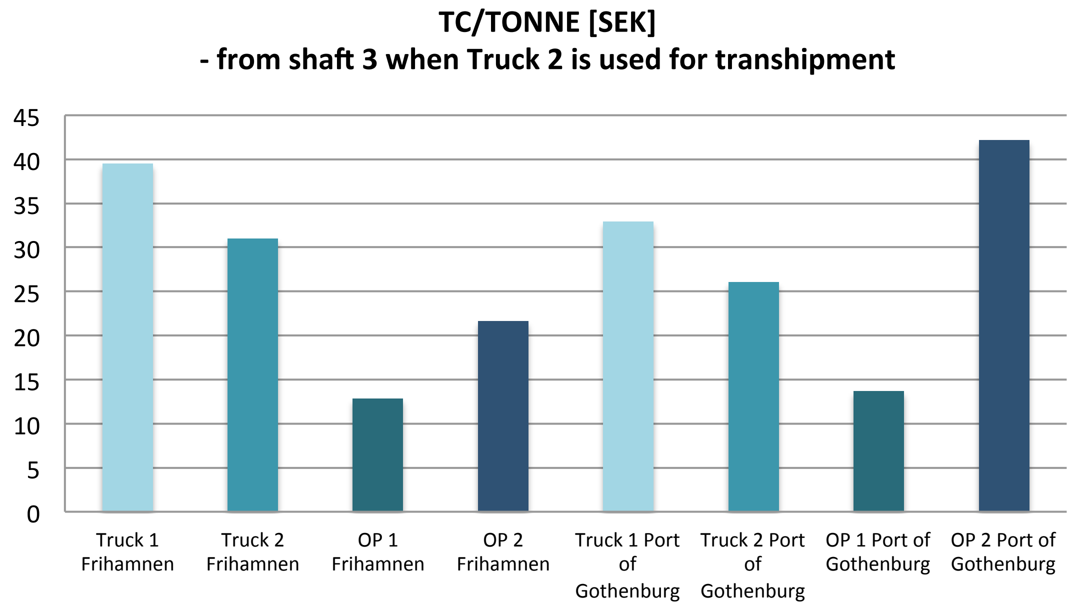

Figure A12. Total cost per tonne from Shaft 3.

Appendix 5 – Congestion

First, in order to calculate the external cost for congestion the total shipments per day and for the entire excavation process was calculated by dividing the excavated mass with each vehicle's capacity, for results see Table A9.

Table A9. Number of Vehicles.

Number of Vehicles			
	Transported tonnes per shipment	Total truck shipments per day	Total shipments for entire excavation
Truck 1	11,59	364	60544
Truck 2	15,675	269	44766
OP1	4275		164
Theoretical	275,5		2547

Second, the average driven distance (11.6 km) for all shafts to both destinations was calculated and subtracted with the average distance (0.5 km) for transhipment from all shafts to a barge docked at Skeppsbron. Out of those 11 kilometres, approximately 10 kilometres are driven on road classified as urban collector and about 1 kilometre on road classified as urban motorway. The distances were then doubled in order to include the return trips, and then multiplied with congestion cost factors, see Table A10.

Table A10. Congestion cost factors.

Congestion cost factors (IMPACT, 2007)	
Small and medium urban areas (< 2 000 000 inhabitants)	
Area and road type	**Goods vehicles [€/vkm]**
Urban motorways	0,88
Urban collectors	0,75

The external cost for congestion was then calculated according to the following formula:

$$No.\,of\ shipments \times \left(Distance_{Urban\ Motorway} \times CCF_{Urban\ Motorway} + Distance_{Urban\ Collector} \times CCF_{Urban\ Collector}\right) \times Congestion\ per\ day_{\%}$$

The results are found in Table A11.

Table A11. Congestion calculations.

Congestion calculations Västlänken [€ - YR2000]			
	Congestion cost per day (5%)	Congestion cost per day (30%)	Congestion cost per day (50%)
Truck 1	309	1851	3086
Truck 2	228	1369	2282
	Congestion total project (5%)	Congestion total project (30%)	Congestion total project (50%)
Truck 1	25634	153805	256342
Truck 2	18954	113723	189538

Appendix 6 – System view

In order to decide the number of trucks needed in the system as well as the size of the intermediate storage that will arise during the vessel's transit the excavation rate per hour was calculated based on the excavation rate per hour and available working hours per day. The results are found in Table A12.

Table A12. Excavation rate per hour.

Excavation rate per hour	
Shaft 1 Clay [tonnes/hour]	30-100
Shaft 2 Rock [tonnes/hour]	82
Shaft 3 Rock [tonnes/hour]	82

Then the excavation time required to fill up one truck or barge was calculated by dividing the carrier's capacity with the excavation rate per hour, results are found in Table A13.

Table A13. Excavation time required to fill up one mass carrier.

Excavation time required to fill up one mass carrier	Truck 1	Truck 2	OP1	Theoretcial Barge
Capacity per mass carrier [t]	11,59	15,68	4275,00	275,50
Excavation time required to fill up one mass carrier with CLAY [h]	0,12	0,16	42,75	2,76
Excavation time required to fill up one truck with ROCK [h]	0,14	0,19	26,07	3,36
Excavation time required to fill up one truck with MIX [h]			16,20	1,51

The total cycle time for the trucks, based on the earlier performed cycle time calculations in Appendix 2, were then calculated and divided with the required excavation time to fill up one truck in order to decide how many trucks that are needed in the system. The results are found in Table 9 in section 8.2. Then the transit time and unloading time for the vessels were calculated and multiplied with the excavation rate per hour in order to decide the required size of the intermediate storage. The results are found in Table 10 and in Table 11 in section 8.2.

Finally and analysis was performed in order to investigate how the total cost per transported tonne varies with the docking time. This was made by exchanging the *TDT*-factor in the time cost calculation. The results are found in Figure 34 and Figure 35 in section 8.2.

$$TCT_{Wheel\ Loader} \times CPH_{Wheel\ Loader} + TCT_{Excavator} \times CPH_{Excavator} + TCT_{Belt\ Conveyor} \times Distance_{Belt\ Conveyor} \times CPH_{Belt\ Conveyor} + (TCT_{Truck} + TUT_{Truck}) \times CPH_{Truck} + TDT_{Barge} \times CPH_{Barge} + (TCT_{Transit\ Barge} \times TUT_{Barge}) \times (CPH_{Barge} + CPH_{Tugboat})$$

Appendix 7 – Shafts

Data about the shafts are found in Table A14 below.

Table A14. Shafts.

SHAFTS		
	Density [t/m3]	Swell-factor
Gault	1.6	1.1
Granite	2.65	1.5
Shaft 1 Rosenlundsgatan - Södra Allégatan		
Excavation volume [m3]		250 000
Excavation rate (low) [m3/day]		300
Excavation rate (high) [m3/day]		1000
Shaft 2 and Shaft 3 from Otterhällan		
Tunnel length [m]		600
Tunnel area [m2]		165
Theoretical excavation volume [m3]		99000
"Real" excavation volume [m3]		113850
Volume exit via Rosenlundsplatsen [m3]		51233
Volume exit via Badhusgatan [m3]		62618
Excavation rate per shaft [m3/day]		495

Appendix 8 – Interviews

All interviewees in this thesis are found in Table A15.

Table A15. Interviews

Interviews			
Name	**Organisation**	**Position**	**Interview**
Andreasson, Ulf	Volvo Group Trucks Technology		Face to face
Areslätt, Hanna	Stadsbyggnadskontoret	Project Manager and Planning Architect	Face to face
Arvidsson, Bertil	BACAB	Senior Advisor/ Marine Director	Face to face
Aspholmer, Lars	Lars Aspholmer Programmering AB	Developer SÅ Kalkylfakta	Phone
Berger, Anders	Volvo Group Trucks Technology	Product Area Manager	Face to face
Bergdal, Håkan	Swecon	Market Support	Phone
Billger, Monica	Chalmers University of Technology	Professor	Face to face
Burman, Peter	Carlbergs	CEO	Face to face
Bäck, Peter	Swecon	Product Specialist	Phone
Ceder, Emil	Kellve	Construction Manager	E-mail, Phone
Cider, Lennart	Volvo Technology	Project Manager	Face to face
Edvardsson, Anna-Maria	Stadsbyggnadskontoret	Strategic Geology	E-mail
Eknander, Johan	Volvo Group Trucks Technology	Feature Specialist	Face to face
Englund, Jan	Chalmers University of Technology	Project manager, Civil and Environmental Engineering, GeoEngineering	Face to face
Eriksson, Anders	Volvo Group Trucks Technology	Product Owner	Face to face
Evans, Markus	PEAB	EHSQ Coordinator	Face to face
Franzon, Bo	Volvo Group Trucks Technology	Product Manager	Face to face
Fredriksson, John-Erik	COWI	Construction and Project Management	Face to face
Fridell, Erik	IVL	Senior researcher and Professor	Face to face
Fritsson, Thomas	Carlbergs	Site Manager	Face to face
Gunnarsson, Ola	PEAB	Project Development Manager	Face to face
Hammarberg, Ulf	DHL	Environmental affairs	Face to face
Hansson, Ralf	Jehander	Sales Manager	Face to face
Hellström, Emma	Port of Gothenburg	Pilot Planning Manager	E-mail
Holmström, Karin	Stadsbyggnadskontoret	Project Manager Västlänken	Face to face
Håstad, Ingrid	Sweco	Consultant	Phone
Jaan, Roy	Sjöfartsverket	Project Manager	Face to face
Josefsson, Anna-Sara	Trafikverket	Environmental Coordinator	E-mail
Knape, Ulf	Trafikverket	Regional Strategy Planning Goods	Face to face
Larking, Josefin	Trafikverket	Manager Mobility Management	Face to face
Lindskog, Erik	Swecon	Sales Financial	Phone
Ljungmark Klas	Transportstyrelsen	Marine Engineer	E-mail
Lundqvist, Christina	Tyréns	Manager Transport and Urban Planning	Face to face
Moback, Fredrik	Trafikverket	Environmental and Technical Manager	Phone
Mårtensson, Jesper	Trafikverket	HMSQ Manager	Face to face

Nydahl, Klas	Malmö Stad	Project Manager	Phone
Odermalm, Jonas	Volvo Group Trucks Technology	Segment Manager	Face to face
Pihl, Claes	Volvo Group Trucks Technology	Project Manager	E-mail
Petersson, Anders	Volvo Group Trucks Technology		Face to face
Portner, Stephan	Marti Technik AG	Project Engineer	E-mail
Sandinge, Bengt	Sandinge Tug	Owner	E-mail
Sandinge, Lennart	Sandinge Bogsering och Sjötransport	Owner	Face to face
Schoemaker Jarl	Panteia	Senior consultant sustainable transport and mobility	E-mail
Styhre, Linda	IVL	Researcher and Project Manager	Face to face
Söderström, Per-Inge	Trafikverket	Production Manager Västlänken	Face to face
Thoren, Anette	Trafikkontoret	Project Manager Green Vehicles	E-mail
Täng, Ulf	Fastighetskontoret	Development Manager, Strategic Planning	E-mail
Uhlin, Erik	KTH	PHD Material Transport and Earthmoving	E-mail
Wahlgren, Peder	Wallenstam	Sales Manager	Face to face
Wallroth, Jörgen	Port of Gothenburg	Port Capatain	Phone
Widegren, Christoffer	Trafikkontoret	Consultant	Face to face
Wilhelmsson, Roger	Innerstaden Göteborg	Responsible for Logistics and Infrastructure	Face to face
Wood, Tara	Chalmers University of Technology	Industrial PhD Student	Face to face
Åsell, Göran	Jehander	Production Manager Shipping and Terminals	E-mail