Master Degree Project in Logistics and Transport Management

High Capacity Transport Associated with Pre- and Post-Haulage in Intermodal Rail-Road Transport

Ying Ye and Jiali Shen

Abstract

Intermodal rail-road transport, known as a possible solution for developing a sustainable and efficient transport system, has received great concerns recently. This thesis develops a model for analyzing the cost and environmental potential of longer and heavier vehicles (LHVs) related to pre- and post-haulage in rail-road intermodal transport chain. This thesis compares economic, emission, and total costs between three different transport networks including intermodal rail-road transport with current Swedish trucks, intermodal rail-road transport with LHVs, and the unimodal road transport. Contribution of the LHVs to cost efficiency of intermodal network will be identified by the traffic volume break-even between the three transport networks. The objective is to give a solution for enhancing the competitiveness of intermodal transport from a full costs perspective. By deducting an empirical diagram, this thesis will take a Swedish project as the case for calculation. The case will present three scenarios respectively, representing the three transport networks mentioned above.

Key Words: Intermodal rail-road transport, LHVs, pre- and post-haulage, economic cost, emission cost

Acknowledgments

The authors would like to thank all the persons who support us during the completion of this thesis. First off, we want to express our deepest gratitude to our supervisor Rickard Bergqvist for his nice guide, great help, comments and inspiration. This thesis required much information and data that were in Swedish and therefore without his help this thesis would not have been possible. Also, much information associated with this thesis came from our interviewees. We are very grateful for the expert knowledge from all our interviewees. Thank you so much for your quick response and helpful suggestions. Finally, thanks to all for making this thesis such a good experience and our apologies for those who are not mentioned here.

Gothenburg, May 2014

_____

Ying Ye   Jiali Shen

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Definitions

Abbreviations:

EIT: European Intermodal road–rail freight Transport

EILUs: European Intermodal Loading Units

EMS: European Modular System

HCT: High Capacity Transport

IRT: Intermodal Rail-Road Transport

ILUs: Intermodal Loading Units

LHVs: Longer and Heavier Vehicles

PPH: Pre- and Post- haulage

TEU: Twenty-foot Equivalent Unit

Definitions:

IRT – "The movement of goods in one and the same loading unit or road vehicle, which uses successively two modes of transport in which road transport is used in the short-haul transit for collection or delivery, while rail transport related to the long-haul transport, without moving the goods itself in changing modes (UNECE, 2001; Nachtmann et al., 2004)."

PPH activities – "The activities of PPH in an IRT system are always taken place by trucks as the initial and final legs of the IRT which we mentioned in the category of drayage (Lowe, 2006)."

LHVs in EU – "All freight vehicles exceeding the limits on weight and dimensions established in Directive 96/53/EC (De Ceuster et al., 2008)。

LHVs in this thesis – The truck exceeding the limits published by Swedish Transport Administration which have the length of 32meter and gross weight of 60 tonnes.

3-TEU truck – Truck can carry one 20ft container and 40ft container at one time.

4-TEU truck – Truck can carry two 40ft containers at one time.

1 Introduction

1.1 Background

Transport is a fundamental factor of the economy and society. Today people pay more attention to improving the efficiency and cutting the external cost of logistics. The noticed two improvement projects in Europe are the intermodal transport and the High Capacity Transport (HCT). According to the European Commission（2011), the utilizations of different transport modes are imbalanced. Road transport which is the least environmentally friendly transport mode takes the largest market share of total transport modes. Furthermore, road transport demand is increasing fastest. In this way, promoting railways, inland waterways and short-sea shipping or integrating different modes will help release the burden of road transport (European Commission, 2011).

In Europe, intermodal freight transport has frequently been seen as a potentially strong competitor to road transportation and to be environmentally friendlier in many contexts (Janic, 2007). According to UIC (2013), comparing to unimodal road transport, intermodal rail-based transport is reducing the external costs (i.e. emissions of greenhouse gases and accident costs) by €0.02 per tonne-km. Besides, the Longer and Heavier Vehicles (LHVs), which are expected to improve the fuel efficiency and reduce the emission, has held the limelight in the EU. In 2007, European Commission adopted the Freight Transport Logistics Action Plan. This includes potential wider use of European Modular System (EMS) vehicles combinations 25.25 meters long. These vehicles are in regular use in Sweden and Finland, with trials underway in some other member states (Netherlands, Denmark and some northern German States) (OECD, 2011). In that case, Sweden is at the forefront in the area of LHVs. LHVs create benefits for business community and society. The use of LHVs vehicles in Sweden on a broad base would provide significant benefits in terms of increased efficiency, reduced demand for investments to lower fuel consumption and reduced emissions. Further, in Sweden, much research addresses in even longer vehicles which are 32m with the capacity of carrying two 40ft containers simultaneously. They report there is a huge potential to be more fuel-efficient and environment-friendly since these vehicles are more suitable for the demand market.

In order to make contribution to the society and environment, a Sweden company called Jula plans to improve their business through shifting trucks from current Swedish ones (25.25m, see Table 4.4) to the LHVs in their intermodality. The ideal solution for Jula is implementation of longer vehicles which have a length of 32 meters

and 60t gross vehicle weight expected to carry two 40ft containers. They believe this solution can gain both economic and environmental benefits. However, the permit of longer vehicles has not been passed by the government yet thus Jula plans to do a research of particular section of its lines to evaluate the feasibilities and benefits of the longer vehicles. This project is expected to provide opportunities for studies of cartage in the combined terminals and intermodal solutions competitiveness. Furthermore, it can be generalized to other similar cases on a national level.

1.2 Problem Analysis

The benefits of intermodality have been stated in the background, however, the increase of transport demand in Europe is mainly met by road (European Commission, 2006) which leads to significant negative impacts on society, especial the environment (Bergqvist & Behrends, 2011). The main reason is that the unimodal road transportation has strong competition in the transport market over short distance which is the main market in the EU (about 46% of the demand is within distances of 150–500 km). Further, the intermodal rail-road transport is associated with the long distance transport which only accounts for 22% of the demand in transport in the EU. According to European Commission (2012), the road freight transport accounts for 73% of all inland freight transport in the EU. Therefore, considering the negative impacts from road transport, the White Paper of Transport in the EU (2011) suggests that "*30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050.*" This goal requires the development of the competitiveness of IRT transport, especially the economic efficiency.

Much research addresses in this area. The competitiveness of IRT transport reported by much previous research depends on the costs of transshipment and the pre- and post-haulage (PPH) which accounts for 25%-40% of the total cost of the IRT system (Ballis & Golias, 2002, 2004; Niérat, 1997). For this reason, this thesis would like to measure the potential of lowering the cost of PPH related to intermodal transport chain. Besides, many other researchers report that, the size and weight of trucks limit the development of road freight transport segment in the IRT system. Bergqvist and Behrends (2011) suggest using longer vehicles has a substantial potential to reduce the cost of PPH. Thus longer and heavier vehicles seem to be a solution to reducing the cost of the IRT system. The longer and heavier vehicles (LHVs) have gained growing attention which is introduced in the background. However, the impacts of high capacity trucks on environment, transport efficiency, safety, and infrastructure should be comprehensively considered. LHVs are proved more competitive when they are used in road part of

intermodal rail-road transport in this thesis. The output shows a reasonable impact on demand of rail transport: a decrease of around 5 - 15 % per tonne-km in comparison to the situation without LHVs (De Ceuster et al., 2008). Knight et al. (2008) give the conclusion that a maximum of 8-18% of the UK total rail market would shift to unimodal road transport with LHVs. The fact that LHVs make unimodal road transport typically 20% cheaper means it will lead to an increase of new road transport because of the cross-elasticity effect, and weaken the competitiveness of other inland modes. It implies that LHVs can only run in defined routes which are coordinated to rail transport transshipment without a general allowance.

1.3 Research Purpose

The purpose of this thesis is to develop a model for analyzing the potential of longer and heavier vehicles related to pre- and post-haulage in rail-road intermodal transport chain. The potential here refers to a reduction of both economic and emission cost which will be defined in Chapter 7. Using the case of Jula and the developed model, this thesis will try to measure the benefits achieved by shifting truck type from the current Swedish trucks to the longer ones with 32m length in the rail-road transport network. This dispensation for longer vehicles enables a competitive intermodal solution between Gothenburg Harbor, Falköpings intermodal terminal and Jula's central warehouse in Skara.

1.4 Research Questions

-What is the international outlook of longer and heavier vehicles?

-What are the disadvantages of High Capacity Transport for road?

-What is the role of PPH related to intermodal transport chain?

-What is the potential of longer and heavier vehicles associated with pre- and post-haulage for the case Jula?

The first two questions will be answered in the literature review in Chapter 4. Then the role of PPH will be addressed both in the Chapter 4 and Chapter 8. The previous research provides general opinions, and analysis based on the calculation will give the specific answer using the data of the case. The last question will be mainly answered in Chapter 8 where the analysis of the results will be conducted by comparing different transport systems.

1.5 Expected Results of the Study

In an intermodal solution for short distances, the road transport which is the weakest part of intermodal transport often accounts for a large proportion of the total cost for the operator. It is reflected even in the case of Jula. The aim of this research is to improve the efficiency of road transport to and from the intermodal terminal in order to conduct a favorable intermodal solution.

The vision is for a sustainable and competitive transport solution. The solution reduces not only the CO_2 emission but also traffic accidents, traffic jams and noise significantly on the highway which is the ordinary choice of short-distance transport. This may lead to a significant difference in terms of environment and cost savings for nearby industry. These effects are difficult to quantify at this stage without monitoring of the overall impact.

According to the research carried out for T&E by FKA Automotive Research, although trucks only account 3% of European vehicles and 7% of mileages, they are involved in 18% of fatal accidents, over 7000 lives passing away across the EU in 2008. Per mileage, trucks are involved in twice as many fatal accidents as cars. Whereas Grislis's (2010) report points out the performances of LHVs are the same as the normal vehicles in the risk of rollover, and the braking performance problem can be solved by technology, the authors will take into account the majority of security measures to maintain safety on the roads. Accessibility for combination (and other vehicles) on the roads will be reviewed as it is of the utmost importance for everyone's safety in traffic.

As for Jula case, the annual volume transported between Gothenburg and Jula's Warehouse in Skara is expected to be about 7,000 containers on the road currently, which will need approximately 4000-5000 trucks (one way) on the road (based on over 75% of containers are 40f). The difference in traffic on the E20 is thus a direct change that will be permanent in both the short and long term. Furthermore, the authors also want to figure out the detailed commodity flow of Jula if the operating cost of IRT is lower than the single highway transport. This kind of calculating model will be generalized to other cases of Jula/other companies in Sweden. The solution will be highly accepted if it cannot only bring the company's sustainable reputation but also cut the operating cost down.

1.6 Limitation

Throughout the entire thesis only one case is discussed. Although the definition of case is strategically important in relation to the general problem, it is more in descriptive aspect rather than in statistical aspect. As a result, it is very time-consuming to verify the effectiveness of the case study.

As the case comes from a Swedish company, only Swedish context is taken into account and analyzed when it comes to legislation, costs, vehicle standards and road conditions. The parameters of the cost model will be totally changed if the national background is changed. In that way, the results of the same model in different counties may be in ranges.

European Commission has declared it does not seek for a general allowance for LHVs for safety and environmental reasons. In the cost structure, the calculation does not consider the time and quality parameters. In many cases road transport is chosen because it is faster than an intermodal alternative. The safety, time and quality cost, these seemed additional aspects need to be considered, but they are out of the scope of this research.

2 Case presentation

2.1 Introduction

In society today, carbon dioxide emission is an increasing threat to the environment and is thus a threat to future generations' well-being and prosperity. This emission has increased in recent decades and been taken more seriously. As a result, limits of different emissions in different countries become more stringent. In addition, companies are forced to supply goods rapidly and constantly to meet changing consumer consumption behavior. Most companies today operate in a very challenging environment where competition is extensive. New competitors from Asia, production in low-cost countries, recession, economic crises, changes in ownership, etc., are some of the most conspicuous factors. Logistically, this kind of situation means big challenge for businesses of long-distance transport.

The overall research idea for Jula is to study the effects of a new transport solution on improving logistic competitiveness related to the largest owner of commodities in Skaraborg, named Jula AB. The commodities are transported to and from the port of Gothenburg. The fundamental research approach is to support a shuttle rail by enhancing the competitiveness of goods transport between the intermodal terminal in Falköping and Jula's Warehouse in Skara. The short distance road transport and its flexibility makes very high requirements on cost and quality of a potential intermodal solution in which this application is a very important component of the intermodal solution's initial competitiveness.

The case is operated by Jula AB and their logistics partners in the current situation (Figure 2.1). Falköping Municipality and the Swedish Transport Administration have contributed to relevant supporting information on nearby roads, current traffic and other information necessary for the application areas. One advantage is to start a peer group where these parties are included along with the Transport Administration. There is also another advantage of the research programs that parties such as Academy ensure that the project research is disseminated to other agents who may benefit from the information. Jula has previously been in contact with University of Gothenburg and the scientists there, and the hope is to involve them in order to realize all the expectations of the project.
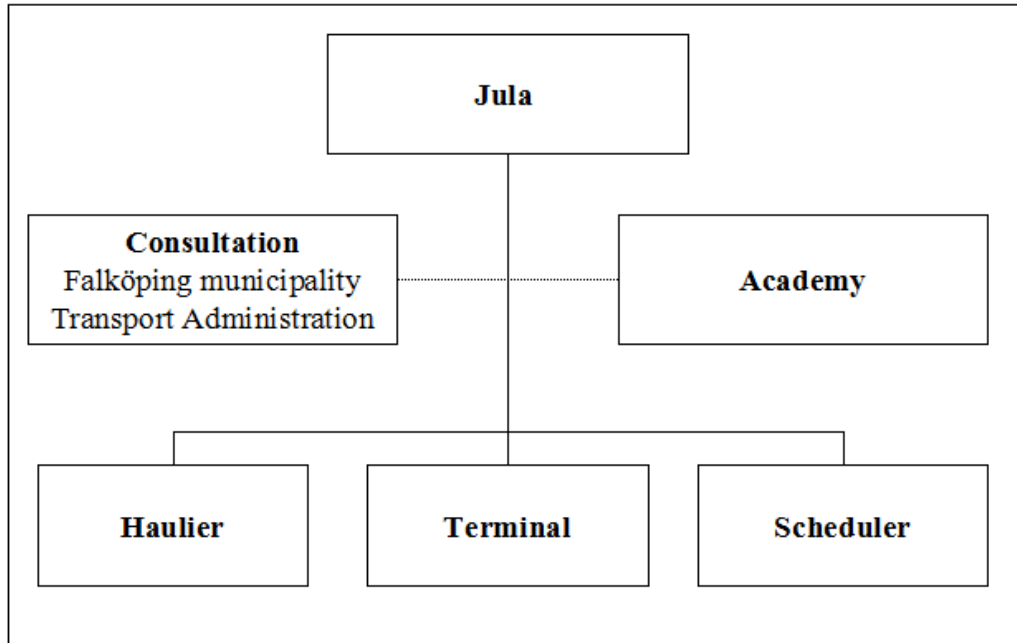
Figure 2.1 Organization of Jula project

2.2 Implementation

Jula's annual volume transported between Gothenburg and Skara central Warehouse is estimated to be about 7,000 containers which is made up of about 70% 40ft containers and the remaining share of 20ft containers (Jula, 2014). A major problem arises when all 20ft containers are transported together with the same number of 40ft containers (every standard vehicle can carry a 40ft container and a 20ft container). There remains a large number of 40ft containers that need to be transported separately and thus without the optimum utilization of the vehicles there will be significant negative environmental and economic effects. Thus Jula starts a project that aims to solve this problem by applying of vehicles of larger capacity (2x40ft or 1x40ft together with 2x20ft).

The Jula project aims to study the effects of a new transport solution for Jula container transport from Gothenburg to Skara where cargos transported by rail to Falköping intermodal terminal and then loaded onto trucks with a maximum length of 40ft which can carry 2 pieces of containers simultaneously and vice versa (Figure 2.2 Supposed vehicle combination). This dispensation for LHVs enables a competitive intermodal solution between Gothenburg Harbor and Skara central warehouse through Falköping intermodal terminal. This project is expected to provide opportunities for studies of cartage in the terminal and intermodal solutions competitiveness. In addition, it can be generalized to other similar cases on a national level. Furthermore, there is considerable interest from other shippers and cargo owners about a possible new intermodal solution.

Most of the participants have already been in contact with Jula and is willing to agree to significant volumes of rail pendulum started.

Figure 2.2 Supposed vehicle combination

The Jula project is expected to benefit the environment and society, create sustainable transportation solutions for companies in the region, strengthen Skara Region's competitiveness and the competitiveness of the railways and reduce mileage on E20 (Figure 2.3 Map of two modes of routes).

An increasing flow of rail transport benefits the nearby region and other landlords who can get their goods with high efficiency by using the terminal. Shipping lines and freight forwarders related to the intermodal solution from Skara plan to open a depot of empty containers in Falköping, which is of possibility to pick-up and drop-off containers at Falköping intermodal terminal instead of driving all the way to Gothenburg Harbor then back. These effects are difficult to quantify at this stage without monitoring of the overall impact which will occur during the project. However, everything indicates that storage of empty containers reduces transport of empty containers from the port of Gothenburg.
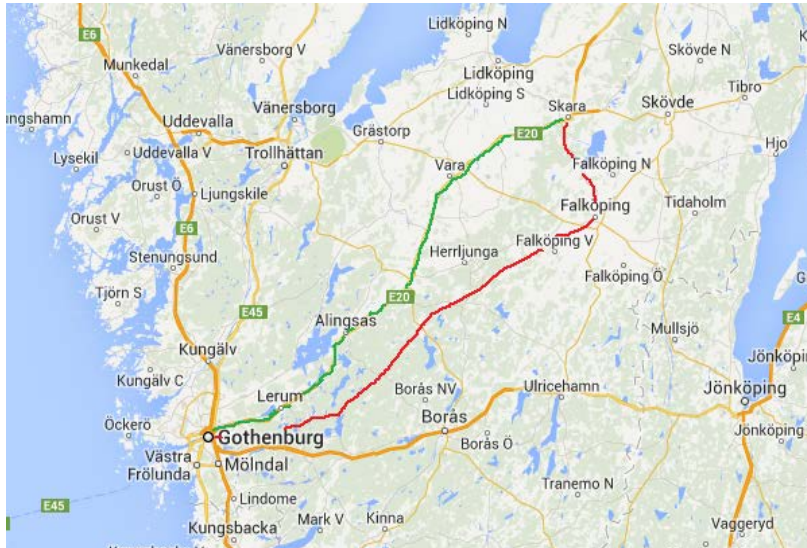
Figure 2.3 Routes of IRT and unimodal road transport

2.2.1 Highway Transport on E20

E20 is one of the three government infrastructural relations (another two are Västra stambanan and Road 40/E4) in the route between Stockholm – Gothenburg with speed limitation of 110km/h.

Approximately 80 km length of the E20 through Västra Götaland lacks meeting separation and there are no measures in the national plan for transport from 2010 to 2021. E20 is used by several different groups of road users: unprotected road users (cyclists), trucks, slow-moving vehicles, local and regional passenger traffic and fast through traffic. The mixed traffic on no meeting separate sections increases the risk of accidents.

Measures are needed to improve safety and accessibility of E20, but how and when are still unclear. To move forward on the issue, the Swedish Transport Administration, together with the Västra Götaland region, Skaraborgs Kommunal förbund and Vårgårda municipality conducted a study of E20 through Västra Götaland. The study includes a multimodal status report and four-stage analysis, in-depth investment analysis, benefit analysis.

A study goal for Jula is to develop a vision and a development strategy for the E20 through Västra Götaland. According to the four stage principle, the method has action selection which is a new and exploratory step in the planning of the transport system. The overall objective for transport provision is drafted by the EU, the Swedish Parliament and the Västra Götaland region. The targets focus on sustainability,

reducing carbon footprint, function to create basic good accessibility and consideration so that no one killed or seriously injured, environmental quality objectives met and health improved.

Traffic flows on the E20 between Gothenburg and Stockholm varies greatly with the largest flows in connection to major cities and the lowest flows on some routes. For parts of the E20 they are no meeting separation, the flows in the majority of cases are 8000 to 11000 vehicles / day (AADT). Currently in the north of Mariestad, the flow is slightly larger with approximately 13000 vehicles / day (Jula, 2014). From a perspective of performance, there are no gaps on either the distances or intersections. However, relatively large truck traffic implies slow-moving vehicles and long access time. Corridors, which are applied to both road and rail, whose importance continues to be large and growing, plays a very important role in Gothenburg Harbor. Both the E20 and Västra stambanan have been identified as nationally important and robust freight routes. Increase of passenger traffic on the E20 is estimated to be relatively slight until 2020. Overall, routes between Gothenburg and Stockholm through Västra Götaland have an important function for freight to and from Gothenburg Harbor and more short-distance freight transport vehicles prefer to runs on E20.

Approval of Jula project leads to immediate change of conditions on the E20. Jula has abandoned the transport of containers by Road E20 between Gothenburg Harbor and Jula's Warehouse in Skara from this year. According to Jula's report, environmental savings of E20 is expected to be 4000-5000 less heavy vehicles per year (one way) and a reduction in CO_2 of 600 tons per year which is equivalent to emission of approximate 250 private cars if the application is approved (Jula, 2014). The difference in traffic on the E20 is thus a direct change that will be permanent in both the short and long term.

2.2.2 IRT on Rail and Road 184

The project involves the transport of containers by rail from the port of Gothenburg to Falköping intermodal terminal and later by road to Jula's Warehouse in Skara. Rail transport implementation is dependent on a state to carry two 40ft containers simultaneously, which means that the project is only feasible with the help of the regulation. Then load consisting of 40ft containers are not divisible, which is not possible to conduct the experiment within the existing legal framework.

Transport of containers between Jula's Warehouse in Skara and Falköping intermodal terminal will take place daily between 06:00 and 24:00. The stretch of freight between the points will be operated by two vehicle combinations. These will include 20 pieces

of trailers, but one of the vehicles initially only runs a few hours a day with this combination.

The trucks and trailers that will be used will not be made up of some new technological features and components which are included in the module vehicle. It will be ordinary vehicles according to rules of trucks, but with an extra trailer with space for a 40ft container.

The cargo being transported will be loaded with 40ft containers containing Jula products without exceeding the maximum weight allowed for the load carriers. In current situation, Jula has a majority proportion of 40ft containers and they predict that the increased purchasing volumes will broaden the use of 40ft containers. The ambition is that the tractor is powered by liquid biogas which is economically and technically feasible.

Falköping intermodal terminal is located on Valsbogatan in Falköping. The trucks leave from the terminal turning left to Brogärdesgatan (about 700 meters) near County Road 184 (Figure 2.4 Map of Road 184). Arriving at the intersection Brogärdesgatan / County Road 184, the trucks turn left and then drive on Road 184 (over 25 km).Then the truck will take a left at the roundabout linked County Road 184, Skaraborgsgatan and Gröneskogsgatan. Final destination will be Julagatan 2. The trip of the trucks will thus consist of two left turns to get out on County Road 184.Then the trucks turn left at the roundabout Skara and eventually reach Jula's central warehouse.

None of the three paths are collision-free. To improve road safety and to reward energy-efficient driving style, all drivers undergo a special training of eco-driving for vehicles that exceed the maximum length. The training shall also include specific requirements on the traffic light. The trucks will be fit with alcohol interlocks and clearly marked with highly visible signs to alert road users about the long load. The vehicles will be inspected prior to the start of the project to ensure that all preventive measures for safety have been taken.

It is important to note that not only the security that will be addressed and considered in the project. In addition, the importance to ensure accessibility on the road for the long rigs should be recognized. One way to consider this is to adjust the driving time and breaks for drivers according to Transport Administration reports of what time is busiest on Road 184. This means that drivers' breaks will be coordinated at rush hour to relieve the most intense periods of the road and to increase the accessibility and safety of everyone. In addition, particular attention of driving is taken into account in the spring

which is the season for birding by cranes at Hornborgarsjön that increases traffic on the Road 184. Driving schedule will be issued with respect thereto, and in relation to this high season, maximum speed will be lowered on Road 184 to 70 km / h.
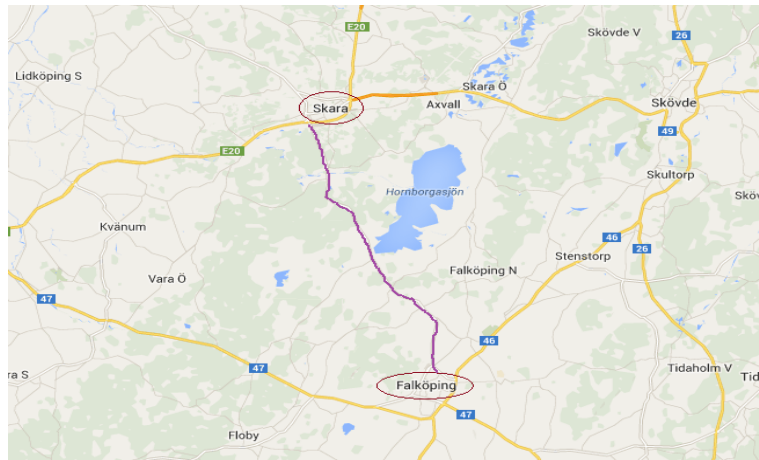
Figure 2.4 Route of Road 184 associated with Jula case

2.3 The Reasons for Using Jula Case

Since the purpose of this thesis is to give an analysis of the benefits of using LHVs in the PPH, the Jula project is suitable to be a case study. First, given the project introduction above, Jula also presents three transport networks. The unimodal road transport had been used by Jula for a long time before it shifted to the intermodal transport network with current Swedish trucks. Currently, they try to apply the LHVs with length of 32m in order to optimize the intermodal chain which is shown in the third transport network. Second, the project needs to prove the potential of using the LHVs as a good reason to get the permission. Third, the transport from Falköping to Skara involves typical haulage in the EU, representative intermodal terminal in Sweden and majority of freight transport according to transport type and volume. Transport demands of small flow and short distance takes the largest market share in the EU, which will also be proved in the literature review. Therefore, a case study between terminal of Gothenburg and Skara is conducted.

3 Methods and Methodology

3.1 Case Study

In social science and life science, a case may be a particular business, person, group, event or other phenomenon. Case study is a methodology that uses to explore a single phenomenon in a natural setting using a variety of methods to obtain in-depth knowledge (Collis & Hussey, 2009). As Yin (2009) defined: The research aims not only to explore single phenomena, but also to understand them in a particular situation. The research uses multiple methods in data collecting stage. The characteristics of research the authors carried out are totally as Yin defined. In this research report, the authors will collect data through documentary analysis and interviews. Furthermore, the authors will not only compare the cost of different transport modes, but also figure out the exact transport volume that the company can change the transport mode.

A critical case is defined as having strategic importance in relation to the general problem. A case leads to the following type of generalization traditionally, "*If it is valid for this case, it is valid for all (or many) cases.*" In its negative form, the generalization would be, "*If it is not valid for this case, then it is not valid for any (or valid for only few) cases (Flyvbjerg, 2006).*" The authors' research result can not only generalize to other section lines of Jula, but also other companies even whole country.

Although the advantages of case studies mentioned above are really persuasive, research can be very time-consuming. The scope of the study is also difficult to determine. As the result of case studies is more in descriptive aspect, it's difficult to be summarized in statistical aspect.

3.2 Data Collection

Theories involved in intermodal transport and LHVs and detailed data of the company Jula such as goods flow is the main information needed to be collected for our research. According to Collis & Hussey (2009), the data can be divided into two types due to the way of collection. Primary data is defined as the data observed or collected directly by the researchers from expriment and interview. Interviews and observation are the common methods used to collect primary data (Collis & Hussey, 2009). Besides, documentary analysis is a popular method to collected secondary data which is the published data by other researchers or the data collected by other parties for the other purpose previously (Collis & Hussey, 2009). Interviews are used when we collect detailed data of company Jula such as goods flow, the involved ports, roads and rail information, vehicles and so on in this thesis. A documentary analysis involves

reviewing all readily available secondary sources which include textbooks, newspapers, magazines, annual reports, speeches, on-line data bases, etc. (Bergqvist & Esping, 2002). In this thesis, documentary analysis contributes to map the theoretical framework including a literature review and a Swedish regulatory framework of intermodality and LHVs as well as experiences of LHVs in other countries.

3.2.1 Interviews

Table 3.1 Interviews

Interviewees (the organizations)	Main purpose of Interviews
Jula	Get the information of detailed transport flows and the data they collected related to this subject.
ETT and DUO2	Get practical advices since they have experience of driving vehicles with 32m length for several years.
Swedish Transport Administration	Gain information of the regulations
Volvo Truck	Gain technical advices and detailed information of vehicles with 32m length

The organizations considered having the key knowledge of using longer vehicles in the intermodal transport are expected to provide the mainly primary data by interviews. Collis & Hussey (2009) suggest interview can be structured, semi- structured or unstructured and can be done face to face, via telephone or email. A structured interview requires a number of prepared questions in order to get comparative results by same context for all interviews (Collis & Hussey, 2009). On contrary, an unstructured interview only needs an interview guide with some basic general questions. According to the interview plan (see Table 3.1), most interviews are supposed to be done via email since it is the most inexpensive way and suitable to get the electronic materials. The semi-structured way will be used according to the requirements of our research.

3.2.2 Documentary Analysis

A literature review aims to collect current knowledge especially the academic findings about the specific topic. To map the theoretical framework, this thesis reviews the definitions, results of evaluations and main obstacles to intermodality and LHVs. This review helps us to understand the scope and purpose of this thesis and methods applied in other research can be referred to. An introduction of the intermodality and LHVs in

Sweden is used to clarify the background of the case study which contributes to the empirical framework.

3.3 Calculation Method

To get a comprehensive comparison of the full costs of the diffident transport networks, the calculation method is important. Janic (2007) suggest that the full cost should include internal and external costs. Internal cost is comprised of operational cost of moving units during the trip and environmental cost is the main source of external cost that networks impose on society (Janic, 2007). Therefore, this thesis will calculate both operational and environmental costs. Moreover, there are two ways to compare the cost of the different systems: finding the different variables involved in the costs and then calculate the different costs from these different variables; respectively calculate the cost of each system and then compare the differences. According to Jensen & Bergqvist (2013), calculating the differential costs per container from different variables is an inexpensive way to get the comparative of both operational and environmental costs of different transport systems. Therefore, this thesis follows this method to compare the costs of different systems.
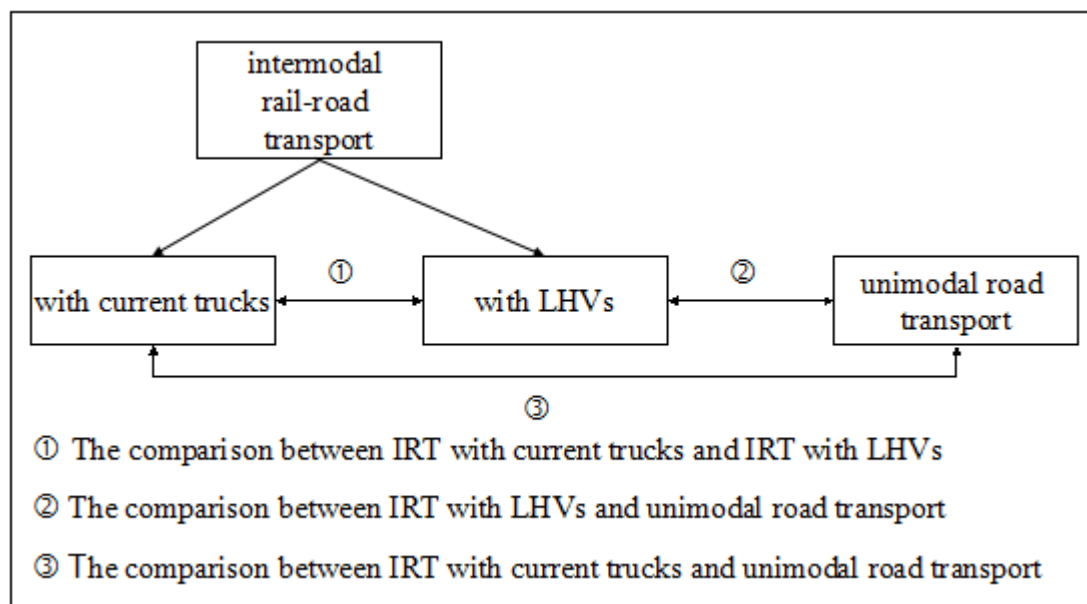
Figure 3.1 The comparison model

The model used to compare different transport networks is showed in Figure 3.1 which is the analysis framework in this thesis. First, the thesis will analyze the difference between IRT with normal truck and with LHVs which suggests how longer vehicles contributes to improving the IRT. Second, the comparison respectively between

17

unimodal road service and two different IRT scenarios will reveal the potential of LHVs to strengthen the competitiveness of intermodal transport.

To get the results of the comparison, both the economic and emission costs will be calculated using the model introduced in Chapter 7. The cost of a transport system, according to previous researches, depends on the volume and distance and can be described as the sum of the fixed costs and variable costs.

3.4 Research Evaluation

The methodology of the thesis is case study. It is generally recognized that the most representative model used to evaluate case study research is called the "natural science model" (Eisenhardt & Graebner, 2007). According to this model, a number of research actions are under four criteria: "construct validity, internal validity, external validity and reliability (Behling, 1980; Campbell, Stanley, & Gage, 1963; Cook, Campbell, & Day, 1979; Cook & Campbell, 1976) ." The assessment of case study will be processed under these four criteria below.

3.4.1 Validity

Validity describe as the research results reflect the phenomena under study accurately (Collis & Hussey, 2009). "*An effect or test is valid if it demonstrates or measures what the researcher thinks or claims it does*" (Coolican, 2009). Research errors, such as faulty procedures, poor samples and inaccurate or misleading measurement, can lead the research findings lack of validity (Collis & Hussey, 2009). Validity is different from reliability, but they are both very important to precise the research in a proper way (Kramer et al., 2009).

The construct validity refers to "*the degree to which a test measures what it claims, or purports, to be measuring (Brown, 1996).*" The great challenge the case study researchers confronted with is developing a well-considered set of actions, rather than using "subjective" judgments (Yin, 2009). Even though interpretivists and positivists find it difficult to develop common ground under the presupposition that construct validity and the notion of "objective" knowledge represent the one criterion, the positivist literature provides specific research actions that need to be considered to ensure construct validity. There are two strategies proposed. First, researchers use multiple sources of data and different research methods to reduce the bias, which is known as triangulation (Fontana, Frey, Denzin, & Lincoln, 1994; Jick, 1979; Pettigrew, 1990; Stake, 1995; Yin, 2009). In this research, the authors have investigated different

models to calculate the cost of road transport and intermodal transport. Second, in order to let the reader to follow how the researchers go from the initial research questions to final conclusions, researchers are suggested to establish a clear chain of structure (Yin, 2009).

Internal validity is a property of scientific studies and refers to the presence of causal relationships between variables and results. Unlike construct validity, the concrete research actions which are taken to warrant internal validity provide common ground for authors of positivist and interpretivist persuasions. According to the previous research, three main strategies have been suggested to ensure internal validity. First, case study researchers should clarify a research framework, which demonstrates the right connection between variables. The authors have listed a series of formulas to clarify the connection between the cost variables in different transport modes. Second, through pattern matching, researchers are not only encouraged to compare empirically observed patterns with history or future patterns but also the collected data with previous ones (Eisenhardt, 1989; Fontana et al., 1994). The models in this thesis not only take reference of previous ones but also renew the parameters in them. Last, triangulation is a theory taken from one discipline and used to explain a phenomenon in another discipline (Easterby-Smith, Golden-Biddle, & Locke, 2008). It enables a researcher to verify findings by adopting multiple perspectives   (Yin, 2009).

"External validity" which is also called "generalizability" is the extent to which the results of a study can be generalized to other settings. As a methodology associated with interpretivism, neither single nor multiple case studies allow for statistical generalization (Lee & Baskerville, 2003; Numagami, 1998; Yin, 2009). However, this kind of negation does not mean that case study researchers should give up on generalizability as long as the case study researchers figure out the difference between statistical generalization and analytical generalization. The statistical generalization refers to the generalization from a single phenomenon to a population; analytical generalization refers to the generalization from empirical observations to theory, rather than a population (e.g. Yin, 2009). In order to ensure the analysis generalization of case study, there are three recommended strategies. First, case studies can be a starting point for theory development and suggest cross-case analysis involving multiple case studies which provides a sound basis for analytical generalization (Eisenhardt, 1989). Second, researchers may undertake different case studies in one group rather than undertake and analyze multiple case studies of different groups (Yin, 2009). Last, but not least, in order to allow the readers to identify with the researchers' sampling choices, the

rationale for the selection of an object in case study should be reported, and so are ample details on the case study context (Cook et al., 1979). In this thesis, there is only one case that has been analyzed. However, the calculating model can be generalized in other cases.

3.4.2 Reliability

Reliability is the extent to which the conformity of the results in repeated studies(Collis & Hussey, 2009). When measure the reliability of the research, the researchers should ask themselves whether the data and conclusions can stand up after close scrutiny (Raimond, 1993). If a research finding is reliable, a repeat study will get the same result. In some way, reliability means stability and consistency. In case study, reliability of research means reliability of data to some extent. As mentioned in Section 3.2, data collection methods include documentary analysis, interviews, questionnaires and observations. According to Silverman (2013), there are a number of means for increasing reliability, including: tape-recording all face-to-face interviews and/or inter-rater reliability checks on the coding of answers to open-ended questions, as well as presenting long extracts of data in the research report. In this thesis, the authors have collected data in multiple ways including documentary analysis, interviews and questionnaires to verify the model constructed. The data used in the calculation model has a clear statement of source which can be repeated easily in further research.

Thus the key words of rising reliability are transparency and replication (Gibbert, Ruigrok, & Wicki, 2008). In order to enhance the transparency of the thesis, strategies such as careful documentation and clarification of the research procedures will be applied in the following part. For example, authors can produce a case study protocol - a report that specifies how the entire case study has been conducted. To some degree, sensitivity analysis enhances the transparency of the thesis. In regard to a case study database, in which data such as the preliminary conclusions of interview and documentary analysis collected during the study, authors are encouraged to make reference to facilitate the replication of the case study (e.g. Leonard-Barton, 1990). Although the original transport volume of Jula cannot be seen in this thesis as an interview result, the summarized values of different parameters can be seen in Chapter 7. Further, multiple models are used in this paper to verify the calculation results and guarantee reliability of this thesis.

4 Literature Review

This section will discuss the results of previous transport research with an emphasis on the intermodal rail-road freight transport (IRT), PPH, and high-capacity vehicles. Intermodal transport first developed out of the transport practice of the 1970s, and has since become an important policy in the 1980s due to environmental factors and the benefits of reducing cost with growing transport flows (Bontekoning et al., 2004). Today, intermodal transportation is still an important research area because it is an effective way of developing a sustainable transport network. At the same time, high-capacity vehicles are also gaining attention, and are currently used commonly in the United States, Canada, Australia, Germany, Sweden, Finland, Denmark, and elsewhere, mostly because of the benefit of improving transportation efficiency (OECD, 2011). There are three stems of transport research associated with this thesis: intermodal rail-road transport, the role of PPH and the effect of the LHVs. These research streams will be illustrated in the following chapter.

4.1 Intermodal Rail-Road Freight Transport（IRT）

4.1.1 Definition

A substantial amount of the research addresses intermodal freight transport issues since 1990. There are many definitions of intermodal freight transport without the establishment of a clear consensus (Bontekoning et al., 2004). The definition of intermodal freight transportation according to the United Nations Economic Commission for Europe is suitable for this research:

"*The movement of goods in one and the same intermodal loading unit(ILU) or road vehicle, which uses successively two or more modes of transport, without moving the goods itself in changing modes* (UNECE, 2001)."

Accordingly, intermodal rail-road freight (IRT) transport combines the two modes in which road transport is used in short-haul transit for collection or delivery, while rail transport is used in long-haul transport (Nachtmann et al., 2004). In this definition, an intermodal loading unit (ILU) is "*a consignment of freight – invariably, but not always, comprising a combination of small consignments, as in a groupage load, which is unitized to save trans-shipment and repacking time and cost at each individual stage of the journey, and also for ease of handling* (Lowe, 2006)." The same loading unit means a standard loading unit which refers to an ISO container or other swap bodies which are

internationally recognized.

4.1.2 The Evaluation of IRT

As a competitive practice, intermodal freight transport has been developed continuously. There is ample research identifying the many advantages of intermodal freight transport comparing with the single mode of transport. Muller (1989) clearly demonstrates that flexibility and efficiency are the direct contributors of intermodal transport which account for the intermodal system as a competitive strategy. The IRT system remains flexible because of the use of trucks in the PPH section to provide a door-to-door service as well as reducing the costs by using large units over long haulage (Bontekoning et al., 2004). Additionally, the intermodal transport system is a possible solution to increasing traffic congestion, especially on roads (Handman & District, 2002). In Brown and Hatch's (2002) research of the contribution of IRT transportation, they argue that the use of railway instead of road transport can not only remedy the problem of traffic congestion, but can also carry significant environmental benefits.

Furthermore, much recent research has been devoted to developing models for measuring the benefits of intermodal transportation. Kreutzberger et al. (2003) give a comprehensive comparison and evaluation of two transportation systems (IRT and unimodal road transport), while focusing on the external impacts including pollutant emissions, energy consumption, traffic congestion, noise and visual pollution and so on. Their conclusion clearly shows that intermodal transport has significant environmental benefits compared with the unimodal road transport. Later, Janic (2007) develops a model for calculating the internal and external costs of IRT transportation which provides a useful tool for calculating full costs of the transportation network and gives a comparison between intermodal system and road transport. In summary, intermodal freight transport has been proved to be an environmentally sustainable method of delivery which has much potential as a strong competitor to unimodal road transportation (Lowe, 2006).

4.1.3 The Categories of IRT Research

Bontekoning et al. (2004) form a review of 92 articles addressing IRT transport. Their conclusion shows that there are five basic research categories associated with this area: "*(1) drayage; (2) rail haul; (3) transshipment; (4) standardization; (5) multi-actor chain management and control.* (Bontekoning et al., 2004)" In this section, we will give a brief summary of these categories, as displayed in Table 4.1. The result of this

research shows that there are still many complex problems related to each category of the research field waiting to be solved.

Table 4.1 The basic concepts of each category

Drayage	These operations refer to full truckload container transport between a terminal and shippers/receivers, including the initial and final activities of an IRT (Morlok & Spasovic, 1994; Bontekoning et al., 2004). Drayage accounts for about 25% to 40% of the transport costs in the IRT system, significantly affecting the competitiveness of IRT (Bontekoning et al., 2004). The main problem in this area is to decrease the costs.
Rail haul	The rail haul is the terminal-to-terminal segment in the IRT system. The main problem of intermodal rail haul research is to organize the rail haul in a competitive way which is efficient and profitable(Bontekoning et al., 2004).
Transshipment	The core concept of transshipment is to develop new transshipment techniques, and gains great research interest (Bontekoning et al., 2004). Woxenius (1998) contributes a method for evaluating transshipment technologies.
Standardization	The problem of Standardization is there are still too many types of "*load units, rail cars and truck-trailer skeletons*" (Bontekoning et al., 2004). It is important for all operators to reach a consensus in order to reduce the amount of standardized unit types.
Multi-actor chain management and control	Multi-actor chain management and control is related to almost all aspects of the intermodal chain such as drayage, rail haul, transshipment and standardization (Bontekoning et al., 2004). The general problem is to manage all activities in the chain in order of "*providing timely information and communicating the right things at the right time*" (Bontekoning et al., 2004).

Source: Bontekoning et al., (2004).

The problems that remained in each category indicate research of IRT requires more attentions in the future. This thesis focuses on the category drayage which has the same meaning of PPH introduced in following section. Additionally, the activities of rail haul and transshipment are also involved in thesis.

4.1.4 The Obstacles to IRT

Even though the advantages of IRT freight transport are significant and obvious, there are still a lot of obstacles in the practice, and the discussion of operation and cooperation associated with IRT is ongoing. The European Commission (1997) published a comprehensive description of the obstacles to the use of intermodal freight

transport. The main question is that transfers between modes system create many "friction costs" which make intermodal transport uncompetitive compared with unimodal transport (European Commission, 1997). Woxenius and Bärthel (2008) list the main reasons for the unsatisfactory development of European intermodal road–rail freight transport (EIT) in the following table:

Table 4.2 Reasons for the unsatisfactory development of EIT

-Inferior frequency

-Time and cost handicap due to the transshipments

-Lack of standardization of swap bodies

-Rigidity of government-owned railways

-Fear of internal competition with wagon-load transport within railways

-Inadequate long-term stable access to rail capacity at strategic times

-Lack of realization of political promises

Source: Woxenius & Bärthel, (2008), pp.13-33**.**

The main barriers for the transport buyers when choosing the mode of IRT for the market of short distance and small flow are the uncompetitive economic costs and time costs of the IRT (Woxenius & Bärthel, 2008). It is widely recognized that road transportation is an environmentally destructive method of transporting goods compared with IRT. Nevertheless, as we have seen for so many years, the market share of the road transport is more than 80% of all inland freight transport in the UK and 73% in the EU (Lowe, 2006). Woxenius and Bärthel (2008) reported that the key to expanding the market of the IRT actually lies in the competition between IRT with unimodal road transport. However, in the small flow and short distance transport market, the performance of unimodal road transport is better in terms of price, flexibility and service (Lowe, 2006). Price and flexibility are associated with internal costs referring to economic and time costs (Daganzo, 2005). Therefore, the barrier to expand the market share of IRT is the internal costs including both the economic and time cost. The costs of the IRT are significantly affected by the cost of PPH and terminal operation (Bergqvist & Behrends, 2011). Therefore, a reduction in the costs of PPH and terminal operation seems to be a logical solution to reduce the cost of IRT and much current research is focusing in this area.

Table 4.3 The friction costs of infrastructure obstacle

- The lack of standard networks leads to a lack of spatial coverage;

- The management of each part within the current system is separate;

-The lack of integration between information technology systems;

-The lack of standardization of ILUs or swap bodies;

Source: European Commission, (1997); Woxenius and Bärthel, (2008).

The main barriers from a supply-side perspective of RIT are related to infrastructure (Woxenius & Bärthe, 2008)". European Commission (1997) published the main friction costs from the infrastructure obstacle. Some of these problems are still here today, and Table 4.3 shows the aspects of infrastructure obstacle as determined by the European Commission (1997) and Woxenius and Bärthel (2008).

The lack of consistent networks and interconnections can increase the friction costs, for example the wider gauge in Spain leads to an extra transshipment which will seriously increase costs. It is suggested that terminal technologies need to be developed since the terminal cost considerably affects the competition of IRT. Furthermore, the lack of the integration between IT systems makes it difficult to effectively organize the activities of loading, trucking, train loading and the handling of terminals between different operators, creating an obstacle in achieving intermodal effectiveness (Stone, 2008). Thus, the crux of the problem lies in standardization. Although there is some standardization, the types of loading units and swap bodies are still too many for an effective intermodal system. The EU makes an effort to popularize the only European intermodal loading units (EILUs) since if all the ILUs are replaced by EILUs, the number of road vehicles would be reduced by 25% when transporting the same amount of goods (European Commission, 2004). Therefore, there is still a long way to go before overcoming infrastructure obstacles.

4.2 The role of PPH in IRT

4.2.1 The Definition

There is a lack of literature that identifies a clear definition of PPH. Regardless, the PPH activities are easy to understand. The activities of PPH in an IRT system are always hauled by trucks as the initial and final legs of the IRT which we mentioned in the category of drayage (Lowe, 2006).
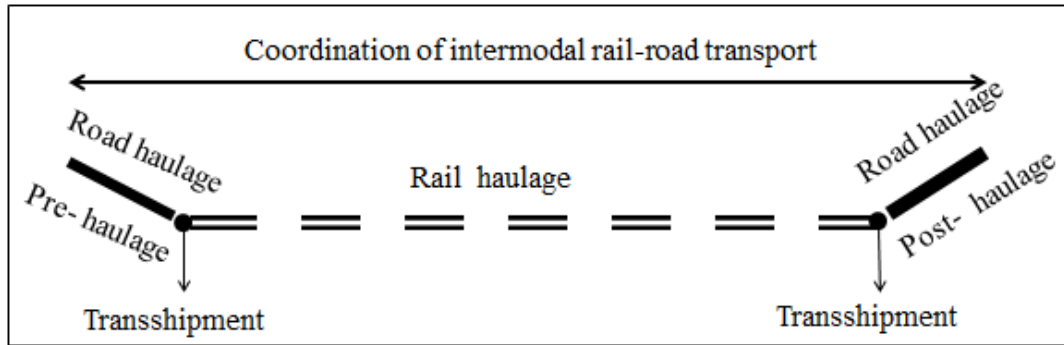
Figure 4.1 A system model focusing on activities in the intermodal chain
Source: Woxenius and Bärthel (2008).

Figure 4.1 is a model of IRT activities which shows the clear role of PPH, transshipment, and rail haulage (Woxenius & Bärthel, 2008). The core activities of IRT are transshipment, rail haulage, coordination activities, and PPH, (Woxenius & Bärthel, 2008) which include the operations of the intermodal loading unit from when it is filled to when it is emptied (Macharis & Bontekoning, 2004).

4.2.2 The Role of PPH in Intermodalism

PPH plays an important role in IRT. In fact, few IRT systems operate without taking PPH as initial and final legs (Lowe, 2006). The flexibility and convenience of PPH by truck is unmatched by any other mode. The truck can go almost anywhere and has a significant advantage for short distance transport demand. In Europe, the distance of most PPH operations around inland terminals is 0–25 km, with only a few cases over a distance longer than 100 km (Kreutzberger et al., 2003). Therefore the truck is the most predominant mode choice for short-distance PPH operations. However, the cost of PPH is so high that more research should be done to develop more cost-effective methods.

PPH accounts for about 25% to 40% of the transport costs, despite the distance of PPH being significantly shorter compared with the rail haulage(Bontekoning et al, 2004). The PPH costs can account for more than 70% of the total costs over a distance of about 300km around a port region in the US (Resor et al., 2004).The shorter the transport distance, the higher the proportion of PPH costs of the total costs, while the cost of transshipment accounts for another 20% of transport costs (Woxenius & Bärthel, 2008). Therefore, Ballis and Golias (2002, 2004) and Niérat (1997) point that the competitiveness of IRT transport basically depends on the costs of the PPH and transshipment operations. PPH and transshipment operations, therefore, seriously

affect profitability and competitiveness of IRT (Bergqvist & Behrends, 2011).

This feature of PPH makes IRT transport more suitable for the market of large flows over long distances rather than short flows over short distances since the high fixed costs of terminals and PPH can be offset (Bärthel & Woxenius, 2004). Over distances of less than 400 km, there is no competitiveness for IRT transport compared with unimodal road service (Williams & Hoel, 1998). Bärthel and Woxenius (2004) point out that long distance transport only accounts for 22% of the total demand for inland transport in the EU, while 46% of the demand is over distances between150 to 500 km, which is covered by short distance transport. This situation makes the market share of unimodal road transport more than 70% of the EU inland transport market despite IRT transport bringing benefits in both social and environmental aspects. Additionally, this situation puts pressure on environmental issues. Accordingly, research into increasing the market share of IRT is still ongoing. Much research focuses on resolving this conflict by making IRT transport more suitable for small flows and short distance transport demands. Research has showed that the break-even distance of intermodal transport compared with unimodal road transport can be decreased by 40% by reducing the PPH cost by 30% (Morlok et al., 1995). Kim and Van Wee (2011) also reported that reducing PPH cost is an effective means of decreasing the intermodal break-even and increasing the intermodal mode share at the same time. Thus, better PPH operation is the key for IRT to expand market.

4.2.3 The Size of the Truck related to PPH

The size and dimensions of trucks plays an important role in PPH, since trucks are by far the most popular method of PPH operation. There are significant operational differences between different vehicle types; in intermodalism, the most significant dimension lies in the length of the truck which determines how many containers or swap bodies can be carried per vehicle (Lowe, 2006). The size of the vehicles will also influence the costs of the PPH. Bärthel and Woxenius (2004) take the Swedish truck for example to explain how high-capacity trucks significantly decrease the average haulage costs. Meanwhile, Bergqvist and Behrends (2011) illustrate that longer vehicles with 32m length have considerable potential to decrease the cost of PPH. Elsewhere, Trip and Bontekoning (2002) show that it is possible to integrate small freight flows by "getting higher degree of loading, a higher frequency, and a larger geographical coverage of the network" through applying new terminal operation concepts within a specific case.

A significant amount of research interest emphasizes the importance of building efficient, integrated, and sustainable intermodal transport systems. Although the development of intermodal transport still faces many obstacles, the promotion of intermodal development has gradually formed the consensus. To develop IRT, we need a clear understanding of the demand for a mode of transport which not only considers environmental and social requirements, but also the economic cost. In summary, IRT represents a progressive and environmentally friendly way to transport goods. However, the main obstacle is that it cannot compete with unimodal road transport in the short distance market, which represents the main market of the EU. High capacity vehicles may contribute to overcome this obstacle since they carry a substantial potential to reduce the cost of PPH, which is the key to improving intermodal competition.

4.3 Longer and Heavier Vehicles (LHVs)

The definition of longer and heavier vehicles (LHVs) in EU could be "*all freight vehicles exceeding the limits on weight and dimensions established in Directive 96/53/EC. (European Commission, 2012)*" The LHVs in EU generally refer to the lorries which is 25.25 meters in length and 60 tonnes gross mass (OECD, 2011).

These LHVs which are used in Sweden since 1972 now are already in circulation in Sweden, Finland and Norway while they are under trial conditions in Belgium, Denmark, Germany and the Netherlands (De Ceuster et al., 2008; OECD, 2011).Currently, European Commission has begun to review the case of the use of LHVs and several administrations are considering the implications in order to deal with the increasing road congestion and environment problems. For the purpose of this thesis, LHVs introduced in this thesis are longer trucks which have a length of 32 meters and a maximum gross weight of 60 tonnes with expected capacity of two 40ft containers. Before focusing on this specific type of longer trucks, research of LHVs to a wider range will be introduced in Table 4.4.

Table 4.4 The current truck and LHVs in the EU

EU level	Current truck (Directive 96/53/EC)	General LHVs	LHVs related to this thesis
The maximum length(m)	18.75	25.25	32
The maximum gross mass(tonnes)	40	60	60

Much research has been done to assess the possibility of the change of the Directive and the use of LHVs. Some of the researchers take the countries that have the practices of using LHVs for a case study, while others estimate the effect of using LHVs in the area where the LHVs are forbidden before (European Commission, 2012). These researches get different conclusions of the effects of changing the Directive 96/53/EC. One group highlights the benefits of LHVs such as decreased costs and environmental benefits (Arcadis, 2006; De Ceuster et al., 2008; European Commission, 2012; Knight et al., 2008; McKinnon, 2008). Christidis and Leduc (2009) give a comprehensive and relatively complete integration of these conclusions which consider the demand market, economic cost, environment, safety and infrastructure. However, there are still a number of papers also show the negative impacts, which will be introduced in the following sections.

4.3.1 Effects on Road Cost

Globally, costs of human resources (26%, according to Larsson, 2008) and fuel (30% according to Larsson, 2008) account for more than half of the total cost (Christidis & Leduc, 2009). The costs of human resources, insurance and reparation all belong to fixed costs. As vehicles become longer and heavier, the cost per unit cargo for transport has changed. According to European research, the current trucks are shifted to LHVs, the road transport cost will be reduced approximately by 15% to 30% on average (De Ceuster et al., 2008; Doll et al., 2009). As well, a change of the size of Swedish lorries, which raises the maximum gross weight from 51 to 60 tons and length from 24 to 25.25m, has reduced the average haulage cost by about 30% per ton/km (Bärthel & Woxenius, 2004). McKinnon (2008) reports an increase in maximum truck weight from 41tonnes to 44tonnes in UK and a decrease of roughly 11% per tonne-km of the road haulage costs. In general, the LHVs are proving to have the potential of reducing road transport cost by 15%-30% on average in the EU.

4.3.2 Effects on Traffic Flow

First, change of cost will cause the of fluctuation of the demand for road transport since there is a key parameter called price demand elasticity which is "*a measure of responsiveness of the demand of a good or service related to changes in its price* (Tellis, 1988)." Graham and Glaister (2004) provide a brief review of elasticity associated with road traffic demand based on international literature which shows the instant of price demand elasticity is negative fluctuating between -0.5 and -1.5. This suggests that the demand of road transport will increase with the reduction of the price. De Ceuster et al.,

(2008) reports that the increase of the road traffic demand is expected to be more than 10% with LHVs and traffic volume (veh-km) to decrease by 12.9% because of the greater loading weight. Arcadis (2006) gives the similar answer that the road transport demand will increase by 0.05%-0.1% and traffic volume (veh-km) will be reduced.

Second, the demand of rail transport will decrease because of the cross-elasticity between the rail and road transport. The definition of Cross-elasticity is "*a measure of responsiveness of the demand for a good to a change in the price of another good (Dean, 1951)*". A comprehensive conclusion by Christidis and Leduc (2009) shows that the cross-elasticity is positive and typically ranges from 0.3 to 2 depending on travelling distance and the type of commodity. This means the raise of the road transport price will increase the demand for rail transport. On the contrary, the reduction of the road transport cost will reduce the demand for rail transport. Much research points out the mode shifts between road and rail transport. De Ceuster et al., (2008) use the TRANS-TOOLS model to evaluate the annual impact of LHVs on European transport market till the year 2020. The output shows a reasonable impact is the demand for rail transport will decrease by around 5 - 15 % per tonne-km in comparison to the situation without LHVs (De Ceuster et al., 2008). Meanwhile, the rail container shipments may face a loss up to 50% of the freight volume if 60t LHVs are used(Doll et al., 2009). Knight et al. (2008) gives a picture of the mode shift that maximum of 8-18% of all rail market would migrate to road with LHVs in the UK situation. In general, the LHVs will cause a mode shift from rail to road by about 5%-18% according to the above research in the EU.

4.3.3 Effects on Environment

With regard to the environment, emission and other environment externalities such as noise are considered. Energy efficiency is linked to fuel consumption and emission. The EU Directive (2006) defines Energy efficiency as "*a ratio between an output of performance, service, goods or energy, and an input of energy*"(Arvidsson, 2013). For road transport, the fuel consumption depends on energy efficiency. As such, improving energy efficiency significantly helps to reduce emission (Doll et al., 2009). Much research addresses in calculating the emission of the transportation system. De Ceuster et al., (2008) reports LHVs (60t) not only improve efficiency in fuel consumed per ton-km compared with the normal ones but also contribute to the reduction of CO_2 emission by 3.58%, NO_x emission by 4.03% and PM by 8.39%.

Table 4.5 Emission rates for vehicles with maximum laden weight

Emission	LHVs(25.2m, 60.0t)	UK truck (18.75m,44t)
CO (g/tkm) carbon monoxide	0.004	0.004
HC (g/tkm) hydrocarbons	0.000	0.000
NOx (g/tkm) oxides of nitrogen	0.202	0.214
PM (g/tkm) particulate matter	0.001	0.001
CO_2 (g/tkm) carbon dioxide	36.447	38.445
FC (g/tkm) fuel consumption	11.494	12.124

Source: Knight et al. (2008).

Table 4.5 shows the comparison of the emission rates for the LHVs and current trucks of Euro 4 emission class, proving LHVs to be more environment-friendly (Knight et al., 2008). Much research gets the similar answer that the LHVs are more efficient in fuel consumption and less pollutive (Arcadis, 2006; Aurell, Wadman, & Trucks, 2007).

However, other research holds some critical thinking of this environmental benefit. Doll et al. (2009) make a research to assess the effect of the LHVs in a long term with focuses on the change of demand for rail and road freight transport. They point out although the LHVs will improve energy efficiency and reduce the emission per unit goods, in the long term (15-30years) LHVs have the risk to lead to more emission due to greater demand for road transport. Further, the energy efficiency only increases when the load rate is more than 77% (Amt, 2007).

Noise is another main effect since the heavier loading weights will increase noise emission (Amt, 2007). However, Knight et al. (2008) provide a computer simulation of sound exposure levels (SEL) of diffident kinds of trucks and the result shows the increase in SEL is not consistent with the increase of number of axles, which means there is no significant influence of loading weight on SEL. However, some research points out the noise increases with heavier loading weights.

4.3.4 The Consideration of Safety

It seems to be intimidating for drivers of small or light passenger vehicles to share the road with LHVs since typically LHVs are large trucks with two or more trailers. Heavier vehicles may be involved in more accidents for the longer braking distance. Longer vehicles may take longer time to pass the corridors and thus are assumed to have higher accidents risk. The question is that if these vehicles are as safe as other commercial vehicles. Much of the discussion has been concerned with the safety of LHVs operation in the EU. Grislis (2010) suggests the safety of the trucks is closely

linked to braking performance and the risk of rollover and so on. The report points out the performance of LHVs is the same as the normal vehicles regarding the risk of rollover, and the braking performance problem can be solved by technology (Grislis, 2010). A Swedish research even shows that the time window of passing a vehicle is 4.5 seconds for 18m length and 4.3 seconds for 24m vehicles (Bertilsson & Olsson, 2009). An European investigation considering the handling characteristics of LHVs reports that there is not inherent increase of safety risks in general (De Ceuster et al., 2008). Moreover, it was recognized that the number of vehicle-kms to move the same amount of goods will be reduced because of the greater loading weights which suggests that the traffic safety would be promoted (Arcadis, 2006). However, some research insists that despite the risk of accident decreases, the consequences of accidents become worse for the heavier loading weight (Amt, 2007). In general, the risk of accident would decrease with LHVs.

4.3.5 The Consideration of Infrastructure

The main infrastructures required for LHVs are the roads and bridges. There are many factors that affect road wear such as axles, road surface, suspension design and so on (Viton, 2011). Among these factors, the axle weight is considered to be the most relative factor and thus the "fourth power rule" is a common rule to calculate the structural road wear from vehicles (Knight et al., 2008). The fourth power rule means that, for example, the road wear increases by 4% with 1% more of axles. A report calculates the road wear factor of several diffident types of trucks and gets the conclusion that the wear factor per vehicle decreases when number of axles and the gross vehicle weight (GVW) increases (Knight et al., 2008). BAST (2006) claims that road damages are not expected to increase using the trucks with 8 axles. However, Knight et al. (2008) also point out large investments are necessary to improve and maintain road infrastructures. With regard to bridges, the LHVs significantly stress the bridges which may increase the cost by around €4-8 billion in the EU (BAST, 2006). However there is no increasing cost related to the infrastructures involved with the LHVs in Sweden since LHVs were put into use since 1970.

In summary, different opinions exist in almost all aspects which shows that the current academy has not get a conclusive answer about whether the LHVs are feasible or not. However, all of the research above mentions that LHVs are of high ability to improve the efficiency of road transport, thus reducing the cost of road transport. In recent years, the attention of intermodal research has been increasing and European Commission has stressed LHVs repeatedly which indicates the significance of high-capacity transport.

Therefore, the study of high-capacity transport deserves more academic attention.

4.4 Implications from Theory

In general, this review explains the core concepts (shown in Table 4.6) and helps to understand the research purpose, which contributes to answer the research questions. The key to improving the competitiveness of the IRT transport in the short distance market is to reduce the cost of PPH and terminal operation. And this research will put emphasis on how to reduce the PPH cost. According to Bergqvist and Behrends (2011), the longer vehicles have potential to substantially lower the cost of PPH.

Moreover, the review of research on LHVs clarifies their impacts and gives suggestions to analyze the specific vehicles which are 32m (maximum length) and 60t (maximum GVW). First, this vehicle is at least as efficient as the normal LHVs because of the same maximum GVW. Bergqvist and Behrends (2011) even report that this longer vehicle would be more efficient than the EU normal LHVs in reducing the PPH cost. Second, the safety problem could be solved by the technology. Then, there is no increasing cost of the roads and bridges related to this longer vehicle in Sweden since the GVM remains 60t. Another problem should be considered is that the LHVs will lead to the mode shift from rail to road. For this problem, this thesis suggests only using this longer vehicle in a specific intermodal network. And this option would also solve problems on other aspects such as the risk of increasing emission due to greater demand for road freight transport.

Table 4.6 the Summary of review results

Important concepts of Intermodal rail-truck freight（IRT） transport

- Intermodal system is a competitive strategy (UNECE, 2001)

- IRT system is adapted to large flows over long distances transport which gain both the flexibility and the deduction of emissions

- The short distance transport market is the main market in the EU. (46% of the demand is over distances of 150–500 km) (Bontekoning et al., 2004)

- The main question of intermodal is modes shift creates many friction costs especial the time and economic cost of PPH which make the IRT cannot compete with unimodal road service with a small flow over a short distance. (Bärthel & Woxenius, 2004)

- The main barriers for the transport buyers to choose the IRT over short distance and small flow are the economic costs and the time costs of the IRT (Woxenius & Bärthel, 2008)

- The main barriers from a supply-side perspective of EIT are related to infrastructure (Woxenius & Bärthel, 2008)

Important concepts of pre- and post- haulage (PPH)

- PPH play an important role in the IRT by accounting for about 25% to 40% of the transport costs, despite the distance of PPH are significant shorter compared with the rail haulage (Bontekoning et al., 2004)

- The break-even distance of intermodal transport compared with unimodal road can be decreased by 40% by reducing the PPH cost by 30% (Morlok et al., 1995)

- High-capacity truck is a way to reduce the cost of PPH by lager loading weights. (Bergqvist & Behrends, 2011)

Important concepts of Longer and heavier vehicles (LHVs)

- The main benefit of LHVs is the transport efficiency which significantly reduces the cost and the fuel consumption (Bärthel & Woxenius, 2004; De Ceuster et al., 2008; Doll et al., 2009; Knight et al., 2008)

- The LHVs will cause a mode shift from rail to road 5%-18% (Arcadis, 2006; De Ceuster et al., 2008; Doll et al., 2009; Knight et al., 2008)

- The LHVs will bring energy efficiency which will decrease the emission per unit. In the long term LHVs would lead to more emission since greater demand of road freight transport (Doll et al., 2009)

- The risk accident would decrease with LHVs and the consequences may be higher (Amt, 2007).

- Large investments are necessary to manage road infrastructures and bridges in the EU. However, there is no increasing cost related to the infrastructures involved with the LHVs in Sweden.

5 Regulatory Framework

This chapter describes the PPH regulations for truck transportation in the EU with an emphasis on Sweden.

5.1 The Regulations in EU

As the economy develops, the demand for transportation increases so that both the size and weight of vehicles are increased in Europe, but specific regulations vary for different countries. Because of the trade cooperation in the EU, the international transport volume raises with high growth rates. Thus the application of standardization attracts great attention from stakeholders. The European Economic Community (EEC) started taking action in this area in 1963 by proposing regulations for the specific weights and dimensions of vehicles (Aurell et al., 2007). After a long process, the first directive for regulated weights and dimensions of international traffic between member countries appeared in 1983, called 85/3 EEC (Aurell et al., 2007). Because standardization has a dramatic effect on transportation capabilities, the amendments in this area are extremely exhaustive. The current directive, which was published in 1996, called Directive 1996/53 EC, regulates the maximum size of vehicles in international traffic. Simultaneously with the aforementioned directive, the ILUs were also being standardized into three main types: ISO container, swap bodies and semi-trailers (Bergqvist & Behrends, 2011).

5.1.1 Directive 1996/53/EC

The core dimensions for trucks described in Directive 1996/53/EC are showed in Table 5.1. According to Directive 1996/53/EC, the maximum permissible length for "road trains" is 18.75m when fully extended and 16.50m for truck-trailer combinations. The maximum gross weight is 40 tons but can be exceeded to 44 tons for international traffic when carrying 40ft containers. The dimensions for width and height are stable since they are significantly limited by the infrastructure. The general width is 2.5m, but the Directive 96/53 EC increased the general width to 2.55m, making the internal space suitable for both non-refrigerated and refrigerated vehicles (Aurell et al., 2007). Directive 85/3 EEC set the maximum height at 4.0m which was confirmed in Directive 96/53 EC for both international traffic and IRT. Although the directive allowed higher vehicles for national traffic, 4.0m is the maximum height in the majority of countries because of the limitations on large parts of the infrastructure.

Table 5.1 The summary of Directive 96/53 EC

Dimensions	Directive 96/53 EC
Length	18.75m/16.50m
Weight	40t(44t when carrying 40ft containers)
Width	2.55m
Height	4.0m

5.1.2 ILUs

Within intermodal transportation, containers are one of the most popular intermodal loading units (ILUs). According to ISO, the most common containers are 20ft with 6.05m length, 40ft with 12m length and 45ft with 13.50m length, and all with the width of 2.44m (Bergqvist & Behrends, 2011). In the container leasing market, the most common containers are 20ft, 40ft, and 40ft-high-cube, for which the specifications are showed in Table 5.2. Since height is the only difference between 40ft containers and 40ft-high-cube containers, this thesis regards these two types as 40ft length containers.

Table 5.2 The specifications of common containers

Dimensions	20ft	40ft	40ft(high cube)	45ft
External Length	6,058 mm	12,192 mm	12,192 mm	13,716 mm
External Width	2,438 mm	2,438 mm	2,438 mm	2,438 mm
External Height	2,591 mm	2,591 mm	2,896 mm	2,896mm

Table 5.3 Change of container demand in leased market

year	size		
	20 Ft(TEU)	40Ft(TEU)	40 Ft High Cube (TEU)
2006	2458720	1196703	1627530
2007	2623111	1188130	1778374
2008	2645849	2071700	3898964
2009	3093918	2185812	4344116
2010	2777337	1781854	4035471

Source: IICL (2006, 2007, 2008, 2009, 2010) Annual Leased Container Fleet Survey

According to IICL (2010), the large size containers have become a trend in recent years, as is demonstrated in Table 5.3. In 2006, the 20ft containers were the most popular; however, as of 2010, the percentage of 40ft length containers (include 40ft high cube) became 68% of the total container leasing market. The TEU which is the abbreviation of twenty-foot equivalent unit has become the industry standard used to

measure cargo volume and vessel capacity. Thus the 20ft container refers to 1 TEU and the 40ft length container refers to 2 TEUs, with the latter representing the most frequently used container today.

There are two different swap bodies according to different types of vehicles. The common "Class C" swap bodies with lengths of 7.15m, 7.45m and 7.82m are widely used for road trains. Otherwise, "Class A" swap bodies with common lengths of 12.50m or13.60m are used for articulated vehicles (Bergqvist & Behrends, 2011). Examples of a "Class C" swap body and semitrailer are showed in Figure 5.1. The maximum length for semi-trailers according to Directive 96/53 is approximately 13.6m, which are also the most commonly used. Therefore, the "Class A" swap bodies are similar in size to the typical semi-trailers and 40ft containers. The "Class C" swap bodies are similar in size to the 20ft containers.
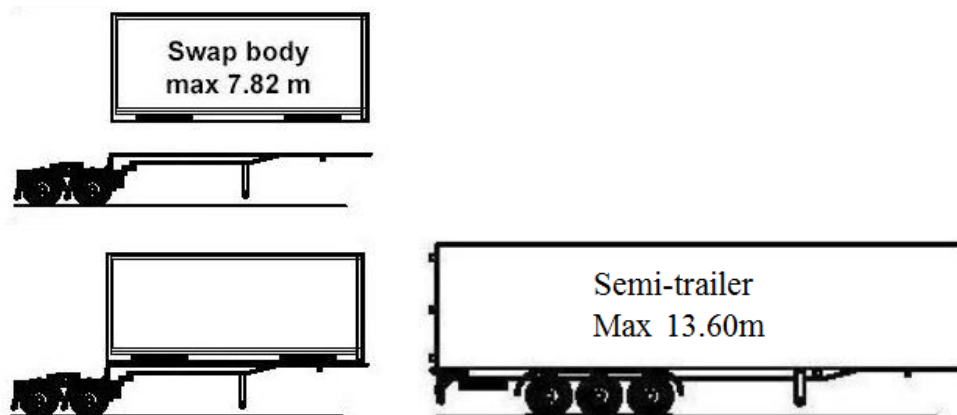
Figure 5.1 Swap bodies and Semi-trailer
Source: Åkerman & Jonsson, (2007), p.15, p.17

Three common types of ILUs following the dimensions described in the Directive 96/53 EC are illustrated in the following figure. The "short carries" used as a module includes 7.82 m, 7.45 m, and 7.15m standard swap bodies and a 20ft ISO container. The long module is 13.60m and includes a 40ft container. The common vehicles are designed to carry a multiple of combinations of these units. The articulated vehicles can carry one "Class C" swap body, one Semi-trailer, one "Class A" swap body, two 20ft containers or one 40ft container (Bergqvist & Behrends, 2011). The capacity of so-called road–train combinations is two 20ft containers or two "Class C" swap bodies (Lowe, 2006).
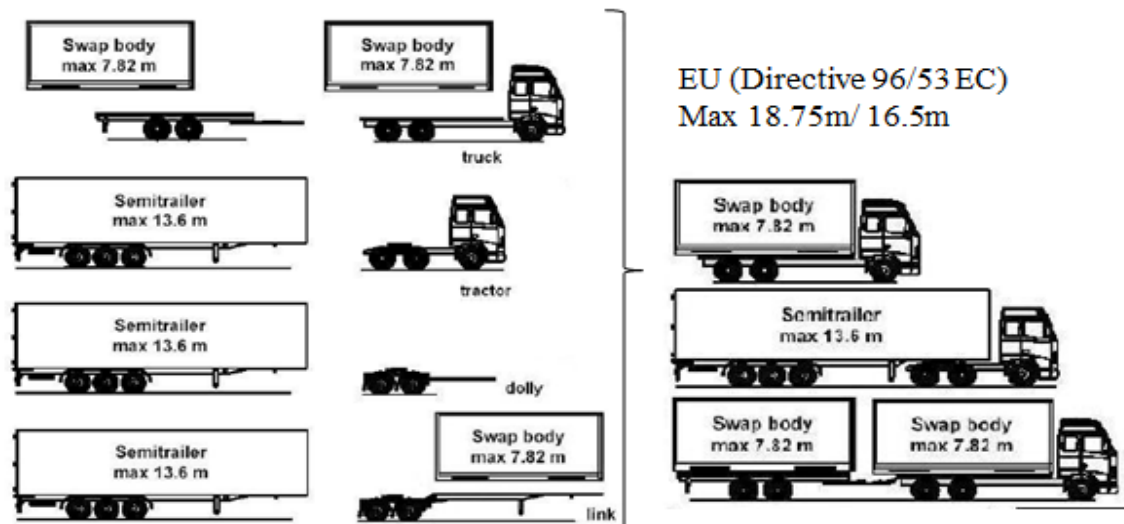
Figure 5.2 Units used according to Directive 96/53 EC

Source: Åkerman & Jonsson, (2007), p.1

5.2 The Regulations in Sweden

Directive 1996/53/EC allows the EU member states to legalize LHVs for national traffic. Vehicle-dimension legislation in Sweden is less strict compared with the general legislation Directive 96/53 EC (Åkerman & Jonsson, 2007). Sweden has a long history of using LHVs where the length of vehicles are 30m or longer, since there was no limit on the length of vehicle combinations before 1968 (Aurell et al., 2007). LHVs with a maximum length of 25.25m and weight of 60t have been regulated in Sweden since 1972. The details of Swedish regulation for trucks are showed in Table 5.4. Åkerman & Jonsson (2007) report that these LHVs are in accordance with the transport demand where there is a high weight and little volume. Therefore, the 24m vehicles are used for the heavier goods and the 25.25m vehicles are used for voluminous goods for national traffic. The maximum height of 4.5m in Sweden is higher than the current EU regulation of 4.0m. Since this size has been used in Sweden since the 1970s, the infrastructure in Sweden is suitable for LHVs unlike many other countries in the EU.

Table 5.4 The Swedish regulation for vehicles

Dimensions	Swedish regulation
Maximum Length	25.25m
Maximum Weight	60t
Maximum Width	2.55m
Maximum Height	4.5m

Since the international traffic in Sweden is increased in proportion with international trade, it is important to use the international standard ILUs. To solve this problem, European Modular System (EMS) developed the idea of combining one long module and one short module as a combination, as illustrated in the following figure (Åkerman & Jonsson, 2007). This situation allows for longer and heavier vehicles, even when the combinations of ILUs are different. The LHVs are allowed to carry combinations of one semi-trailer and one swap body or the combination of one 20ft ISO container and one 40ft ISO container. In this way, Swedish heavy commercial vehicles are able to transition into common standard vehicles within the Directive 96/53 EC by adopting the same ILUs when crossing borders.
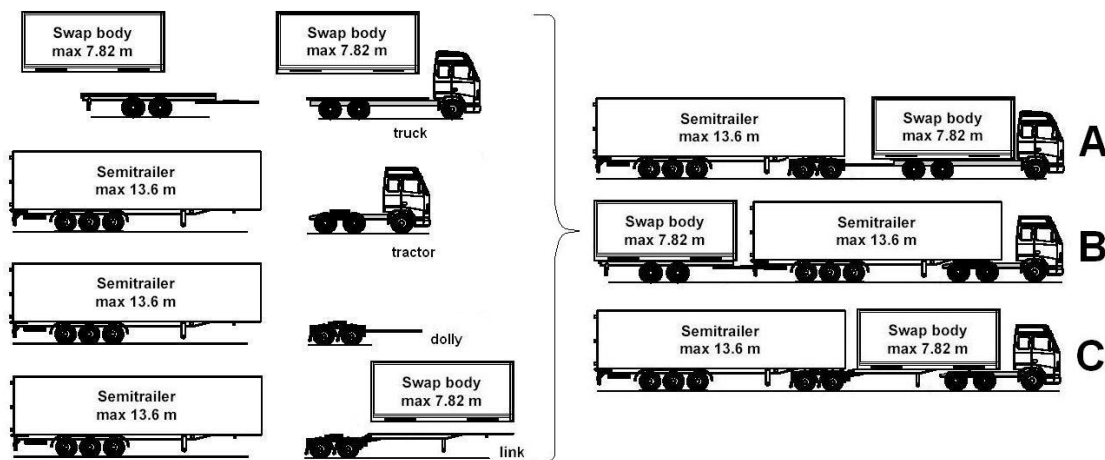
Figure 5.3 Units used according to EMS
Source: Åkerman & Jonsson, (2007), p.10

However, the transitional operation carries an extra cost. As the advantages of LHVs were discussed in the literature review, the European Commission is considering changing the regulation to allow for the use of LHVs in international traffic. To gain more effective intermodal transportation, some Swedish haulers prefer to apply for longer vehicles with a total length of 32m which can achieve a modular combination of two 40ft containers or even two 45ft containers.

6 Practices of LHVs

6.1 Practices in the World

This section will introduce the implementations of LHVs in other countries/areas. The practices from other countries may be a mirror for Sweden which can support re-regulation of LHVs in Sweden.

6.1.1 Australia

In Australia, B-doubles (name of a LHV) which are 26m in length and 68.5t GCM, B-triples and road trains are Higher Capacity Vehicles as well as called higher productivity vehicles. Australians have applied double and triple road trains (up to 53.5m and 125t) widely in remote areas for many years (OECD, 2011). Tractor-semitrailers and B-doubles are mainly driven for road freight task in urban areas and densely populated areas. As for the remote areas, tractors with four trailers which have forms of coupling in variety are permitted to be used (Koskinen, 2010; OECD, 2011).

In Australia general B-doubles have eight or nine axles. The Quad-axle B-double has the quad-axle at the rear of the lead trailer. With increasing acceptance in Quad-axle B-doubles in some trials, the capacity of two 40ft containers through urban areas is included. However, B-triples are attracting increasing interest as they have better conventional performance characteristics than the double (A-coupled) road train and BAB quads (two B-double trailer sets joined by a converter dolly) (Koskinen, 2010).

In September 2009, a trial of 'next generation High Productivity Freight Vehicles' was initiated in Victoria. The next generation high productivity freight vehicles are referred to Super B-doubles with up to two quad-axles, maximum 30m length and 77.5t GCM and two 40ft containers carriage. They will be tested via some particularly defined routes through Melbourne (containers) and then into Portland (woodchips) regional port. Operation will be subject to route limits, time limits (no peak period operations in Melbourne), compliance the conditions and qualifications in accordance with the national Mass Management program. Vehicles and operations must be evaluated by PBS process (Koskinen, 2010).

6.1.2 Canada

In Canada, Higher Capacity Vehicles are referred to Long Combination Vehicles (LCVs). They consist of a prime mover and two or three trailers or semi-trailers where the combined length is more than 25 meters limit of normal-sized trucks provincial

regulatory scheme prescribed. The three types of LCV are Rocky Mountain Doubles (RMDs), Turnpike Doubles (TPDs) and Triple Trailer combinations (triples). Permitted GCM are between 53.5 and 62.5 tons as well as lengths are up to 38 meters depending on the type of LCV. According to the standard configuration regulation, LCVs are allowed to add cubic capacity but not additional gross or axle mass   (Koskinen, 2010).

Long Combination Vehicle (LCV) is based on a permit license to be operated in some provinces (Alberta, Saskatchewan, Manitoba and Quebec). In addition, experimental study of LCVs has started in Ontario. LCVs are generally limited to a four-lane highway travel.

6.1.3 United States

The definition of higher capacity vehicles in USA is similar to that in Canada. In the United States, higher capacity vehicles are also Long Combination Vehicles and include Rocky Mountain Doubles and Turnpike Doubles. In contrast to the regulation in Canada, the permit for LCVs in the United States could also represent a general increase in the amount of the statutory limit.

LCVs were first introduced in the United States during the late 1950s with the tandem trailers via defined routes. The LCV network was frozen on 1 June 1991 by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Before that time 21 states allowed the use of at least one form of LCV. In 2009, LCVs were re-allowed in some specific areas in order to improve fuel efficiency   (Koskinen, 2010).

6.1.4 Europe

Higher capacity vehicles are generally referred to in Europe as Longer and/or Heavier Vehicles (LHVs). The most common example of a standard LHV in Europe is called European Modular System, i.e. as combinations of trucks, tractor and trailer with standardized load spaces. They include up to 25.25m in length and up to 60t of the total vehicle weight. These vehicles are firstly used in Sweden (since 1972), Finland and Norway, and under the trial conditions in Belgium, Denmark, Germany and the Netherlands.

In 2007, European Commission launched the consultations and discussions of instructions and possible revision on the weight and size of heavy commercial vehicle in the EU. A study funded by the Commission to change the instructions for the use and impact of LHVs in international transport in the critical part of European road network. Report was published in November 2008 (De Ceuster et al., 2008). The study concludes

that a wide range of topics are constantly debated, especially assumptions about the elasticity of demand and cross elasticity between road, rail and other modes of transport. Therefore, European Commission has conducted further, more detailed, studies of impact of potential changes in the economic and technological aspects.

- The Netherlands and Denmark

Experimental work of longer and heavier vehicles is carried in the Netherlands and Denmark. Only four companies firstly conducted longer and heavier vehicles in the Netherlands from 2001 to 2003. A larger trial was followed between 2004 and 2006 (66 companies and 100). The 'Experience Phase' beginning in 2007 continued into 2011. There were 139 companies and 330 vehicles involved in this phase. A three-year trial began in Denmark in November 2008, about 250 modular vehicles whose operation could be registered in Denmark.

- Other countries

The possibility of promotion longer and heavier vehicles in other European countries (including Germany, Belgium, France and the UK) has already been discussed. The German government plans to carry out a test and the British government after a preliminary desk study decided to refuse to use LHVs "for the foreseeable future". Germany and the UK are also considering the possibility of allowing a small increase in the existing semi-trailer length (OECD, 2011).

6.2 The Previous Project of LHVs in Sweden

As illustrated in Section 4.2, to gain more competitiveness in intermodal transport, some Swedish hauliers are making efforts to apply for permission for longer vehicle with total length of 32m. This section will present the previous examples of using longer vehicles in Sweden which are showed in Table 6.1. The well-known project is ETT that is a test to run LHVs between Piteå and Överkalix in the north of Sweden since 2009. The following example is the Dou2 project which runs the LHVs with 32m length and 80t weight between Gothenburg and Malmö. Additionally, the port of Gothenburg has the experience of LHVs for several years. In 2002, the exemption of allowing an operator to carry 2x40ft containers had been extended. This kind of vehicles is allowed to run back and forth between the port and Arendal with a single trip of over 5km. Bertilsson and Olsson (2009) point out that this exemption decision reduces the number of vehicles by 50% and emissions by 30%-40%. GA Åkerierna has put long vehicles in use since 2007 and this regulation is valid until 2015

(Bertilsson & Olsson, 2009).

Table 6.1 The previous experience of longer vehicles in Sweden

Start Time	Project	Detail
2009	ETT(En Trave Till/ One More Stack)	The timber truck with the length of 30m and the weight of 90 ton is rolling between Piteå and Överkalix.
2012	Duo2	The test of running LHVs with 32m length and 80t weight between Gothenburg and Malmö.

6.2.1 ETT

The ETT project aims at increasing the gross weights of the timber truck to reduce the total number of vehicles in Sweden and thus reduce the emissions and fuel consumption (Kyster & Tetraplan, 2013). Besides, the project will reduce the economic cost. The ETT project was initiated in 2006 based on the idea of extending a timber vehicle from usual three-stack to four-stack type. And the name of ETT refers to "En Trave Till" in Swedish which means one more stack being used. Therefore the ETT vehicles are longer and heavier than the current Swedish ones with a length of 30 meters and a gross weight of 90 tons. Thus ETT vehicles increase the payload by 50 percent compared to the traditional ones. In this way, the vehicle is supposed to reduce both environmental and economic costs by 20%-25% (Kyster et al., 2013). The combination model of ETT vehicle is shown in Figure 6.1.
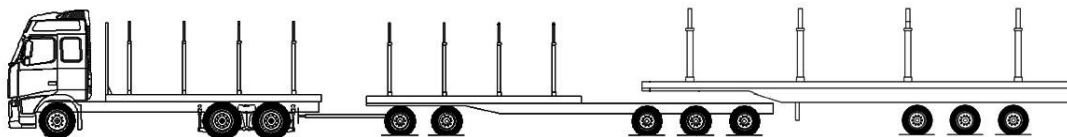
Figure 6.1 The ETT: Truck Dolly B-semitrailer Semitrailer
Source: Löfroth et al. (2013), P7.

These vehicles have been test-driven for three years. The distance is approximately 170km. The results of this three-year test will be reported recently. The first-year data shows that ETT truck has reduced the CO_2 emission by 22% and achieved the reduction in cost by 20% (Löfroth et al., 2013). Meanwhile, there is no negative impact found on road safety and road wear. The reason is that the axle loads do not increase (Löfroth et al., 2013).

6.2.2 DUO2

Another on-going project called DUO2 is the test of running LHVs carried general cargo between Gothenburg and Malmö. This project is under the cooperation of the Swedish Governmental Agency for Innovation Systems called Vinnova and the Volvo Group. The target of this project is to find the potential of the LHVs in reducing environmental impact and increasing the transport efficiency. Figure 5.2 shows DUO2 vehicle and the map of the project. DUO2 vehicles are the combination of two semitrailers or two 40ft containers which follow the standard of European modules as introduced above. The travel distance is approximately 300 kilometers from Gothenburg to Malmö.

DUO 2
From Gothenburg to Malmö
Length: 32m
Weight: 80t
Distance: approximately 300 kilometers

32 meter

GÖTEBORG

MALMÖ
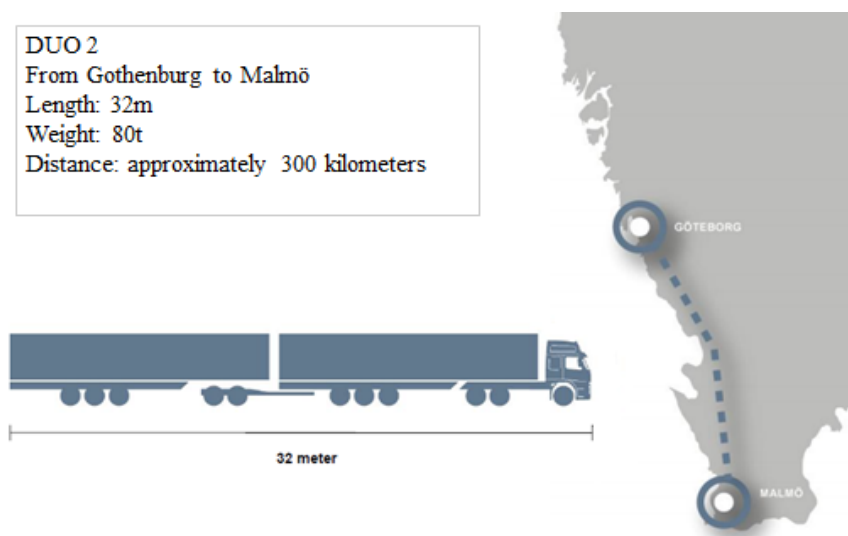
Figure 6.2 The detail of DUO2
Source: Volvo group, (2012), P18

The project tries to test all aspects of the LHVs including the effects on costs, traffic flow, emission, safety, infrastructure and some other logistic features during 7 years from 2010 to 2016. The goals set for the project are to reduce the carbon dioxide emissions by 15 % (per m3×km), to increase the transport efficiency by 40% and to reduce congestion by 30% (Henriksson & Davidsson, 2011). The Volvo Group reported the first set of test results in 2013. The data shows the DUO2 vehicles have achieved the reduction in fuel consumption by 27% compared to standard vehicles (Volvo group, 2014). DUO2 also reduces road wear because of the reduction of number of vehicles for the same mileage and the lower axle loads.

7 Calculation of Different Performances

7.1 Scenarios Presentation

There are three alternative transport solutions concerning the cargo that is transported from Gothenburg to Skara in the Jula case. When we compare these scenarios the unit must be assumed to be the same. According to the standard container unit in transport, a 20ft container is referred to as 1TEU (Twenty-feet Equivalent Unit) and a 40ft container is equivalent to 2TEU. In that way, the truck which can carry one 20ft container and one 40ft container is called 3-TEU truck in the following section while the truck which can carry two 40ft containers is called 4-TEU truck. Therefore, the three alternative transport solutions refer to the IRT with 3-TEU truck (which is the current network of Jula), the IRT with 4-TEU truck, and the unimodal road transport with 3-TEU truck.

Table 7.1 Carriage of two types of LHVs

EU level	General LHVs	LHVs related to this thesis
The maximum length(m)	25.25	32
The maximum gross mass(tonnes)	60	60
The maximum TEU	3TEU	4TEU

Given the transport network based on the project of Jula showed in Figure 7.1, the three solutions are described as three scenarios in order to make a clear basis for the calculation.
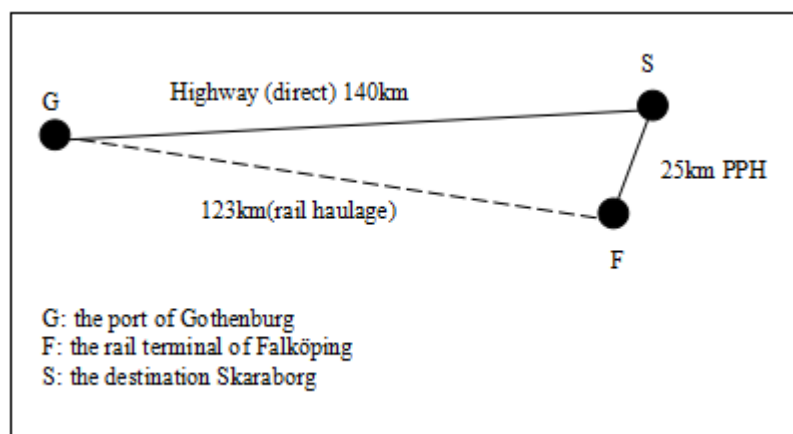
Figure 7.1 The transport network based on the project of Jula

Scenario 1 refers to the solution that uses 3-TEU truck in the PPH of the IRT. In Scenario 1(see Figure 7.2), the cargo is transported from the port of Gothenburg to Falköping by train and from Falköping to Skara by general 3-TEU LHVs. As this kind of truck can carry maximum 3TEU, such a scenario is named 3-TEU Intermodal transport. It should be noted that this scenario is currently implemented by Jula.
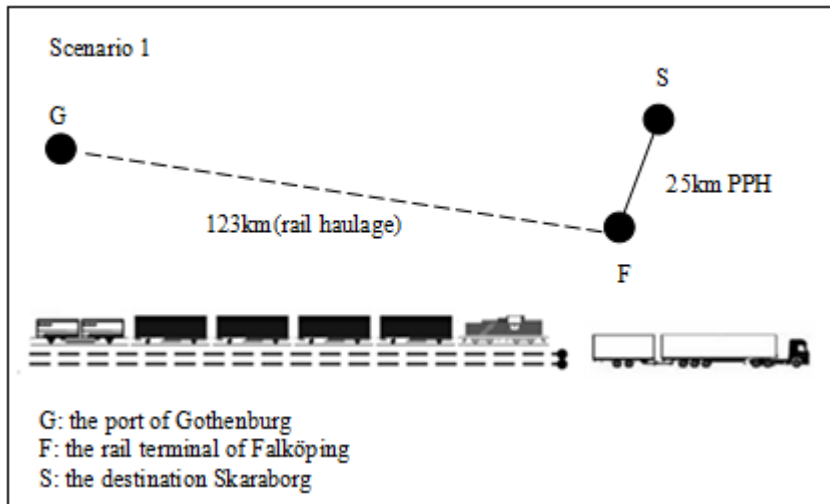
Figure 7.2 The network of scenario 1

Source: the picture of the train and truck is from Bertilsson and Olsson, (2009).

Scenario 2 refers to the solution that uses 4-TEU truck in the PPH of the IRT. In scenario 2 (Figure 7.3), cargo is transported from Gothenburg to Falköping by train and from Falköping to Skara by 32m LHVs. As this kind of truck can carry maximum 4-TEU, such a scenario is named 4-TEU Intermodal transport, and represents the recommended solution of the thesis.
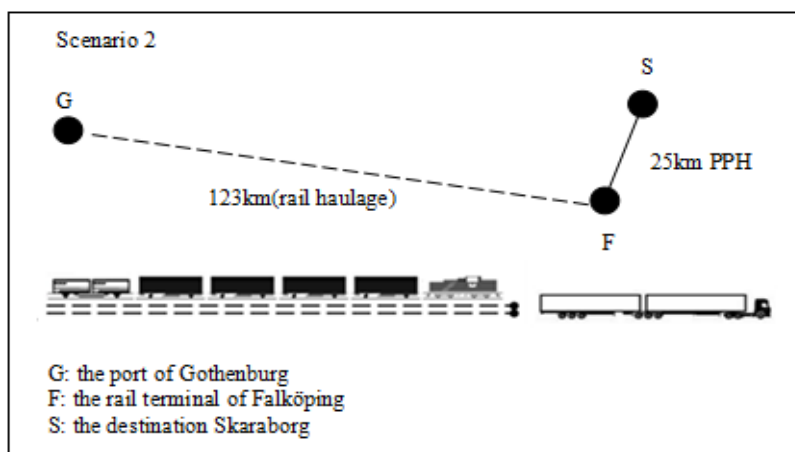
Figure 7.3 The network of scenario 2

Source: The picture of the train and truck is from Bertilsson and Olsson, (2009)

In scenario 3 (Figure 7.4), the goods are transported from the port of Gothenburg to the terminal of Skara directly by general LHVs on highway 20E. This scenario is named Unimodal Road transport, and was being used for a long time by Jula.
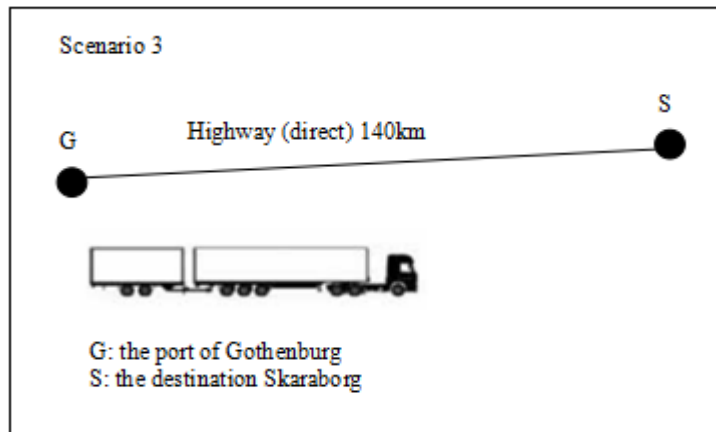
Figure 7.4 The network of scenario 3
Source: the picture of the truck is from Bertilsson and Olsson, (2009)

Since the only difference between Scenario1 and Scenario 2 is the truck size related to the PPH, the cost difference between Scenario1 and Scenario 2 implies the potential of the LHVs associated with PPH for the case Jula. The cost differences between Scenario1 and Scenario 3 suggest the competition between the IRT and unimodal road network.

7.2 Costs Structure

Within any transport system there are internal and external costs associated with cargo movement. Internal costs usually refer to the operational costs (Janic, 2007) but in this thesis relate to the economic cost of transporting units from origin to destination. Additionally, the transport system imposes many external costs on society including congestion costs, environmental costs, and accident costs, among others (Janic, 2007). Therefore, this thesis will consider not only operational and economic costs, but will also take into account these additional external costs that are imposed on society.

7.2.1 Economic Costs

The internal costs of a transport network are determined by all the operations associated with the movements of goods from production to consumption as showed in Table 7.2. Daganzo (2005) showed that these operations incur costs related to "motion" and "holding". The motion cost is defined as the total cost resulting from the handling and transport of goods. The holding costs refer to the waiting-time costs. This thesis just

considers the motion costs which are so-called economic costs according to the real situation of the case.

Table 7.2 The activities of the cargo moved from production to consumption

-carried from the production area to a storage area

-wait for a vehicle in storage area

-loaded into a vehicle

-transported to the destination

-unloaded, handled, and held for consumption at the destination

Source: Daganzo (2005), P30.

There are various cost components to consider when calculating transport costs, as showed by Daganzo (2005). When calculating transport costs, the cost structure can be divided into fixed costs and variable costs, where the division is completely dependent on the time period (Flodén, 2011). Many fixed costs are "shared costs," including overhead costs and some of the variable costs, which are taken as fixed costs in many calculations, for example as vehicle taxes. When calculating the economic costs of the Jula project, this thesis will also consider the costs from the company perspective. The costs can also be counted by items, including the cost of vehicle taxes, insurance, salary, repair, overhead costs, fuel cost, taxes, etc... As a means of organization, this thesis will classify these cost items into fixed costs or variable costs.

7.2.2 External Costs

External costs refer to "those costs that are incurred by other parties as a result of an operator's transport or terminal activities" (van Essen et al., 2011). The general external costs include five groups of "air emissions, accidents, noise, global warming and congestion (van Essen et al., 2011)". Vehicle transport causes air emissions, which as a result causes air pollution and damage to people's health and the environment. Traffic accidents necessitate financial compensation for the affected people and can occur in each operation step, determined by the different frequency and character of occurrence (Janic, 2007). Additionally, the consequences of traffic accidents due to the gross weight of transport vehicles are taken into consideration. Traffic congestion will also significantly increase the time costs of the traffic network and incur external emissions, and the impact of noise and congestion is considered in the operations of collection and distribution in an urban area. Ideally, this thesis will consider just consider the costs of the environment which focus on the air emissions.

The external costs of the operation depend on three factors as identified by the European Commission (1997): "the scale of the initial production of emissions, the physical impact of these emissions such as the damage of the health and delay and finally the valuation of these impacts." There are many research outcomes contributing to the evaluation of the external cost of different transport modes, as well as the monetary values of environmental costs. There are many internet-based calculators which are used to determine the environmental impacts of a freight operation. In order to clarify the significance of these impacts, we will identify environment costs with a monetary value, by translating physical impacts into the common economic metric. The valuation will be based on the estimates built by previous researchers. The structure used to calculate the external costs of the intermodal system in this thesis is to sum the cost of each section of the traffic network, and is similar with the economic costs.

7.3 The Calculation Model

According to Daganzo (2005), total cost of a transport system is composed of fixed and variable costs and can be general described as:

$$C_{total} = c_f + c_v \times v \times d$$

where C_{total} is the total costs of the transport, c_f is the fixed cost per shipment, c_v is the rate of variable cost increased per shipment size, v is the volume of the cargo and d is the transport distance. Considering the case scenarios, the total economic cost of the intermodal system can be divided into the cost of the rail haulage, handling and the road haulage.

Daganzo (2005) reported that if one uses a public carrier to transport the cargo, the total costs are the sum of the cost of each transfer unit. In this way, the costs of rail-haulage in this case depend on the volume and distance and the mathematical relationship is:

$$C_{rail\text{-}haulage} = c_{f-rail} + c_{v-rail} \times v \times d_{railway}$$

where $C_{rail\text{-}haulage}$ is the total costs of the railway transport, c_v is the rate of variable cost increased per shipment size, $c_{f\text{-}rail}$ is the fixed costs for rail transport, v is the volume of the cargo and $d_{railway}$ is the distance of the railway haulage.

The costs of road can be calculated in the same way. As the road haulage is operated

by the company, the costs of salary and general overhead costs are regarded as fixed costs. And the fixed costs are assumed to be just dependent on the number of shipments.

$$C_{road} = c_{f-road} + c_{v-road} \times v \times d_{road}$$

where C_{road} is total costs of the road haulage, the c_{f-road} is the fixed cost of the road.

Handling costs are incurred by the operations of loading and unloading the ILUs. The handling costs depend on the cargo flow:

$$C_{handling} = c_{v-handling} \times V$$

where $C_{handling}$ is the costs of handling happened in the terminal, c_v is the rate of variable cost of handling per loading unit, and V is the total volume of the cargo.

Therefore, the final economic costs are the sum of the costs mentioned above and the mathematical relationship is:

$$C_{total} = C_{rail-haulage} + C_{road} + C_{handling}$$

This is the structure to calculate costs of the intermodal system in this thesis.

7.3.1 Rail Freight Cost

As illustrated above, the economic costs of the rail haulage can be divided into the fixed costs and the variable cost. Compared to the road transport, rail transport has the feature of high fixed costs associsated with the equipment. Thus, the utilisation of the equipment is a key factor influencing the cost of running a train. In order to lower the fixed cost per unit, it is important to utilise the equipment as much as possible (Flodén, 2011). Accoding to Flodén (2011), in Sweden, costs of rail opration include costs of salary, infrastructrue use, and energy consumption. The costs of the salary is 517.14SEK per train hour as evaluated by Flodén (2011). The rail infrastructrue is owned by pubulic in Sweden and every operator pays a fee to use the infrastructrue. The infrastructrue fee according to Trafikverket (Swedish rail adminstration) includes four parts : train path for a freight service, track charge, operating charge and accident charge. In Sweden, rail operators also have to pay their electricity consumption (Flodén, 2011). The fee of electricity consumption published by Trafikverket vary depending on both the train type and vehicle type. To calculate the fee, this thesis will

choose the intermodal trains with the vehicle of New TRAXX engine. The cost of repair and maintenance should also be identified as the fixed cost according to Flodén (2011) . Items of the costs of the train are showed in the Table 7.3. Since train loading weight and loading carry will also influnce the costs, it is reasonable to assume a typical train. This thesis will use an previous estimation of a typical train with 75% loaded wagons and 20% spare wagons which can carry 60 TEUs published by Flodén (2011) . This train is introduced in the medium sceniro that the carriers can be both 20ft container and 40ft container in Flodén's research.

Table 7.3 The items of rail cost in Sweden

Items	Fixed or Variable costs	The fee rate (SEK)	The fee rate (evaluted 2014) SEK
Salary cost	Fixed(c_{f1})	517.14SEK per hour (Flodén, 2011)	548.6 (assume 2%increase per year)
The fixed cost	Fixed($c_{f2)}$)	782.13 SEK per hour(Flodén, 2011)	782.13 (assume no increase in equipment)
Train path for a freight service	Variable(c_{v1})	4.29 per train kilometre for high level (Trafikverket, 2014)	4.29
Track charge	Variable(c_{v2})	0.0045 per gross tonne kilometre(Trafikverket, 2014)	0.0045
Operating charge	Variable(c_{v3})	0.18 per train kilometre (Trafikverket, 2014)	0.18
Accident charge	Variable(c_{v4})	0.88 per train kilometre (Trafikverket, 2014)	0.88
Electricity consumption	Variable(c_{v5})	0.0212 KWH/gross tonne kilometre, 0.661 per KWH	0.661
Maintenance cost	Variable(c_{v6})	7.5 per kilometre(Flodén, 2011)	7.5(assume no increase)

Given the background above, the following costs calculation formulas are constructed:

Formulas 1. The costs calulation of the rail haulage

$$C_{rail-haulage} = \sum_1^i c_{fi}h + \sum_1^j c_{vj}v_j$$

$$= c_{fr1}h + c_{fr2}h + c_{vr1}n_{train}d_{rail}$$
$$+ c_{vr2}wd_{rail} + c_{vr3}n_{train}d_{rail} +$$
$$c_{vr4}n_{train}d_{rail} + c_{vr5}awd_{rail} + \quad,$$
$$c_{vr6}n_{train}d_{rail}$$

$$n_{train} = V_{TEU} / n_{TEU} \; ,$$

$$w = V_{TEU} \times w_{ac} \; ,$$

where $C_{rail\text{-}haulage}$ is the total operating costs of the rail transport section; c_f is the fixed cost; h is the number of hours that associated with the operation; cv is the rate of variable cost of each item; i is the number of types of the fixed costs; j is the number of number of the types of the variable items; d_{rail} is the distance of the rail haulage which is 125km according to the Jula case; c_{fr1}, c_{fr2}, c_{vr1}, c_{vr2}, c_{vr3}, c_{vr4}, c_{vr5}, c_{rv6} respectively refer to the different items of the costs which can be seen in the Table 7.1 and the rate is given; n_{train} is the number of the trains required depending on the scale of cargo; w is the grass weight; a is the charge of electricity consumption which is 0.0212 KWH per gross tonne published by the Trafikverket; t is the number of train holding hours per operating day(assumed 24h per day); $d_{operation}$ is the day of operating train assumed to be 53 days per year since one day per week according to the case; V_{TEU} is the total volume per year (TEU) ; n_{TEU} is the average shipment size for the train assumed to be 45TEU per train; w_{ac} is the average weight per TEU which is 5.7 ton per TEU evaluated from the Jula case.

The external costs of the railway can also be calculted in the similar structure. Rail transport is a quite environmental mode. There are huge number of researches and internet-based calculators addressed at estimating the emission of different transport modes. Flodén (2011) reported a rate of 0.21014 SEK per kilometer based on Swedish perspective. The calculation formula is :

$$C_{rail-emission} = c_{re} \times V$$

where c_{re} is the rate of variable emission cost increased per kilometer and is set to be 0.21014SEK per kilometer; v is the total shipping volume.

7.3.2 Handling Costs

Handling costs are identified as the costs of the operations of loading and unloading the ILUs. The cost of handling in much estimation just depends on the number of the ILUs. Therefore the cost of the terminal can use the formula mentioned in Section 7.2 . Additionally, the formula is valid for both economic and emission cost calculation. Here, in order to illustrate clearly, we will respectively give the formulas for calculating economic cost and emission cost:

Formulas 2. The costs calulation of handling

$$C_{handling1} = c_{v-handling1} \times N_{ILUs}$$

$$C_{handling2} = c_{v-handling2} \times N_{ILUs}$$

$$N_{ILUs} = V_{TEU} / (s_{40ft} \times 2 + s_{20ft})$$

where $C_{handling1}$ and $C_{handling2}$ respectively refer to the total economic and emission costs of the terminal; $c_{vhandling1}$ and $c_{vhandling2}$ are the rates of variable costs increasing with the cargo volume which is given to be 257kr and 14.22kr respectively Flodén (2011); the N_{ILUs} is the number of the ILUs which is estimated based on the Jula case; V_{TEU} is the total volume per year (TEU); s_{40ft} is the share of the 40ft container which is 0.6934 according to the 2013 Jula data; s_{20ft} is the share of the 20ft container which is 0.3066. The value of the parameters are showed in Table 7.4.

Table 7.4 The default value of the parameters in Formulas2

Parameter	Value
$c_{vhandling1}$	257kr
$c_{vhandling2}$	14.22kr
s_{40ft}	0.6934
s_{20ft}	0.3066

7.3.3 Road Freight Cost

The cost structure of road freight cost is mentioned above which is also divided into fixed costs and variable costs. Compared to the rail transport, road transport has lower fixed costs and higher variable costs. Fixed cost of road transport for one year includes equipment cost, overhead cost and salary. Additionally, the cost of equipment usually refers to depreciation of the purchase price, vehicle taxes, insurance and the fees of other equipment. Ideally, this thesis will assume the fixed cost is dependent on the number of working hours of the vehicles. We assume if the volumes of cargo rises, the company should increase vehicles and drivers as a result the overhead costs will increase too. According to Flodén (2007), the fixed cost of a typical 24m lorry per year is 321kr per hour. In order to transfer the fixed cost of 24m lorry from 2007 to 2014, we assume a rate of 2% increasing of salary while the price of the equipment stays the same and thus we use a price of 374kr as the fixed cost per hour. The main variable costs include fuel consumption, cost of reparation and cost of the tires. Flodén (2007) gives 4.17kr per kilometer as the variable costs. The current pump

price of the diesel fuel in Sweden is \$2.16 per liter and we assume a 50% improvement of fuel efficiency and thus the variable price for the truck is 4.6kr per kilometer. The LHVs are more efficient in fuel consumption per ton per kilometer but have the high costs per vehicle per kilometer because of the heavier loaded weight. Therefore, the number is 5.52kr per kilometer with the assumption of 20% more fuel consumption for LHVs.   The calculation is followed the cost structure mentioned above and it is the same way to calculate the cost of emission.

The variable costs of the road are increasing with per vehicle per kilometer. Therefore the number of possible shipments is the core factor that influences the cost. To estimate the possible shipments, this thesis will base on the data of Jula which suggests a share of 69.34% for 40ft containers and 30.66% for 20ft containers in 2013. Ideally, the number of the shipments is assumed to be stable in relationship with the shipping volume. Considering the situation of different scenarios introduced in Chapter 6, the number of the shipments are various due to the truck size. Given the statement above, the road freight costs can be calculated as followed formulas.

Formulas 3. The costs calulation of road freight

$$C_{road-economic} = c_{ft}h_t + c_{vt1}N_{truck}d_{road}$$

$$C_{road-emission} = c_{vt2}N_{truck}d_{road}$$

As the 3-TEU truck is the only truck: $N_{truck} = s_{40ft}N_{ILUs}$,

As both 3-TEU and 4-TEU are used: $N_{truck} = s_{20ft}N_{ILUs} + (s_{40ft}N_{ILUs} - s_{20ft}N_{ILUs})/2$

$$h_t = N_{truck}(d_{road}/s)$$

where the $C_{road-economic}$ is the total economic costs of the road transport; $C_{road-emission}$ is the total emission costs; c_f is the fixed cost rate increasing with the requited work hours; the h_t is the requited work hours; c_{vt1} is the rates of variable economic costs increasing with the cargo volume; c_{vt2} is the rates of variable emission costs increasing with the cargo volume; N_{truck} is the number of the shipments related to the truck; d_{road} is the distance; s_{40ft}, s_{20ft} and N_{ILUs} has been introduced in the Section 7.3.2; s is the speed of the truck based on the Sweden transport regulation.

Here, the speed of the truck is various dependent on different roads. The regular speed of the E20 is 110km per hour and 70km per hour for the Road184 associated with the Jula case. In the calculation, we assume the speed of truck is 110km/h for the highway

and 60km/h for the PPH. The core values of the parameters are showed in the following table.

Table 7.5 The default value of the parameters in Formulas3

Parameter	Value
c_{ft}	374kr per hour
c_{vt1}	4.6kr per kilometer
c_{vt2}	5.52kr per kilometer
S	110km/h or 60km/h
s_{40ft}	0.6934
s_{20ft}	0.3066

7.3.4 Total Costs Calculation Model

Total costs are the sum of the cost of each section as introduced in the cost structure. Given the calculation of each section, the total cost of the traffic system is constructed and showed in Table 7.6.

Table 7.6 Components of the total costs

Rail section	Handling section	Road section
$C_{rail-haulage} = \sum_1^i c_{fi}h + \sum_1^j c_{vj}v_j$ $= c_{fr1}h + c_{fr2}h + c_{vr1}n_{train}d_{rail}$ $+c_{vr2}wd_{rail} + c_{vr3}n_{train}d_{rail} +$ $c_{vr4}n_{train}d_{rail} + c_{vr5}awd_{rail} +$ $c_{vr6}n_{train}d_{rail}$ $n_{train} = V_{TEU} / n_{TEU}$, $w = V_{TEU} \times w_{ac}$ $C_{rail-emission} = c_e \times V$	$C_{handling1} = c_{v-handling1} \times N_{ILUs}$ $C_{handling2} = c_{v-handling2} \times N_{ILUs}$ $N_{ILUs} = V_{TEU} / (s_{40ft} \times 2 + s_{20ft})$	$C_{road-economic} = c_{ft}h_t + c_{vt1}N_{truck}d_{road}$ $C_{road-emission} = c_{vt2}N_{truck}d_{road}$ $N_{ILUs} = V_{TEU} / (s_{40ft} \times 2 + s_{20ft})$ As the 3-TEU truck is the only truck: $N_{truck} = s_{40ft}N_{ILUs}$, As both 3-TEU and 4-TEU are used: $N_{truck} = s_{20ft}N_{ILUs} + (s_{40ft}N_{ILUs} - s_{20ft}N_{ILUs})/2$ $h_t = N_{truck}(d_{road}/s)$

For the intermodal network:	For the unimodal road transport:
$C_{total-economic} = C_{rail-haulage} + C_{handling1} + C_{road-economic}$ $C_{total-emission} = C_{rail-emission} + C_{handling2} + C_{road-emission}$ $C_{total} = C_{total-economic} + C_{total-emission}$	$C_{total-economic} = C_{road-economic}$ $C_{total-emission} = C_{road-emission}$ $C_{total} = C_{total-economic} + C_{total-emission}$

7.4 The Different Performance

This section will give the calculating results of the different scenarios based on the data from Jula. This thesis will follow the comparison structure introduced in the methodology section. First, the comparison between scenario1 and scenario2 which aims at finding the potential of the LHVs related to PPH in improving the IRT will be constructed. Second, this thesis will give sensitivity analysis focuses on the single variable: V_{TEU}. The purpose of this sensitivity analysis is to show how LHVs help to improve the competition of the IRT compared to the unimodal road transport.

7.4.1 The Performance of LHVs related to the PPH of the IRT

Given the scenarios introductions in the Section 7.1, the comparison of Scenario1 and Scenario2 will investigate the potential of the LHVs related to the PPH. In the Scenario1 and Scenario2, all costs components keep same. Thus the costs only change with the size of the truck. Put the data from Jula showed in Table 7.7 into the calculation model for intermodal network, the result is showed in Table 7.8. The result implies that the LHVs have the potential to reduce the total economic cost of the intermodal network by 5.43%.

Table 7.7 The default value for parameter from case

Parameter	Value
d_{rail}	123.14km
d_{road}	25km
V_{TEU}	8137(count directly from data)
Number of trucks for Scenario1	3340(count directly from data)
Number of trucks for Scenario2	2421(count directly from data)
Number of 3-TEU trucks for Scenario2	1502(count directly from data)
Number of4-TEU trucks for Scenario2	919(count directly from data)

Table 7.8 The result of the two scenarios

Total economic costs		Total emission costs		Total costs	
Scenario1	Scenario2	Scenario1	Scenario2	Scenario1	Scenario2
4190649	3962890	539940	411463.8	4657581	4301346
Decrease 5.43%		Decrease 23.79%		Decrease 7.53%	

Bergqvist and Behrends (2011) reported a strategic calculation model to compare the similar IRT system with different vehicles. The strategic model are proved to be useful and simplified since there is no need to consider the detail costs components due to the same network. The strategic model built by Bergqvist and Behrends (2011) is showed as followed:

$$TCC_{chain} = (1 - CS_{road}) + TCC_{road} \times CS_{road}$$

$$TCC_{road} = FCC_{road} \times FCS_{road} + VCC_{road} \times VCS_{road}$$

$$FCC_{road} = (N_{s2-4TEU} + N_{s2-3TEU}) / N_{s1-3TEU}$$

$$VCC_{road} = (\alpha N_{s2-4TEU} + N_{s2-3TEU}) / N_{s1-3TEU}$$

where TCC_{chain} is the total cost change for the intermodal network (%); CS_{road} is the road freight cost as the share of the total cost(%); TCC_{road} is the total cost change for the road freight (%); FCC_{road} is the total cost change for the fixed cost of road freight (%); VCC_{road} is the total cost change for the variable cost of road freight (%); FCS_{road} is the fixed cost share for the road part (%); VCS_{road} is the variable cost share for the road part (%); $N_{s2-4TEU}$ is the number of the 4-TEU truck used in Scenario2 (NO.); $N_{s2-3TEU}$ is the number of the 3-TEU truck used in Scenario2 (NO.); $N_{s1-3TEU}$ is the number of the 3-TEU truck used in Scenario1 (NO.); α is the variable cost share for 4-TEU truck compared with the 3-TEU truck (%).

Given the model above and the value based on the case in Table 7.9, the result show that the total cost change for the intermodal network is 94.6%. This means the LHVs achieve a cost reduction with the rate of 5.4%. Therefore, two different methods get the similar result.

Table 7.9 The default values from the case

CS_{road}=21.5%
FCS_{road}=53%
VCS_{road}=47%
α =130%
$N_{s2-4TEU}$=919
$N_{s2-3TEU}$=1502
$N_{s1-3TEU}$=2421

7.4.2 Sensitivity Analysis

Sensitivity analysis will give a clear picture for drawing the change of the cost dependent on the shipment volume. For the purpose of the sensitivity analysis, the volume of shipment is the independent variable. The default value of the basic parameters and variables which are defined above is showed in Table 7.10 from Jula case. The other variables are derived on the volume. And the results are showed in

Table 7.11.

Table 7.10 The default values from the case for sensitivity analysis

c_{rf1}=548.6	c_{rv6}=7.5	d_{rail}=123.14
c_{rf2} =782.13	c_{re}=0.21014	d_{road}=25 or 140
c_{rv1}=4.29	$c_{vhandling1}$=257	s=110 or 60
c_{rv2}=0.0045	$c_{vhandling2}$=14.22	s_{40ft}=0.6934
c_{rv3}=0.18	c_{ft}=374	s_{20ft}=0.3066
c_{rv4}=0.88	c_{vt1}=4.6	
c_{rv5}=0.661	c_{vt2}=5.52	

Table 7.11 The results of the sensitivity analyses

The economic cost			
Volume (TEU)	Scenario1	Scenario2	Scenario3
1000	1999406	1971101	458608.7
3000	2612841	2527927	1375826
5000	3226275	3084753	2293044
7000	3839710	3641578	3210261
9000	4453145	4198404	4127478
11000	5066580	4755229	5044696
13000	5680015	5312055	5961913
15000	6293449	5868881	6879131
17000	6906884	6425706	7796348
19000	7520319	6982532	8713566

The emission cost			
Volume (TEU)	Scenario1	Scenario2	Scenario3
1000	66216.54	50250.25	320567.5
3000	198649.6	150750.7	961702.5
5000	331082.7	251251.2	1602837
7000	463515.8	351751.7	2243972
9000	595948.8	452252.2	2885107
11000	728381.9	552752.7	3526242
13000	860815	653253.2	4167377
15000	993248.1	753753.7	4808512
17000	1125681	854254.2	5449647
19000	1258114	954754.7	6090782

The total cost			
Volume (TEU)	Scenario1	Scenario2	Scenario3
1000	2065622	2021352	779176.2
3000	2811490	2678678	2337529
5000	3557358	3336004	3895881
7000	4303226	3993330	5454233
9000	5049094	4650656	7012586
11000	5794962	5307982	8570938
13000	6540830	5965308	10129291
15000	7286697	6622634	11687643
17000	8032565	7279961	13245996
19000	8778433	7937287	14804348

8 Analysis

In this chapter, we will analyze and define the role of the PPH related to IRT, as well as the potential of LHVs associated with PPH for the Jula case, based on the calculation results.

8.1 The Role of the PPH related to IRT

As we illustrated in the literature review, the PPH operations significantly affect the profitability of IRT. In the Chapter 4 we stated that PPH accounts for about 25% to 40% of the transport costs, despite the distance of PPH being significant shorter compared with the rail haulage (Bontekoning et al, 2004). In the case of Jula, the distance of the PPH is 25km and the cost of PPH accounts for 21.5% of the total transport costs. The cost of the terminal operation accounts for another 29.5% of the total cost. This result from the case study is similar with the previous research. Since we just consider the economic costs of the internal costs, the share of the PPH of the total cost will be greater if we consider the waiting cost which is mentioned in the cost structure. Waiting costs refer to the cost of the value lost due to the delay to the items (Daganzo, 2005). Since there are more operations associated with IRT, there is more waiting cost of IRT compared with the unimodal road cost. According to Janic (2007), the time cost accounts for about 20% of the total cost of the IRT and just 1% of the unimodal road transport. Therefore, PPH and terminal operations seriously limit the markets of the IRT which are also the key to reduce the cost of the IRT and gain the competitiveness.

Table 8.1 The cost saving of PPH due to LHVs

The PPH cost of Scenario1	The PPH cost of Scenario2	The cost saving due to LHVs
904583.3333	676824.5	25.2%

Previous research defines many methods of reducing the cost of PPH and terminal. To reduce the time cost transport operators need a development of information technology and the cooperation of the operators involved. This thesis suggests using the LHVs in the PPH to reduce the economic cost of the PPH. Table 8.1 shows the costs are reduced by 25.2% due to the LHVs based on Jula project. Additionally, the LHVs also help to save the emission by approximately 24.1%. The costs reduction here is dependent on shipment volume and the share of 40ft containers in Jula case. If

the share of 40ft containers reaches 100% and the shipment volume gets enough large to full-load the vehicles, the reduction of economic cost could be up to 50% which is the maximum saving of cost in Jula case. LHVs can support the PPH and make the PPH more efficient in both economic and environmental fields.

8.2 The Potential of the LHVs

Woxenius and Bärthel (2008) report that the key to expanding the market of the IRT lies in the competition with unimodal road transport. In this section, this thesis will not only give the performance of the LHVs related to the IRT based on the Jula case, but will also define the break-even of the different scenarios. The break-even means the point where the costs of the different transport modes are balanced, thus representing the key factor for the transport buyer when making a purchase. The analyses of the break-even will indicate the competition between the IRT and unimodal road transport. The different break-evens discovered by shifting from scenario1 to scenario2 imply how LHVs contribute to enhancing the competitiveness of the IRT and explore the IRT market.

8.2.1 The Economic Effect

The figure below shows the average economic cost of three scenarios where the horizontal axis represents the volume of TEUs and the vertical axis the price in SEK. It is obvious that Scenario 1 gets the top average economic cost because of the high fixed intermodal cost from transshipment, rail part, and the high variable cost from the 3-TEU truck in the PPH. However, when we change the truck to 4-TEU (Scenario 2), the variable cost in PPH comes down, making the IRT more competitive. Furthermore, the average economic cost gets lower when the volume of goods becomes larger in IRT mode. In Scenario 3, as the unimodal road transport mode seldom has fixed cost, the average cost is lowest when the volume is less than 9500 TEUs, but the average cost will rise when the goods flow gets large in proportion with the high road transport variable cost. If Jula do not change from the 3-TEU to 4-TEU truck, the IRT mode will not be competitive unless the TEUs exceed 11000. In 2013, the total TEUs of goods transported from Gothenburg to Skara reached 8137. It seems that unimodal road transport is currently the most competitive mode if we ignore the external cost, and according to the Jula demand the transport volume is increasing at a rate of 15% per year. Therefore, the IRT with the 4-TEU truck will be the competitive alternative in the coming years.

The result indicates that the average economic cost of intermodal network depends on

the shipment volume and the average economic cost decrease for increasing volume due to the high rail haulage fixed cost. The average cost of unimodal road transport is the same since the fixed cost associated is assumed to be zero. This indicates that IRT enhances its competitiveness by increasing shipment volume and represents the competitive alternative to unimodal road transport beyond the break-even volume. The average economic cost of IRT with the 4-TEU truck decreases at a higher rate than the network of IRT with the 3-TEU truck. Thus the break-even volume of the IRT compared with the unimodal road reduces from 11000TEU to 9500TEU. This means that at the same distance the LHVs can expand the IRT market over a smaller transport flow.
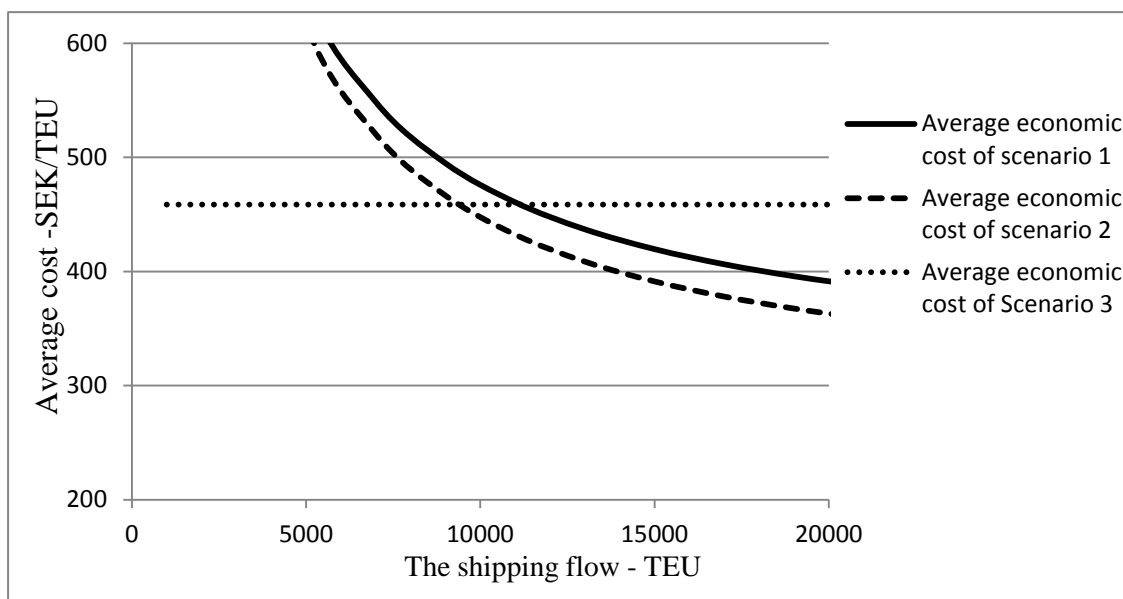
Figure 8.1 Dependence of the average economic costs of given scenarios on the volume of units

Table 8.2 The sensitive results of the cost reduction with LHVs

Volume	Cost reduction
1000	1.44%
3000	3.25%
5000	4.39%
7000	5.16%
9000	6.15%
11000	6.48%
13000	6.75%
15000	6.97%

Table 8.2 shows the sensitive results of the cost reduction from the comparison

between Scenario 1 and Scenario 2 due to the LHVs. The result shows that the cost decreasing rate increases with the volume. Since increasing the transport demand of Jula appears to lower costs, loosening the traffic regulation will achieve economic cost reduction in the future.

Given the analyses above, it is reasonable to draw the conclusion that the LHVs not only help the Jula project to achieve more cost reduction but also can expand the IRT market if the LHVs are used in the PPH. For Jula, the LHVs will achieve a 5.43% reduction of economic costs on the volume of 8137 TEU in 2013, and the decrease rate will increase with the increasing transport demand. Meanwhile, as illustrated in the literature review, the IRT is competitive over long distance and large flow. The LHVs decrease the break-even compared with the unimodal road and thus expand the IRT market over a smaller transport flow.

8.2.2 The External Effect

The external cost is calculated with the help of emission calculators. The advantage of IRT is clearly visible in the picture below. The external cost of all road transport is 5 times greater than the external cost of IRT because of the decrease in fuel consumption and emission in rail transport. Additionally, when the LHV is shifted from 3-TEU to 4-TEU the environmental effect decreases about 5 SEK per unit. Thus, intermodal transport with the 4-TEU truck performs best in environment aspect.
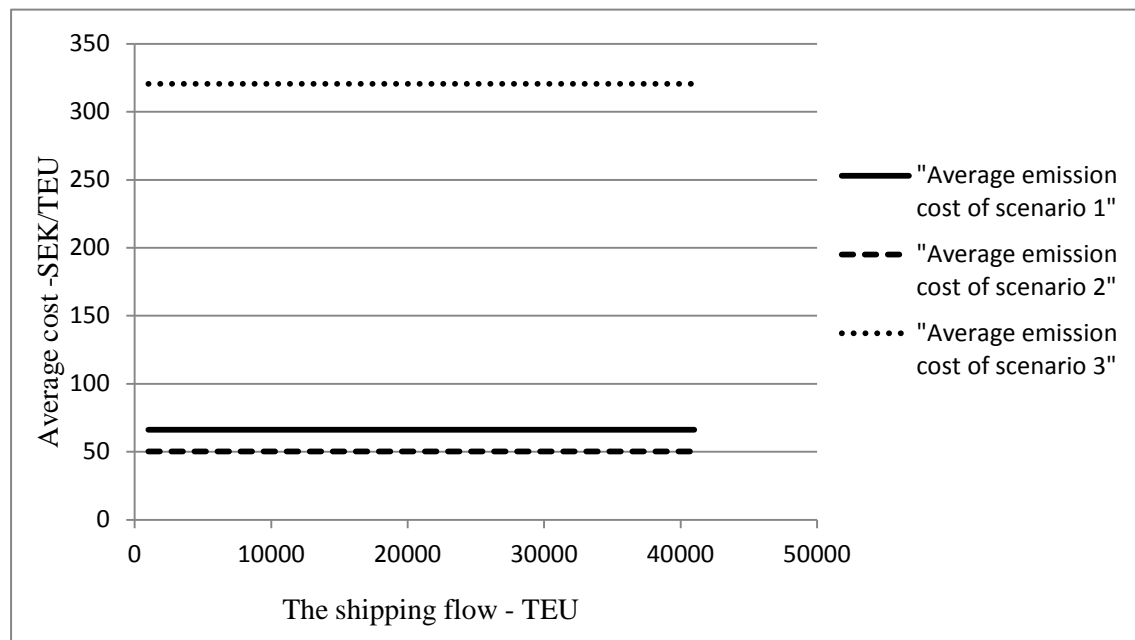

Figure 8.2 Dependence of the average emission costs of given scenarios on the volume of units

As discussed in Chapter 7, the external cost of transport has received great attention. It is obvious that the unimodal road transport is the worst mode in terms of environmental considerations. However, the road transport is the most popular way to transport goods in EU due to the flexibility and the low economic costs associated with short distances and small flow markets. It is evident that the IRT achieves great savings in the emission aspect of transportation costs. Table 8.3 indicates emission decreases around 80% when employing the IRT instead of the unimodal road mode. Scenario 2 saves 24.1% on emission costs compared to scenario 1, implying that using LHVs in PPH of the IRT will reduce emissions. Therefore, it is important to regard the environmental aspects as one of the core factors influencing transport buyer decision-making.

Table 8.3 Emission saving of the IRT

	IRT with 3-TEU truck	IRT with 4-TEU truck
Decreasing compared to unimodal road transport	79.3%	84.32%

8.2.3 The Effect of Total Cost

The Figure 8.3 below combines the average economic cost and the average external cost of three separate scenarios. Each line shows the average cost of different transport modes. When the truck is changed from 3-TEU truck to 4-TEU truck, the overall average cost decreases, regardless of how many TEUs are transported. As a result, there is no point of intersection of the line of scenario1 and the line of scenario 2. As the main types of all road cost are variable, the line of scenario 3 (which refers to the unimodal road average cost) is almost parallel to the horizontal axis. When the volume of TEU is less than 3400, unimodal road transport is the best solution. Otherwise, the IRT with 4-TEU truck is more efficient. As the total TEUs of goods transported from Gothenburg to Skara was 8137 TEU in 2013, even the IRT of 3 TEU saves more cost compared to unimodal road transport (the line of scenario1 and the line of scenario3 meet at 3800 TEUs). The break-even point shifting from 3800TEU to 3400TEU indicates that the 4-TEU truck has more benefits if the cost of emission is taken into consideration. Therefore, we believe that longer truck enhanced the competitiveness of the IRT by gaining more transport demand such as the market of smaller flow transport over shorter distances.

When considering total cost, it is evident that the mode employed in scenario 2 is the most efficient way when the traffic flow is over 3400 TEU. The break-even is 9500 TEU when exclusively considering the economic cost, indicating that the IRT market will be significantly expanded if we consider the emission costs. In other words, if the government takes actions in charging for the emission from the transport operator and buyer, the IRT will become a competitive alternative in EU transport market. In the project of Jula, the IRT with 4TEU will bring benefits both environmental and economic aspects.
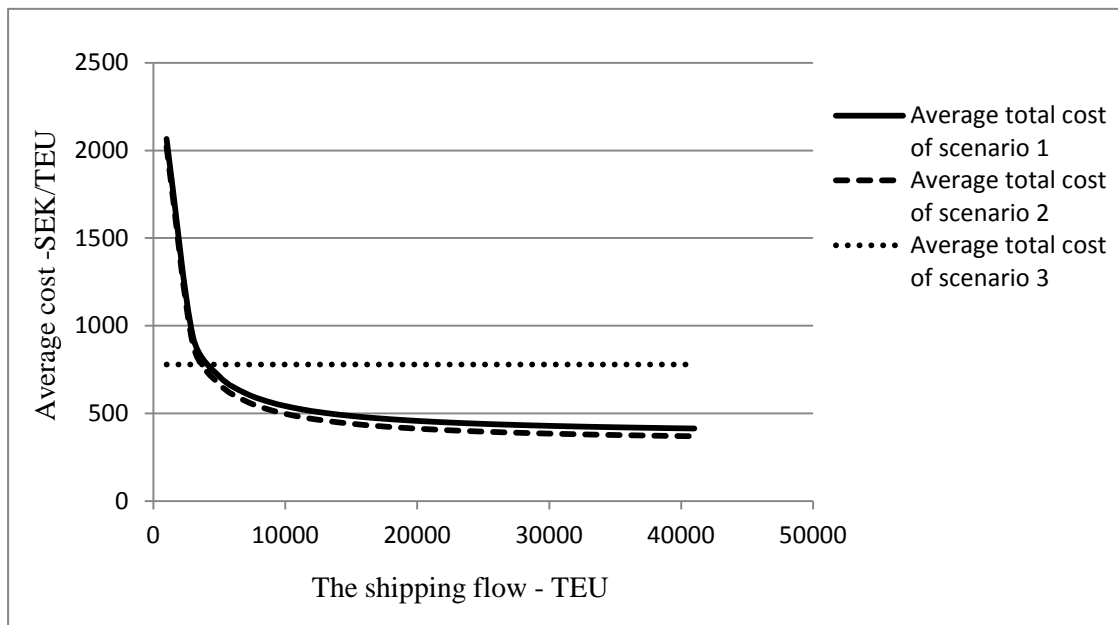

Figure 8.3 Dependence of the average total costs of given scenarios on the volume of units

9 Conclusion

This chapter will draw the conclusions by highlighting the findings based on the literature review and case study.

9.1 The Potential of using LHVs in IRT

This thesis develops a model for analyzing the potential of longer and heavier vehicles related to pre- and post-haulage in a rail-truck intermodal transport chain. It can be concluded from both the literature review and the case study that the LHVs improve efficiency, which can reduce both the economic and emission costs. The result of the calculation shows that PPH plays an important role in the IRT, accounting for 21.5% of the total cost in the Jula case.

There are significant differences in performance between IRT with and without LHVs. Intermodal transport network with LHVs performs better in in terms of both economic and emission costs. In the PPH, the LHVs save approximately 25.2% of economic costs and 24.1% of emission costs. A reduction of approximately 5.43% for IRT chain (without considering the emission costs) and 7.53% for total cost is achieved by LHVs. Additionally, LHVs also help to enhance the competitiveness of IRT, compared with unimodal road transport.

The break-even of the IRT and unimodal road transport moves from 11000 TEU to 9500 TEU when current trucks are shifted to LHVs. This indicates that the LHVs contribute to expanding the market of IRT by enabling commercial use with smaller flow. So far this thesis has pointed out the benefits of applying LHVs in the PPH related to the IRT. Other opinions that should be considered are about the possible consequences of the LHVs. According to the literature review, there is no direct evidence that proves LHVs would lead to negative effects on safety and environment. However, there is a possibility that much of rail transport would shift to the road mode if the regulations are changed to allow LHV s to be run in circulation. To control this risk, this thesis suggests using the LHVs in a specific IRT network instead of circulating freely all over the roads. Since Jula project applies for a permission of using LHVs to optimize their IRT, this thesis suggests Swedish Transport Administration considering a specific exemption for this project.

In sum, the use of LHVs in PPH has been proved to provide significant benefits to the intermodal rail-road transport in terms of increasing efficiency, reducing demand for investments to lower fuel consumption and reducing emissions. It is reasonable to take

the LHVs associated with PPH into account. Finally, the environment problem and developing methods of sustainable transportation should be considered by all transport operators. The proposed cost calculation model can be used as a tool for analysis. Throughout the thesis work we contend that applying LHVs in a specific IRT network will benefit both economic and environmental interests.

9.2 Future Research

Although this thesis tries to prove using LHVs is a solution to improving IRT network, there are still many limitations which are introduced in Section 1.6. Since to change a regulation requires a comprehensive consideration of possible effects of all aspects, more research of the possible effects of LHVs is required. Moreover, in our cost structure, this thesis just involves the economic and emission cost, the calculation model could be a further developed. Janic (2007) develops a model which includes almost all costs associated with intermodal transport and road transport system. However, more research is needed in order to develop a valid model based on the comparison of different models. As illustrated in Section 4.1.3, there are still many complex problems related to each IRT category of the research field to be solved. Also, since there are still a lot of obstacles to developing IRT, we expect more research in this area.

References

[1] Åkerman, I., & Jonsson, R. (2007). European Modular System for road freight transport–experiences and possibilities. *TFK Report*.

[2] Amt, U. B. (2007). Longer and Heavier on German Roads: Do megatrucks contribute towards sustainable transport. *Umwelt Bundes Amt, Dessau*.

[3] Arcadis. (2006). Monitoringsonderzoek vervolgproef lzv resultaten van de vervolgproef met langere of langere en zwaardere voertuigcombinaties op de Nederlandse wegen. *ARCADIS*.

[4] Arvidsson, N. (2013). Essays on operational freight transport efficiency and sustainability.

[5] Aurell, J., Wadman, T., & Trucks, V. (2007). Vehicle combinations based on the modular concept. *Nordiska Va Gteknisk Fo Rbundet (Nordic Road Association)*, *1*, 2007.

[6] Ballis, A., & Golias, J. (2002). Comparative evaluation of existing and innovative rail–road freight transport terminals. *Transportation Research Part A: Policy and Practice*, *36*(7), 593–611.

[7] Ballis, A., & Golias, J. (2004). Towards the improvement of a combined transport chain performance. *European Journal of Operational Research*, *152*(2), 420–436.

[8] Bärthel, F., & Woxenius, J. (2004). Developing intermodal transport for small flows over short distances. *Transportation Planning and Technology*, *27*(5), 403–424.

[9] BAST. (2006). Effects of new vehicle concepts on the infrastructure of the federal trunk road network Final report Abstract. *BAST*, (November 2006).

[10] Behling, O. (1980). The case for the natural science model for research in organizational behavior and organization theory. *Academy of Management Review*, *5*(4), 483–490.

[11] Bergqvist, R., & Behrends, S. (2011). Assessing the effects of longer vehicles: the case of pre-and post-haulage in intermodal transport chains. *Transport Reviews*, *31*(5), 591–602.

[12] Bergqvist, R., & Esping, P. (2002). The Potential of West European Sea-Based Intermodal Systems. *MASTER THESIS*, (2002: 34).

[13] Bertilsson, A., & Olsson, C. (2009). The Road to Intermodal Transport: A study of the economic, environmental and societal effects from the usage of 2x40 feet vehicles for pre and post haulage.

[14] Bontekoning, Y. M., Macharis, C., Trip, J. J. (2004). Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice*, *38*(1).

[15] Brown, J. D. (1996). *Testing in language programs*. Prentice Hall Regents New Jersey.

[16] Brown, T. R., & Hatch, A. B. (2002). The value of rail intermodal to the US economy. *An Article by American Association of Railroads Last Assessed on February*, *15*, 2007.

[17] Campbell, D. T., Stanley, J. C., & Gage, N. L. (1963). *Experimental and quasi-experimental designs for research*. Houghton Mifflin Boston.

[18] Christidis, P., & Leduc, G. (2009). *Longer and Heavier Vehicles for freight transport*. Institute for Prospective and Technological Studies, Joint Research Centre.

[19] Collis, J., & Hussey, R. (2009). *Business research: A practical guide for undergraduate and postgraduate students*. Palgrave Macmillan.

[20] Cook, T. D., & Campbell, D. T. (1976). The design and conduct of quasi-experiments and true experiments in field settings. *Handbook of Industrial and Organizational Psychology*, *223*, 336.

[21] Cook, T. D., Campbell, D. T., & Day, A. (1979). *Quasi-experimentation: Design & analysis issues for field settings*. Houghton Mifflin Boston.

[22] Coolican, H. (2009). *Research methods and statistics in psychology*. Routledge.

[23] Daganzo, C. F. (2005). *Logistics systems analysis*. Springer.

[24] De Ceuster, G., Breemersch, T., Van Herbruggen, B., Verweij, K., Davydenko, I., Klingender, M., … Bereni, M. (2008). Effects of adapting the rules on weights and dimensions of heavy commercial vehicles as established within Directive 96/53/EC.

[25] Dean, J. (1951). Managerial Economics.

[26] Doll, C., Fiorello, D., Pastori, E., Reynaud, C., Klaus, P., Lückmann, P., … Hesse, K. (2009). Long-Term Climate Impacts of the Introduction of Mega-Trucks-Study to the Community of European Railways and Infrastructure Companies (CER). *Fraunhofer ISI (study Co-Ordinator, Karlsruhe) TRT (Milan), NESTEAR (Gentilly), Fraunhofer-ATL (Nuremberg), Fraunhofer-IML (Dortmund), Karlsruhe*.

[27] Easterby-Smith, M., Golden-Biddle, K., & Locke, K. (2008). Working with pluralism determining quality in qualitative research. *Organizational Research Methods*, *11*(3), 419–429.

[28] Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

[29] Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: opportunities and challenges. *Academy of Management Journal*, *50*(1), 25–32.

[30] European Commission. (1997). Inermodality and intermodal freight transport in the European Union.

[31] European Commission. (2004). Proposal for a Directive by the European Parliament and the Council on Intermodal Loading Units. *Brussels*, *0056*(2003).

[32] European Commission. (2006). *Keep Europe Moving: Sustainable Mobility for Our Continent*. OOPEC.

[33] European Commission. (2011). White paper, Roadmap to a single European Transport Area, Towards a competitive and resource efficient transport system. COM (2011).

[34] European Commission. (2012). Review of EU rules concerning access to the EU road haulage market and access to the occupation of road transport operator, (April).

[35] Flodén, J. (2007). *Modelling Intermodal Freight Transport. The Potential of Combined Tranport in Sweden*. Department of Business Administration Företagsekonomiska institutionen.

[36] Flodén, J. (2011). Rail freight costs: some basic cost estimates for intermodal transport.

[37] Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245.

[38] Fontana, A., Frey, J. H., Denzin, N. K., & Lincoln, Y. S. (1994). Handbook of qualitative research. *By Norman K. Denzin and Yvonna S. Lincoln. London: Sage,, pp.–.(Cit. on P.)*.

[39] Gibbert, M., Ruigrok, W., & Wicki, B. (2008). What passes as a rigorous case study? *Strategic Management Journal*, *29*(13), 1465–1474.

[40] Graham, D. J., & Glaister, S. (2004). Road traffic demand elasticity estimates: a review. *Transport Reviews*, *24*(3), 261–274.

[41] Grislis, A. (2010). Longer combination vehicles and road safety. *Transport*, *25*(3), 336–343.

[42] Handman, A. L., & District, G. H. T. (2002). 3.3 Weather Implications for urban and rural public transit.

[43] Henriksson, A., & Davidsson, C. (2011). Development of a dolly trailer. Designing a dolly for large-volume goods.

[44] IICL. (2006). Annual Leased Container Fleet Survey, 7–10.

[45] IICL. (2007). Annual Leased Container Fleet Survey.

[46] IICL. (2008). 2008 Annual Leased Container Fleet Survey Institute of International Container Leassors, Institute of International Container Lessors.

[47] IICL. (2009). 2009 Annual Leased Container Fleet Survey Institute of International Container Leassors, Institute of International Container Lessors.

[48] IICL. (2010). Annual Leased Container Fleet Survey Institute of International Container Leassors, Institute of International Container Lessors.

[49] Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment*, *12*(1), 33–44.

[50] Jensen, A., & Bergqvist, R. (2013). Seaport strategies for pre–emptive defence of market share under changing hinterland transport system performance. *International Journal of Shipping and Transport Logistics*, *5*(4), 432–448.

[51] Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly*, 602–611.

[52] Jula, (2014). Interview.

[53] Kim, N. S., & Van Wee, B. (2011). The relative importance of factors that influence the break-even distance of intermodal freight transport systems. *Journal of Transport Geography*, *19*(4), 859–875.

[54] Knight, I., Newton, W., McKinnon, A., Palmer, A., Barlow, T., McCrae, I., … Daly, A. (2008). *Longer and/or Longer and Heavier Goods Vehicles (LHVs): a Study of the Likely Effects if Permitted in the UK: Final Report*. IHS.

[55] Koskinen, O. H. (2010). Nordic vehicle configuration from viewpoint of fuel and transport economy, emission reduction and road wear impact. In *HVTT11: International Heavy Vehicle Symposium, 2010, Melbourne Victoria, Australla*.

[56] Kramer, Geoffrey P., Douglas A. Bernstein, V. P. (2009). *Introduction to clinical psychology* (7th ed.). Upper Saddle River: NJ: Pearson Prentice Hall.

[57] Kreutzberger, E., Macharis, C., Vereecken, L., & Woxenius, J. (2003). Is intermodal freight transport more environmentally friendly than all-road freight transport? A review. In *nectar conference* (pp. 13–15).

[58] Kyster, H., Tetraplan, H., and S. J. (2013). Roadmap High Capacity Transports on road in Sweden.

[59] Larsson, S. (2008). Data and indicators for road freight transport. In *Presentation to the IEA workshop on 'New energy indicators for transport* (pp. 28–29).

[60] Lee, A. S., & Baskerville, R. L. (2003). Generalizing generalizability in information systems research. *Information Systems Research*, *14*(3), 221–243.

[61] Leonard-Barton, D. (1990). A dual methodology for case studies: synergistic use of a longitudinal single site with replicated multiple sites. *Organization Science*, *1*(3), 248–266.

[62] Löfroth, C., Larsson, L., Enström, J., Svenson, G., & Johansson, A. (2013). ETT – A MODULAR SYSTEM FOR FOREST TRANSPORT A three-year roundwood haulage test in Sweden. *Skogforsk and Volve*, 1–18.

[63] Lowe, D. (2006). *Intermodal freight transport*. Routledge.

[64] Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research*, *153*(2), 400–416.

[65] McKinnon, A. (2008). Should the maximum length and weight of trucks be increased. *A Review of European Research*.

[66] Morlok, E. K., Sammon, J. P., Spasovic, L. N., & Nozick, L. K. (1995). Improving productivity in intermodal rail-truck transportation. In *The service productivity and quality challenge* (pp. 407–434). Springer.

[67] Morlok, E. K., & Spasovic, L. N. (1994). Redesigning rail-truck intermodal drayage operations for enhanced service and cost performance. In *Journal of the Transportation Research Forum* (Vol. 34).

[68] Muller, G. (1989). Intermodal freight transportation.

[69] Nachtmann, H., Rossetti, M. D., & Taylor, G. D. (2004). Webshipcost-quantifying risk in intermodal transportation.

[70] Niérat, P. (1997). Market area of rail-truck terminals: pertinence of the spatial theory. *Transportation Research Part A: Policy and Practice*, *31*(2), 109–127.

[71] Numagami, T. (1998). Perspective—The Infeasibility of Invariant Laws in Management Studies: A Reflective Dialogue in Defense of Case Studies. *Organization Science*, *9*(1), 1–15.

[72] OECD. (2011). Moving Freight with Better Trucks. *International Transport Forum*. doi:10.1787/9789282102961-en

[73] Pettigrew, A. M. (1990). Longitudinal Field Research on Change: Theory and Practice. *Organization Science*, *1*(3), 267–292. doi:10.1287/orsc.1.3.267

[74] Raimond, P. (1993). *Management projects: Design, research and presentation.* Chapman & Hall.

[75] Resor, R. R., Blaze, J. R., & Morlok, E. K. (2004). Short-haul rail intermodal: can it compete with trucks? *Transportation Research Record: Journal of the Transportation Research Board*, *1873*(1), 45–52.

[76] Silverman, D. (2013). *Doing qualitative research: A practical handbook.* SAGE Publications Limited.

[77] Stake, R. E. (1995). *The art of case study research.* Sage.

[78] Stone, B. (2008). 12. Critical success factors: interconnectivity and interoperability. *The Future of Intermodal Freight Transport: Operations, Design and Policy*, 225.

[79] Tellis, G. J. (1988). The Price Elasticity of Selective Demand: A Meta-Analysis of Economic Models of Sales. *Journal of Marketing Research (JMR)*, *25*(4).

[80] Trip, J. J., & Bontekoning, Y. (2002). Integration of small freight flows in the intermodal transport system. *Journal of Transport Geography*, *10*(3), 221–229.

[81] UIC. (2013). 2012 report on combined transport in Europe. *Intermodal Union of Railways*.

[82] UNECE. (2001). Terminology on Combined Transport, New York, Genua: The United Nations Economic Commission for Europe.

[83] Van Essen, H., Schroten, A., Otten, M., Sutter, D., Schreyer, C., Zandonella, R., … Doll, C. (2011). External costs of transport in Europe-Update study for 2008. *UIC, Delft, The Netherlands, Nov*.

[84] Viton, P. A. (2011). Understanding Road Wear and its Causes. *Transportation*, *181*(93,902), 87,419.

[85] Volvo group. (2012). ETT, modulsystem för skogen & DUO2. *Forskningsprojekt För Ökad Transport, Teffektivitet*.

[86] Volvo group. (2014). The Volvo group sustainability report 2013.

[87] Williams, B. M., & Hoel, L. A. (1998). Freight planning requirements for interstate corridors. *Transportation Quarterly*, *52*(2).

[88] Woxenius, J. (1998). *Development of small-scale intermodal freight transportation in a systems context*. Chalmers University of Technology.

[89] Woxenius, J., & Bärthel, F. (2008). Intermodal road-rail transport in the European Union. *The Future of Intermodal Freight Transport, Concepts, Design and Implementation, Edward Elgar Publishing, Cheltenham*, 13–33.

[90] Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

Appendix Interviews

Interviewees (the organizations)	Main purpose of Interviews
Jula	Get the information of detail transport flows and the data they collected related to this subject.
ETT and DUO2	Get practice advices since they have experience of driving vehicles with 32m length for several years.
Swedish Transport Administration	Gain information of the regulations
Volvo	Gain technical advices and detail information of vehicles with 32m length

(1) Questions for Jula

Q1. Can you give me some information about the cargo volume transported from Gothenburg to Falköping?

Q2. As I know from the professor, Jula changed the transport mode this year (from all road to intermodal), why did you make this decision?

Q3. Finland has passed the longer and heavier vehicles permission of 74 tonnes, which goes further in LHV area than Sweden does. Do you have any ideas about this?

Q4. Will you ask a privilege from The Swedish Transport Administration to have a test of combined-vehicles carried two 40ft containers on defined routes?

Q5. If you will, what effects do you make?

(2) Questions for ETT and DUO2 project

Q1. What is the effect of longer and heavier vehicles on reducing fuel consumption? If you can give the data of the fuel efficiency like X liter fuel per kilometer respectively for the normal truck and LHVs will be perfect (the number can be "a usual number").

Q2. What is the effect on the safety? People may have confused of the safety problem since the bigger vehicle size. If you can give some data of the accident rate and the consequence of the accident from the project of the ETT and DUO2 will be great.

Q3. We know from other documents that the Swedish transport infrastructure such as road wear and bridges, do you think so? Do you get some new found from the two test projects?

Q4. Some reports and rail operators point out that the reduction of the cost due to the LHVs will cause the increase of road transportation flow (a lot of traffic flow will shift from rail to road) in the long time (20-30years) which is not good to the environment. What is your opnion about this question?

Q5. Do you think it is possible to just use the LHVs in the intermodal transportation which means the LHVs are used under control in some specific roads and areas? Do you think it is easy to "control"? If not, what are the "may" and main questions?

(3) Questions for Swedish Transport Administration

Q1. The report stated that the policy instruments and community planning are the basic instruments of yours. But the report mentioned little about it. Do you have some detailed information about them?

Q2. As I know from the report, you support the Intermodal transport which is more eco-friendly. However, it is less competitive in short distance. Do you have any plan to raise the competitiveness of short distance IRT?

Q3. Finland has passed the longer and heavier vehicles permission of 74 tonnes. Do you have any ideas about this?

Q4. Will you permit a privilege for a company to have a test on defined routes?

Q5. If you will, what conditions should the company meet?

(4) Questions for Volvo

Q1. What is the effect of longer and heavier vehicles on reducing fuel consumption? If you can give the data of the fuel efficiency like X liter fuel per kilometer respectively for the normal truck and LHVs will be perfect (the number can be "a usual number").

Q2. What is the effect on the safety? People may have confused of the safety problem since the bigger vehicle size. If you can give some data of the accident rate and the consequence of the accident from the project of the ETT and DUO2 will be great.

Q3. Does this new vehicles have the problem with the technology?

Q4. What are the components of the cost related to the longer and heavier vehicle?

Q5. When do you think is the time to use these LHVs?