Graduate Business School
School of Business, Economics and Law

UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

SYSTEM ANALYSIS OF HIGH CAPACITY TRANSPORTS

Impact Assessment in the Terminal Network of DHL Freight Sweden

Lindqvist David

Salman Marwan

Essay/Thesis:	30 credits
Program and/or course:	Transport and Logistics Management
Level:	Masters (Second Cycle)
Semester/year:	St/2019
Supervisor:	Rickard Bergqvist

System Analysis of High Capacity Transports

Impact Assessment in the Terminal Network of DHL Freight Sweden

By Lindqvist, David and Salman, Marwan

Department of Business Administration at the School of Business, Economics and Law- University of Gothenburg
Vasagatan 1, P.O. Box 600, SE 405 30 Gothenburg, Sweden

Contact: David.Lindqvist@live.se; Marwan.Salman@live.se

Abstract

Purpose:	The purpose is to study the potentials and risks of a HCT introduction in the established terminal network of DHL Freight Sweden to provide a holistic understanding from a system perspective of how benefits can be achieved with respect for the environmental, operational, economic and social aspects. The finished report should further contribute to comprehensive knowledge that could be used as a feasibility study and decision basis in an application to the Swedish Transport Agency in order to receive a permit to use HCVs in DHL Freight's terminal network.
Theory:	There is not an adequate amount of literature from the Nordic countries or other environments presenting empirical evidence, but most researchers do still agree upon a large potential of HCT and many advantages. The risks of advantages can however create a transmodal shift from inland waterways and rail freight to road freight. Even though there is little empirical evidence that supports this reasoning, it is not unlikely that the demand for road transportation increases further if HCT results in lower costs for the consignors which might cause a transmodal shift. The effects on the overall system differs slightly in previous literature towards the better and worse, depending on the literature's examined environment, type of goods or other contexts in alternative aspects.
Method:	A case study with a mixed methodology accompanied by an explanatory sequential mixed method is applied. A quantitative model has been developed based on all transportation between the 1st of January and the 12th of October in 2018 in 600 relationships. The majority of the calculations are based on an average fill rate of 75 and 80 % in a LHV and HCV. A sensitivity analysis has been conducted to examine different situations. Three different scenarios have also been reviewed, (a) an analysis of only LHVs in the operations, (b) a theoretical analysis in which HCVs do replace all LHVs and (c) an optimal scenario in which the model computes calculations based on the most advantageous vehicle setup per transport and relationship.
Result:	HCT can contribute to the development of road transportation in the perspectives of energy consumption and emission releases. It can further strengthen the trade and competitiveness of Swedish haulers. The introduction of HCT does provide a more cost-efficient system for DHL and the society. The socio-economical calculation shows reductions in emissions of approximately 7 % and a yearly reduction in external costs of 25M SEK. The overall safety on the road will also increase as an effect of a changed driving behavior and more importantly less vehicles on the road. The cost benefit calculations show that DHL can decrease their operational costs with approximately 6 % or 56M SEK in total. An introduction of HCVs in the whole system would however result in increased costs as larger vehicles are neither required nor appropriate between all 600 relationships in the terminal network of DHL.
Keywords:	HCT, LHV, Transportation, System Analysis, Sustainability, Road Freight, Transport Management, DHL

Acknowledgements

This project has been instituted as a final paper in the M.Sc. in Logistics and Transport Management program. The master thesis has been carried out via the Academy of Graduate School at the School of Business, Economics and Law, University of Gothenburg. The assigner of the project has been DHL Freight Sweden in cooperation with the University of Gothenburg and the Swedish Transport Administration.

We would like to thank all the professors and lecturers at the University for the learning outcomes and their contribution of increasing our ability to discuss, analyze and resolve problems, and to critically integrate knowledge and analyze complex issues, situations and different phenomenon. We are also grateful for the support and encouragement from our families and friends during the period of this project.

Last, but definitely not least, we would like to thank DHL Freight Sweden with Maria Nilsson Öhman and Martin Jelvestam for the opportunity to be a part of this project, for sharing transport data and their valuable feedback and discussions. We would further like to express our deepest gratitude to our supervisor Prof. Rickard Bergqvist for the inspirational and insightful discussions, rich consultation and for his motivation and guidance throughout the project.

Gothenburg, May 2019

Lindqvist, David

Salman, Marwan

Table of Content

List of Figures

List of Tables

Abbreviations and Terminologi

EMS = European Modular System
A solution allowing combinations of modules into heavier and/or longer vehicles to be operated on parts of the road network. EMS do in practice allow national authorities to provide permissions for trucks larger than what is considered as 'normal' limits in weight and length (see full definition in EU Directive 96/53 EC).

HCT = High Capacity Transport
Freight transport that is carried out by longer and/or heavier vehicle combinations than what is normally permitted by the government's regulations or typical allowance.

HCV = High Capacity Vehicle
Vehicles with a gross weight over 64 tonnes and a maximum length of 34,5 meters.

HGV/LGV = Heavy/Large Goods Vehicle
A vehicle intended for transportation of large and/or heavy loads, any truck with a gross weight over 3,5 tonnes but maximum 44 tonnes and length up to 18,75 meters (see EU Directive 2015/719).

LHV = Longer and Heavier Vehicle
Also known as 'megatrucks'. Vehicles with a weight between 44 tonnes and 64 tonnes, and a length over 18,75 meters but maximum 25,25 meters. LHVs are typically not allowed to operate on roads under local governments regulations or typical allowances in the EU, with exceptions in Sweden and Finland.

TEU = Twenty-foot Equivalent Unit
Measurement of an ISO container used to describe the capacity in the loading unit.

Tonne-km = Unit measure of freight transportation
Represents one tonne transported by a given transport mode over a distance of one kilometer. Calculated by total load carried measured in tonnes multiplied by total distance covered measured in kilometers.

1. Introduction

The introduction section describes why the phenomenon of high capacity transport is important to study and why it is of high interest to Deutsche Post DHL. Moreover is the research topic and the factors that form the foundation of the purpose, research questions and delimitation of this report discussed in the introducing chapter.

1.1 Background

Transportation is an important component to a state's economy as it relates to the gross domestic product (GDP). This relationship has been the object of several studies and it is established that the growth of freight transport has accompanied the economic growth historically (Fang & Han, 2000; Tapio, 2005; Garcia, Levy, Limão, & Kupfer, 2008; Liddle & Lung, 2013; Ben Jebli & Hadhri, 2018). The relationship can however be questioned as there are weaker correlation in some periods. These are however justified by increased fuel prices, decreased funding for infrastructure developments, a greener urban lifestyle through raised environmental awareness or increased unemployment (Tapio, 2005). Stridsberg and Sunding (2017) further argue that the relationship between GDP and transportation is important to consider when developing the infrastructure and implementing new or adjusting current regulations.

In Europe, freight transport systems have been trending towards an increased development of transportation by road (European Commission, 2011). This development is equivalent to an increase in the total number of driven tonne-kilometers and vehicle-kilometers linked to transportation of goods (Pålsson, Winslott Hiselius, Wandel, Khan & Adell, 2017). This brings consequences which will have negative impacts on the society, economy, and environment. An increased use of environmentally friendly fuels in combination with trucks that are continuously more fuel-efficient, cleaner, and reduced in terms of noise will minimize the negative external effects per kilometer driven (Bergqvist & Behrends, 2011).

In Sweden, the demand for transportation has been increasing during the last decades which is seen positively by the Swedish Transport Agency (Stridsberg & Sundin, 2017). The largest growth in transportation is found in the rail and long-haul traffic and the emergence of e-commerce and globalization creates a perception that this trend of development in transportation might continue for many years. The GDP in Sweden is the seventh largest in the European Union (Statistics Sweden, 2019) and the National Institute of Economic Research (NIER) present in an occasional study (Stockhammar & Brusewitz, 2018) an estimated growth of the GDP in Sweden with 2,1 % in 2019 and 1,9 % in 2020. This growth is however considered to be low in relation to other European Union states (EU).

	Total tonne-km (in millions)	Domestic Share	Foreign Share
Air	5 777	2 %	98 %
Rail	21 456	61 %	39 %
Road	41 848	99 %	1 %
Sea	36 088	19 %	81 %
Total	*105 169*		

Table 1.1: Freight Transport in Sweden 2017, adapted from TRAFA (2019).

In 2017, the freight transportation industry was accountable for 105 169 million tonne-kilometers through the modes of air, sea, road (lorries with gross-weight over 3,5 tonnes) and rail in Sweden. The road alone allocates almost 40 percent of the total movement of goods measured in tonne-kilometers, and 67 percent of the domestic transportation (TRAFA, 2019), and 2 841 980 thousand vehicle kilometers. Table 1.1. clarifies that the road is the largest transport mode in which 'foreign share' is defined if the point of destination or origin is outside Sweden while 'domestic share' is defined if the point of destination and origin is in Sweden. Thus, road freight is an interesting phenomenon to analyze and investigate upon. The increasing demand for road freight has resulted in a higher utilization, but also an urgency of additional vehicles. The outcome of more vehicles on road has negative environmental impacts through congestion, air pollution, noise and decreased space. If international transport is excluded, approximately half of the total CO_2 emissions from the non-effort sharing regulation sector (ESR) in Sweden derive from transports in which road transport covers almost 93 %. (Swedish Environmental Protection Agency, 2018ab).

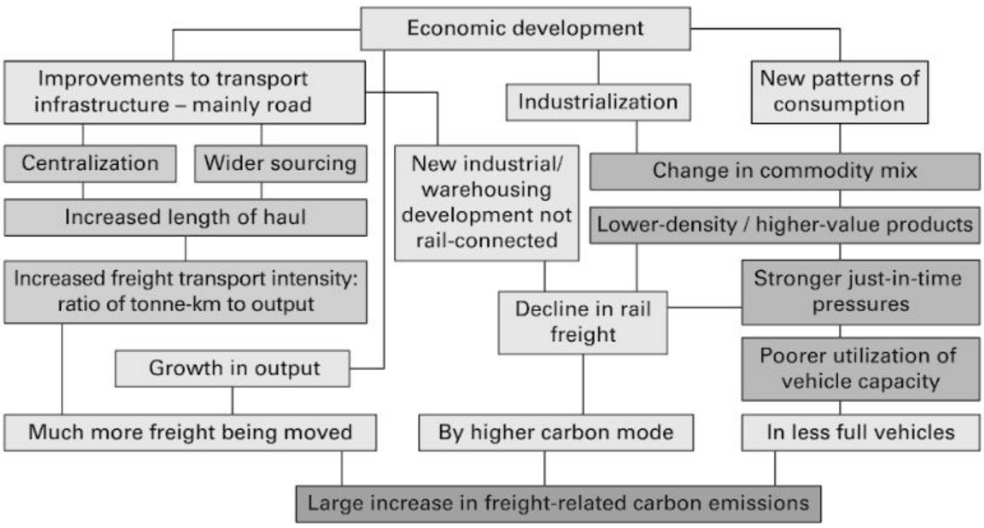


Figure 1.1: Mapping the relationship between economic development and freight transport (McKinnon, 2018. p.81).

The economic development has resulted in a concentration of operations in fewer locations that allows companies to achieve substantial reductions in inventory levels while maintaining a higher service level. Changes in consumer demand have also altered the mix of commodities that is channeled through the freight transportation network. As customers continuously expect faster deliveries, just-in-time (JIT) pressures are experienced in a broader sense and as the value of inventories increase, logistical operations are becoming more tightly scheduled than ever before. The global market expansion that cause centralization does further extend the average distance of freight movement between the customers and stockholding points. Freight hauls are growing longer and the transport intensity is becoming greater. These relationships are illustrated in figure 1.1. Nonetheless, infrastructural investments have historically favored the road network over railways and waterways in the EU. This has strengthened the road freight's position as the dominant mode, and has furthermore caused a long-term logistical lock-in to the use of trucking and the consequence has been companies locating new investments in warehouses and factories at points of high accessibility on the highway network. Nonetheless, a load consolidation is able to reduce the carbon intensity and mitigate the negative environmental effects. (Rodrígues et al., 2015; McKinnon, 2018)

The Swedish government office has further defined the previous climate target of 2050 and conjoined to decrease greenhouse emissions were an updated roadmap has been presented to reach a zero vision for 2045 instead, with interim targets in 2030 and 2040, to reach a net zero emissions of greenhouse gases (Nyström, 2018; Government Offices of Sweden, 2017; Swedish EPA, 2017). The target in transportation is specifically related to reducing emissions by at least 70 % by 2030 compared with 2010. The definition of road transport that accounts for the heaviest emissions includes buses, heavy goods vehicles, light commercial vehicles, passenger cars and motorcycles. The heavy goods vehicles (HGV) represent 3 262 CO_2 million tonnes per year out of the total 27 222 million tonnes that originate from the transport sector (Statistics Sweden, 2019).

This does decipher a need for innovation regarding new approaches for conducting freight on the road. The possibilities of high capacity transport (HCT) are an efficient practice of achieving a higher capacity in the road transportation network without highly time-consuming rehabilitation of the infrastructure which also is equivalent to a huge investment cost. By increasing the maximum permitted weight and/or length of the trucks that is used to freight goods, there is potential to reduce negative aspects such as congestion in the cities and release of CO_2-emissions. The increased capacity that derives from HCT enables more weight and volume of goods to be loaded onto the trucks. There is a high potential to both reduce the costs for transportation per unit of carried freight and simultaneously reduce the hazardous emissions from the trucks (Meers, van Lier, & Macharis, 2018). The positive and negative effects of HCT along with key sources and offsetting factors are presented in Figure 1.2, a framework developed by McKinnon (2012a).

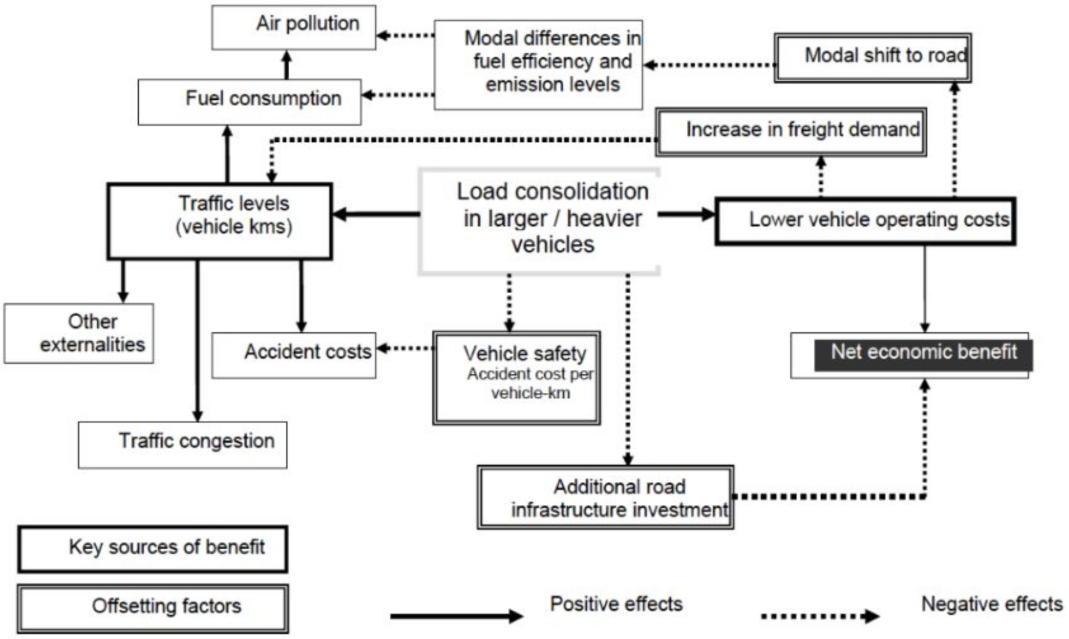


Figure 1.2- Inter-relationships in the cost-benefit analysis of LHVs (McKinnon, 2012a. p.188).

Congestion and environmental concerns accompanied by a growth in demand for road transportation makes HCT an interesting alternative to compare with the current long and heavy vehicles (LHV) in Sweden. There are, however, both opponents and adherents of HCT. Logistics service providers, for instance, demand high capacity vehicles (HCVs) to better support and serve the modern supply chains whilst opponents argue that this could cause a modal shift from rail and short sea shipping to road. Previous literature and research emphasize further impacts related to such as energy efficiency, infrastructure, safety, emissions and costs. McKinnon (2012a) considers that the introduction of larger vehicles could establish the best approach to reduce road freight transportation vehicle-kilometers and as a direct effect of this also reduce the negative impact on the environment.

Within Europe, the potential benefits and risks regarding the introduction of LHVs or HCVs have been conducted. Many research papers and government studies has and are currently testing or considering to grant larger and heavier trucks, as for instance Belgium (Debauche, 2008; Meers et al., 2018), Denmark (Danish Ministry of Transport, 2011; Hellung-Larsen, 2012), Finland (Åkerman & Jonsson, 2007; Liimatainen & Nykänen, 2017), Germany (Rodrigues, Piecyk, Mason, & Boenders, 2015), Spain (Ortega, Vassallo, Guzmán, & Pérez-Martínez, 2014), Sweden (Pålsson et al., 2017; Vierth, Lindgren, & Lindgren, 2018), Netherlands (Salet, Aarts, Honer, Davydenko, Quak, de Bes van Staalduinen, & Verweij, 2010), and UK (McKinnon, 2005; Leach & Savage, 2012). In the past years different HCT programs have been carried out in Sweden by, among others, Closer, Swedish Transport Agency, Swedish Transport Administration, Swedish National Road, Transport Research Institute (VTI), Vinnova and Trivector that has focused on the positive and negative effects of introducing HCV on Swedish roads. The current legislation however forbid HCVs, were the Swedish Transport Agency and the Swedish Transport Administration have only given an exception to a few companies that are allowed to operate with HCVs. HCT pilot case studies have been conducted in, as for example, the ETT-project (Löfroth & Svenson, 2012), the Duo2 project (Cider & Ranäng, 2013), One Coil More (Adell, Ljungberg, Börefelt, & Hanander, 2013), and the Case of Jula (Bergqvist &

Monios, 2016). The Swedish Transport Agency's interest has been growing in this subject over the past years and a large potential is discussed in several different research reports.

The current restrictions in most European countries do allow up to 18,75 m in length, Sweden, however, has adopted trucks with a length of up to 25,25 m (Bergqvist & Behrends, 2011). Some could argue that it may be difficult to achieve a high fill rate in LHVs and HCVs. However, a study delivered by the Dutch Ministry of Infrastructure and Environment (2011) of larger trucks presents evidence that waste is the only sector that has difficulties avoiding running empty on return journeys that have on average 34 % less utilization compared to the onward journey, independent of the size of the truck. Nonetheless, it is in reality difficult for the majority of 3PLs and haulers to go above an average fill rate of 70 % as they must ensure flexibility in the transport network and be able to handle fluctuations over the full season (Kohn, 2005). It is further known that increased capacity does not only reduce freight transport cost, but also the environmental impact (Knight et al., 2008; Åsman & Asp, 2018). Large parts of grouped and consolidated goods are managed by forwarding companies in extensive terminal networks. Many of these actors have the potential to increase their internal efficiency in which HCVs are a desirable solution (Arnäs, Arvidsson, Börjesson & Liljestrand, 2013).

	No. Of Transports	Vehicle Kilometers	Tonne Kilometers	Number of Tonnes
1	Ore and other products from extraction (20%)	Grouped Goods (23%)	Grouped Goods (21%)	Ore and other products from extraction (28%)
2	Equipment (18%)	Food, drinks and tobacco (17%)	Agriculture, forestry and fishing (17%)	Agriculture, forestry and fishing (17%)
3	Grouped Goods (11%)	Agriculture, forestry and fishing (9%)	Food, drinks and tobacco (16%)	Wood and articlesmade of wood and cork (excl. furniture) (9%)
4	Waste (9%)	Equipment (9%)	Wood and articlesmade of wood and cork (excl. furniture) (10%)	Grouped Goods (8%)
5	Food, drinks and tobacco (8%)	Wood and articlesmade of wood and cork (excl. furniture) (7%)	Ore and other products from extraction (7%)	Food, drinks and tobacco (7%)

Table 1.2: Ranking of different commodity groups in different aspects in Sweden during 2010 (Arnäs et al., 2013. p.31).

Arnäs et al. (2013) identifies commodity groups of high interest with respect to the number of transportation, vehicle-km, tonne-km and total carried weight (see table 1.2). Grouped goods, mails and packages are mainly consolidated in trailers which is their most common mode of transport (Kyster-Hansen & Sjögren, 2013). Grouped goods are furthermore placed high and interesting in most parameters that can be studied, e.g. vehicle mileage, transport performance, number of transportations or quantity of goods (Arnäs et al., 2013; Kyster-Hansen & Sjögren, 2013; Eurostat, 2017; TRAFA, 2019). HCT solutions are therefore especially attractive for this type of goods. A large part of grouped goods is carried out by forwarding companies with large terminal networks such as DHL, Postnord, Schenker and FedEx. In the EU, grouped goods were answered for approximately 6 % of the total tonnes being transported but roughly 10 % of the total tonne-kilometers (Eurostat, 2017). These forwarding companies are, according to Kyster-Hansen and Sjögren (2013), very likely to have a significant increase in their internal efficiency if they implement HCVs.

DHL Freight Sweden has in later years experienced a rapid growth in grouped goods and packages and is experiencing an urgent need for increased capacity. DHL had an average utilization of 65 % including journeys with fully empty trucks during 2017 (DHL, 2018) and 75 % during 2018. DHL has experienced an increase in grouped goods of approximately 20 % per year and the terminal in Malmö alone had an increased demand of 35 % during 2018. This has been challenging due to capacity restrictions and there is currently a high average fill rate in the hauler trucks. A need for increased capacity will most likely result in an increased number of trucks on the road which will increase the costs for both DHL and society through the amount of CO_2 and other external costs. However, there has historically been issues in the transportation by road due to a lack of trucks and lately also an absence of drivers. These factors together with other elements that are to be discussed in this report compose HCT as a promising solution and alternative for the society, DHL and other haulers.

1.2 Purpose

The purpose of this paper is to 'examine a HCT introduction in the terminal network of DHL to provide an understanding in how benefits can be achieved with respect for different aspects that is to be viewed from a system perspective'. The report does further contribute to a holistic understanding and knowledge that can be used by DHL as a feasibility study and a decision basis for the Swedish Transport Agency in order to receive a permit to operate with HCVs.

1.3 Research Questions

The effects deriving from an introduction of HCVs are examined in relation to current operations of LHVs. Operational costs represent the different expenses related to transportation that might increase or decrease if a HCV is used instead of a LHV. The vital factor of an overall logistics quality includes reliability, lead-time, frequency and value. For example, the quality does increase if findings indicate that costs can be reduced without additions in the lead-time. A system analysis involves all actors, including the society. It is therefore vital to examine the environmental effects, i.e. congestion, pollution, use of space, noise and emissions, wear of infrastructure and safety of drivers, pedestrians and cyclists among others. Nevertheless, the mentioned aspects related to the environment that is to be discussed is also presented in hard figures in form of external costs as it is essential to present quantitative findings to illustrate the strengths and weaknesses of HCT in a direct and transparent manner.

1. What are the potential benefits and disadvantages of HCT?
2. How can HCT affect DHL's established terminal network?
    a. How does HCT affect operational costs and the overall logistics quality?
    b. How does HCT affect the environmental aspects and the external costs?

1.4 Delimitation

A certain number of delimitations are applied to this report as the scope of research in HCT are considered to be very broad. The report is delimited to an investigation into potential benefits and disadvantages with HCT in DHL Freight's terminal network. Only a Swedish context is accounted for, even though comparisons can be found with other countries. DHL currently has 25 terminals with a large flow of freight traffic between terminals in Skåne, Stockholm, Gothenburg and Sundsvall. Specific routes between these terminals are therefore examined and reviewed in detail while the flow and relationships between other terminals are only reviewed roughly. Furthermore, a HCV in this report is defined to a size of 34,5 meters with a maximum weight of 74 tonnes. An analyze of HCVs that have a maximum weight 64 tonnes are therefore not considered and compared with LHVs. Technical solutions such as specifications and security of HCVs are only mentioned briefly in this paper and are not covered in detail as this needs to be further thoroughly analyzed and tested by DHL in cooperation with the Swedish Transport Agency. This report is further delimited to the aspects of economic effects, safety and performance, environmental effects and infrastructure wear and tear.

1.5 Disposition

Chapter 1- Introduction

The first chapter introduced the background to the study and further defined the purpose, research questions and the applied delimitations.

Chapter 2- Methodology

The second chapter explains the methodology and applied approach that is carried out to achieve a concluded result and discusses the reliability and validity of the research.

Chapter 3- Theoretical Framework

The theoretical framework presents the results and theories of previous literature, investigations, research studies and other academia's. Enablers and barriers of HCT that include several aspects related to the environment, infrastructure, costs, safety and performance are further presented in detail.

Chapter 4- Result

The following chapter concludes and summarizes gathered empirical data from primarily DHL, but also the Swedish Transport Agency and Swedish Transport Administration. The empirical data aim to present, organize and describe the current situation without HCT and the possible future situation with HCT introduced and define potential terminals and routes for HCVs.

Chapter 5- Analysis

The fifth chapter advances with a comprehensive discussion of the empirical data in combination with the theoretical framework. This part aims to summarize, motivate and criticize different aspects. The system analysis is further described with respect to the introduction of HCVs on a designated road network.

Chapter 6- Conclusions

The last chapter revisits the initial purpose and research questions of the paper and compiles observations and concludes the essential interpretations of the findings to the research questions. The authors wind up the report with recommendations for future research.

2. Methodology

The methodology describes the process and workflow of this paper. Applied methodologies, aspects related to reliability and validity, how data has been obtained and processed are presented and discussed in this chapter.

2.1 Case Study

As this paper seeks to explain the contemporary circumstances of HCT, a case study is a relevant research method and therefore applied as a research inquiry to this paper. A case study allows the research to focus in-depth on the specific case of DHL with a real-world and holistic perspective. Yin (2017, p 15) outlines a case study as “an empirical method that investigates a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident." Schramm’s (1971) definition also cites cases of decisions as the major focus of a case study. This report benefits from the theoretical frameworks propositions to guide the collection of data, analysis and finally the conclusion. The theoretical references are also the foundation for the analytical generalization that compares the results from previous cases and discussed theories with the findings of this report. The literature discussed in the third chapter originate from multiple different cases but resemble greatly similar results and are often shown to support the same theories. Generatability can consequently be considered to be acceptable to apply in Swedish road freight to logistics service providers that transport grouped goods.

A comparative case method as a distinctive form is used to compare the potential effects of a HCT in the system of DHL with effects from other permits in the same environment for larger vehicles that are normally not approved by standard regulation. The report does not further include any propositions as it might limit the exploration. Additionally, the purpose, research questions and delimitations is considered to be adequate and rationale to dismiss the need of a proposition in the report. This is moreover a pilot case report in specificity. One of the differences between a general case study and a pilot case report is that the pilot case is a research case that only tests the feasibility (Frey, 2018) that will later be used in a main study by DHL and the Swedish Transport Agency. A pilot study can be an extremely powerful tool as it provides a justification of HCT. The pilot study can also be viewed as a feasibility study with an aim to determine if the result of a main study can be accomplished. A feasibility study is very practical when there are concerns about costs, organizational structure, network etc. (Yin, 2017). Even though the results of other exemptions have been examined, this report is based primarily on a single case of DHL and the corporation’s terminal network.

It is vital to mention that a case study has its strengths and limitations just like any other research inquiry. A common issue with case studies as research methods is that they are perceived to have an inability for generalization as only one single, or only a few, cases are studied (Yin, 2017). The same statement could nevertheless also be applied for experiments. Generalization should not be based on a single experiment or case, but together with a set of similar cases and experiments that are repeated in a similar environment. Nonetheless, case studies cannot be generalizable to larger populations or areas as the environment will probably not be identical on a detailed level. The research method of a case study are, however, generalizable to theoretical propositions. It is however important to recall that the goal of this report is to expand and apply current theories through analytical generalizations and not to extrapolate probabilities.

2.1.1 Mixed Methodology Approach

Creswell and Poth (2017) and Creswell and Creswell (2017) argue that including both qualitative and quantitative data neutralizes the weaknesses of each form. By collecting diverse types of data, the findings provide a more complete understanding. The selected design of including both types of data is an explanatory sequential mixed method in which quantitative data is first analyzed and later discussed with the support of the theoretical framework. In brief, the quantitative data is interpreted and explained with the assistance of the qualitative data. Different types of calculations, that are described in later sections, are instruments to measure behaviors and effects of HCVs in this particular case and later discussed in combination with the theoretical framework.

The use of both qualitative and quantitative data is vital to yield significant findings to the research questions and purpose. The quantitative data in the paper is very important in the sense it explains the potential outcomes in the evaluation of a HCT implementation in DHL's network, but is also critical for a causal-comparative analysis between current length and weight restrictions against larger vehicles. Figure 2.1 below provides an overview of the systematic methodology throughout this paper.

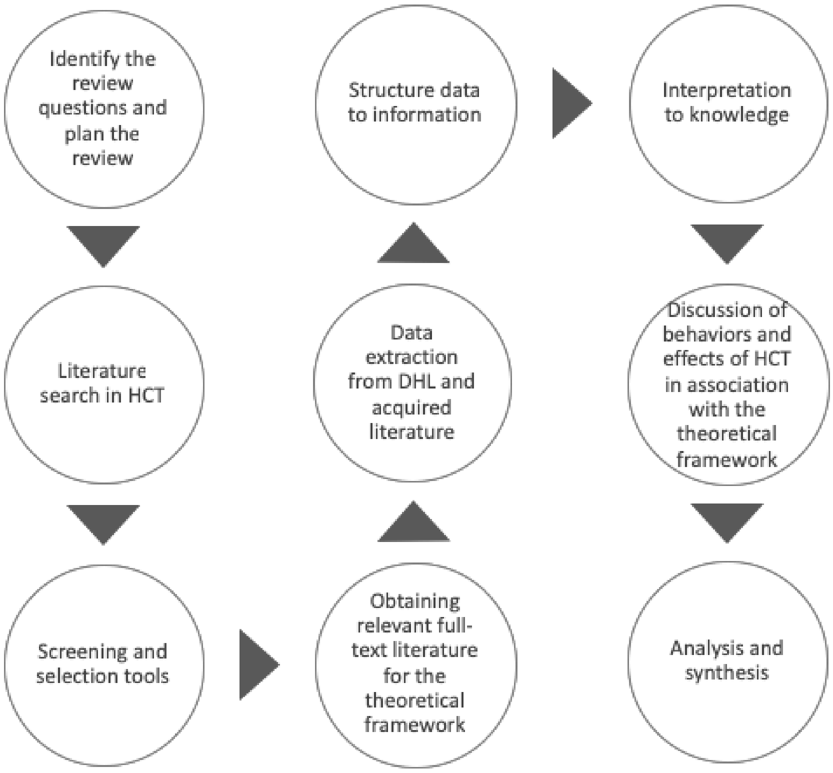


Figure 2.1: Roadmap of the methodological framework.

A systematic review of the literature has been carried out that integrates the findings of obtained secondary data in the form of different studies that have been related and criticized to point out the central issues. The systematic literature review is designed to locate, appraise and synthesize evidence related to the research questions to provide only evidence-based answers for the result and conclusion (Boland, Cherry & Dickson, 2017). Appendix 1 presents the literature that is considered to have contributed vital findings in the phenomenon of HCT, and has therefore been essential for the findings of this particular report. This literature has also been analyzed and examined in detail, while some other literature has only been reviewed thoroughly and is therefore not included in Appendix 1.

The interviews are guided conversations rather than structured questions. As the respondents have advised their own insights and propositions into the subject while recommending other people to interview as other sources of evidence and data, did the interviews take place over an extended period of time. The respondents might be considered as "informants" in this method which moreover possess a risk of being overly dependent on a key informant (Yin, 2017). To avoid this risk, the interviews have been built on previous research of HCT based on countries within the EU, results of other companies' exemptions in the Swedish Transport Agencies regulations and reports published by the Swedish Transport Administration, Closer and other academia that are related to HCVs. These studies, together with different informants, minimize the risk of being dependent on one key informant and provide a careful exploration for contrary evidence. Interviewers have been adaptive and flexible for newly encountered circumstances that have been absorbed as opportunities for new information. Through the literature analysis, the authors have been able to have a steady grasp of the issues and elements that are studied and discussed. It has however been important to be unbiased by preconceived notions that could derive from previous studies, discuss important and relevant subjects and interpret the replies in a good manner.

2.1.2 Data & Evidence

To answer the research questions and the purpose of the report, primary data is gathered through interviews and DHL's ERP-system. The secondary data is gathered through other reports and academia and has been validated through triangulation. As a comparative case method is applied, reports from for example Finland, UK, Australia, Netherland and previous permits in Sweden have been examined and the result of introducing larger vehicles have consequently been explored and discussed in the theoretical framework to provide an understanding of the potential benefits and disadvantages of HCT.

Multiple sources have been investigated through a method of triangulation. Different sources such as scientific research papers, archival records and interviews that address the same phenomenon have been compared to reduce any bias. The results from the closely related studies to the one being undertaken have been carried out in the theoretical framework have been found on multiple sources to ensure a high reliability and ensure that the result is the same in similar environments or in even slightly diverse surroundings. By using multiple different sources many, a document can also be assumed to contain the mitigated truth. To certify that relevant scientific research papers have been found with a considerably complete collection of information, the authors have applied a systematic search in academic journals and bibliographic databases such as Google Scholar, Ebsco and ProQuest among others. The keywords HCT, LHV, Transportation, Freight, Road Transportation, Sustainable Logistics, Road Traffic, System Analysis, Transport Management and Transport Capacity have been used as phrases in the search engines to find broad data regarding the subject.

To provide an understanding of how HCT would influence the terminal network of DHL, a calculation between each terminals relationship has been investigated and analyzed. Three scenarios have then been compared, in Scenario A is all transportation in the terminal network performed with LHVs, in

Scenario B is all transportation in the terminal-network performed with HCVs, and in Scenario C are HCVs performed on specific transports were they are more cost effective than LHVs.

	Scenario A	Scenario B	Scenario C
Vehicle Type	LHV 64 tonnes / 25,25 meters	HCV 74 tonnes / 34,5 meters	LHV 64 tonnes / 25,25 meters HCV 74 tonnes / 34,5 meters
Extent	Full Terminal Network	Full Terminal Network	HCV does only operate when it is more cost efficient for DHL Freight than LHVs, and LHVs are used elsewhere.
Description	A current situation analysis and net present value in which only LHVs are permitted to operate in the terminal network.	A situation analysis in which HCVs are introduced in the full terminal network and replace all LHVs	A situation analysis in which the vehicle most optimized for every single trip between two different terminals is used, with respect to capacity and costs.

Table 2.1: Map of the different Scenarios.

The different scenarios are developed mainly because of the importance to illustrate transparency between the results, as only a result alone is not sufficient enough to just compare the costs of LHVs with the costs of HCVs. There might, for example, exist a more optimum equilibrium between these, depending on several parameters like costs, consumption of time, fill-rate utilization, and average speed of the vehicles executing freight transportation. The fact that each terminal's traffic differs from day to day regarding demand for freight also indicates that the suggested setup of vehicles is probably a combination of both LHVs and HCVs and thus not just one of the two.

The calculations has been based primarily on Flodéns (2007) and Adell et al. (2016) analysis with adjustments to the financial inflation through the Sweden Statistics price calculator (Statistics Sweden, 2019) and is further illustrated in the third chapter. The fixed costs are broken down per kilometer and the variable costs are broken down per km or hour. The data is not presented in this report due to confidentiality with DHL Freight. The analyzed data contains the traffic between the 25 terminals in DHL Freight's network during the period 01/01-2018 – 12/10-2018 which presents the volumetric weight per day and relation. Some data, as transports between 'fictive' terminals and goods that have been picked up by customers at the terminals are excluded, resulting in a decrease from 138 574 to 119 701 rows of data to analyze. The data has been addressed through a summarizing and aggregated method, but also in detail considering each transport separately. As the cargo of DHL is usually limited to primarily the loading meters (LDM) and secondary to the volume, the volumetric weight has been recalculated and compared to both volume and LDM in the transports. The first step was to create a cross matrix to identify if any relations have potential for HCVs and preclude terminals with no demand of HCVs, to determine the relationships in the terminal network with highest potential. Each row of data has also been analyzed separately, an example could be that a shipment in 26/6-2018 from Terminal A to Terminal B is of 19,1 LDMs and does hence not result in any savings if HCVs are used. The total cost of this particular shipment with HCV would be approximately 3250 SEK, and 2717 SEK with LHVs. This step is only to increase the validity of the result in this report in which every single transport is considered for Scenario C. Furthermore, all numbers for future scenarios are presented in totals whilst historical numbers are presented on a more detailed level. The external costs are mainly related to emissions that have been calculated through the Network for Transport Management (NTM) in which the vehicle kilometers, weight and volume are inserted and difference of greenhouse emissions are presented automatically calculated through NTMs equations.

A master file in Microsoft Excel has been developed together with a model consisting of variables that are adjustable for DHL, i.e. kg per LDM, capacity of vehicles, fixed-/variable-costs per hour, average speed and utilized hours per year. The aim with the Excel-file is to create a basis for DHL that can be adjusted for DHL's preferred variables and perception, e.g. if a LDM should be equal to 1950 kg or 1300 kg.

The costs have been gathered from scientific reports. In order to take consideration to the variance in the gathered data, a minimum cost and a maximum cost was taken for each cost in the overall structure and from these costs was an average cost-value calculated. Costs has also been gained from DHL and compared with the theoretical minimum and maximum values. As there was not a high degree of variance found between the costs, both the theoretical cost and costs from the real-world practice of DHL was validated. The cost structure of DHL has been applied when calculating the costs for LHVs. The minimum cost value has been applied to HCVs as the costs of DHL were identical and extremely similar to the theoretical minimum costs of LHVs that were initially calculated. The theoretical costs used have been gathered from Flodén (2007), Asmoarp, Jonsson and Funck (2015), Adell et al. (2016), Johansson and von Hofsten (2017), and Transport Administration (2018).

2.2 DHL Freight Sweden

DHL was founded in the USA by Dalsey, Hillblom and Lynn in 1969. German logistics company Deutsche Post, one of the world's largest logistics groups, began to acquire shares in DHL in 1998 and had acquired all shares by December 2002. Deutsche Post DHL Group operates today under two brands: Deutsche Post, which is Europe's leading postal service provider, and DHL, with a comprehensive range of freight transportation, supply chain management services and international express. The group does in total employ approximately 550 000 employees in over 220 countries. DHL does carry 360 000 of these employees in four different divisions consisting of DHL Express, Global Forwarding, Freight and Supply Chain. DHL Freight offers road and rail transportation in Europe with consignments that are consolidated or full truck loads. DHL Freight Sweden consists of 35 offices, 2300 employees and 25 terminals (see Appendix 3 for a larger map of all terminals). There are approximately 2250 vehicles operating per day, carrying 100 000 packages or 32 000 tonnes. 500 vehicles transport goods in the longer haulage between the terminals every day and carries 700 tonnes in total. (DHL, 2019)

Figure 2.2: The terminals of DHL

The terminals in Malmö, Helsingborg, Gothenburg, Jönköping and Rosersberg (Stockholm) are international terminals with a higher capacity and average traffic. Västberga (Stockholm) and Sundsvall do also have traffic activity that is considered to be stronger than the remaining terminals. An amount of goods is consolidated in the terminals of Sundsvall and Jönköping to optimize the fill rates and capacities. The routes between these seven terminals are therefore of significant importance to investigate upon for the introduction of HCVs. (Öhman Nilsson, personal communication, February 8, 2019)

Deutsche Post DHL Group does have a mission for 2050 of zero CO_2 emissions, with a milestone in 2025 of reducing the CO_2 releases to 50 % measured with 2007 as an index. In DHL, there is also a zero tolerance for fossil diesel use in 2020, 12 % of the current fleet must therefore be substituted. The government of Sweden also has a national target to decrease the emissions from the transportation sector with 70 % to 2030. DHL, however, has experienced an absence of adequate truck drivers and might experience an absence of renewable fuel in the near future. The impacts of a HCT program is therefore an interest in DHL's terminal network as well for the society.

The HCT project is appealing to DHL for many reasons which, among others, are:

1. A lack of vehicles has been experienced historically, and lately also a lack of drivers.
2. Forecasts show an increasing demand for freight transportation
3. Volumes in packages are increasing by 20 % per year
4. High optimization and capacity constraints are found in both terminals and vehicles, and excess capacity is needed
5. Scarcity of capacity and quality issues on rail are experienced

DHL's aim is therefore to investigate in how an introduction of HCVs affect a terminal network with consideration of economic, environmental, safety, flexibility and capacity aspects. A system analysis is required in the project to understand the effects on the full network and society.

The vehicle fleet of DHL is mainly limited by the loading meters as much of the goods are not stackable. In these cases, DHL invoices a loading meter even though the whole volume of a LDM is not fully used as the empty space cannot be utilized. A second limitation is the volumetric weight (also known as cubic weight) that is invoiced when the cargo covers a large volume in relation to its weight. A LDM during 2018 was calculated to be equivalent to 1300 kg, meaning that most packages were primarily invoiced based on LDMs or volumetric weight. The vehicles are only loaded to the maximum permitted weight a very few times every year, and the weight is therefore of no current limit or challenge for conducting freight transports in the terminal network of DHL. The average fill rate is currently approximately 75 % as accessible space must be available for the company to become able to manage variations in demand during the season and imbalances in volumes between different terminals. (Jelvestam, personal communication, February 15, 2019)

DHL do also cover approximately 70 % regarding the freight transportation of the tire market in Sweden which is, together with the changing consumer behaviour and e-commerce, one of the reasons behind the increased demand for transportation. The growing e-commerce market, in which the volume of packages in Sweden grew by 20 % during 2017 (TRAFA, 2019), do also create very strict demands of short lead-times. These aspects together create challenges for DHL in their line-haul operations. To transport goods via rail is an alternative that the company are looking into to increase their share of rail transport, but the capacity on the rail network is experienced to be full and the service levels are low compared to road when customers require a high level of flexibility and service quality. An example of this could be seen through the average time before goods are picked up by the final customers at the pick-up points. While DHL's customers require very short lead-times, the actual average time before the final customers pick up their products from service points is 48 hours. (Jelvestam, personal communication, February 15, 2019)

The line-haul operations between the terminals of DHL Freight are managed by 20 % through own subsidiaries, and by 80 % through external haulage contractors. There are approximately 80 contractors of different sizes and 250 drivers in the organic subsidiary alone. The terminals in Tibro and Visby are smaller terminals that are operated by external actors. The terminal in Sundsvall is a cross-docking hub that collects all goods from the south with a destination to the northern destinations of Sweden. The terminal in Jönköping is a hub-and-spoke terminal that is used as an overflow concept when the capacity is full in nearby terminals. DHL therefore believe that both Jönköping and Sundsvall, along with Gothenburg, Rosersberg, Västberga, Malmö and Helsingborg have a large potential for HCT based on the volume of goods between these terminals. Introducing HCVs on a limited number of strategic routes is believed to reduce the total number of vehicles with 25 units per day and CO_2 emissions with 5 %. The project is further led by Maria Nilsson Öhman, Sustainability Manager at DHL, with support from Martin Jelvestam, Linehaul Manager at DHL, and Rickard Bergqvist, Professor at the University of Gothenburg.

2.3 The Swedish Transport Agency

The Swedish Transport Agency does issue permits for pilot activities for vehicles that are longer and/or heavier than what is normally permitted by the government's regulations and allowances. The Swedish Transport Agency does issue the permits with the requirements for new technology and construction that is to be tested. The issued permit is however limited in time and to a particular road and route. If the requirements are not met or other special reasons occur, the Swedish Transport Agency has the right to revoke the granted permit. (The Swedish Transport Agency, 2019b)

It is important to demonstrate that the HCVs will not create any risks in the safety aspect and can be carried out in a roadworthiness method when applying for the permit. A description is therefore required of the technical specifications of the vehicle and its surroundings.

	Required Information
1.	Contact information for the seeking corporation
2.	Contact persons responsible for the pilot project
3.	The time-period in which the pilot project will be operating (maximum 5 years)
4.	A comprehensive description of the purpose and objective of the pilot project
5.	Details of the owner of the vehicles

6.	A description of the new technologies or constructions that is to be tested and evaluated
7.	Discussion on why the new technology or construction should be tested on a HCV
8.	Discussion on how the new technology or construction will be performed and evaluated
9.	Geographical information related to the routes and roads that the HCVs will operate in
10.	Statement from the authorities carrying the affected roads and concerned by the pilot project
11.	A risk assessment and analysis which evinces that risks exist within an acceptable level and the pilot project can be carried out without creating any danger or increased risks related to the safety
12.	Technical description and specification of the vehicles
13.	Discussion as to why the vehicle is not permitted to operate under current permissions in respect of the current limited regulations of weight and length
14.	Requirement for a speed exemption according to 4th ch., 20 § (provisions for speed on road with certain vehicle combinations) in the traffic constitution (1998:1276)
15.	Other vital information relevant for the examination of the application for the permit of a pilot project

Table 2.2: Scores that must be satisfied when applying for a pilot project (The Swedish Transport Agency, 2019b).

2.4 Validity, Reliability and Generalizability

The validity and reliability are important aspects in research papers, researchers must therefore convey different steps to check for accuracy and credibility in the findings. The case study tactics for four design tests developed by Yin (2017) has been practiced.

Criteria	Case Study Tactics	Application in general	Application in this study
Construct validity	• Use multiple sources of evidence • Establish a chain of evidence • Have key informants review draft case study report	• Data collection • Data collection • Composition	Multiple reports with different perspectives Structuring and presenting the data Part of the report reviewed by members
Internal validity	• Do pattern matching • Do explanation building • Address vital explanations • Use logic models	• Data analysis • Data analysis • Data analysis • Data analysis	Cross-case analysis Triangulation Member checking & peer debriefing
External validity	• Use theory in single-case studies • Use replication logic in multiple-case studies	• Research design • Research design	Designed in multiple-case study Results are discussed with the consideration of other theories and findings
Reliability	• Use case study protocol • Develop case study database	• Data collection • Data collection	Database developed and presented in section 3

Table 2.3: Case Study Tactics for Four Design Tests. Adapted from Yin (2017, p. 43).

This report has sustained the validity of the findings by employing procedures for triangulation, using member checking and peer debriefing for the validity. Different data sources have been triangulated through an examination of evidence the sources present in different themes and that is established from different participants which calls for an increased validity. Decisive parts of the final report have also been reviewed by participants in DHL to verify if the findings are legitimate. Peer debriefing is further applied to enhance the validity. Peer debriefing involves a person, i.e. peer debriefed, with an expertise in the phenomenon of HCT that questions the report to add further validity to the account.

Internal validity is mainly a concern for explanatory case studies such as this. The concern derives from discussion regarding a limited number of variables and missing out on an unknown variable. For example, if a researcher incorrectly concludes a relationship about how variable *aa* effects *ab* but does not consider a third factor, *ac*, that may have caused the effect of factor *ab*, the researcher has failed to deal with the risks of internal validity. External validity on the other hand suggests whether the findings are generalizable beyond the actual case study. Yin (2017) argues that single case studies are able to be generalized on a broader theory if qualitative researchers evaluate other cases and discuss or develop their findings in new case studies. As a comparative case method is applied, the results of other cases have been evaluated, discussed and compared with the findings of this report. The replication logic also shows the findings of specified theories to be applicable to this report. It is, however, critical to note that this particular study is limited and focused on single countries and corporations. The findings might therefore not entirely reflect practices in other sectors or countries.

Different approach methods have been discussed and explained so other researchers can follow the procedures of this report. As formal and presentable data is displayed throughout the report, other researchers and investigators can review the evidence directly which increases the reliability of this case study. This case study is conducted in a manner that an auditor are be able to repeat the procedures if needed and achieve the same results to ensure consistency.

3. Theoretical Framework

The forthcoming chapter presents the results within the scope of the literature review. The topics cover barriers and enablers of HCT in Sweden from a business as well as a societal perspective. Complex relations in a system analysis is highlighted by previous literature, it is nevertheless demonstrated in different subsystems and features, such as environmental challenges, operational and external costs and safety concerns. Lastly, a proposed cost benefit model is suggested based on the theoretical findings

3.1 Road Transportation

In a global context, more products are transported over longer distances due to the concentration of production facilities in low-cost areas and centralization. Long-distance transportation has therefore become more important in the development of efficient logistics operations. The mode selection of freight transportation is a fundamental decision in logistics, with the main criteria of customer service and costs included. Road freight transport is currently the dominant mode of transport in many countries, including Sweden, and has been growing. Continued growth in road freight transport is further expected (Wee, Annema & Banister, 2013; Rushton, Croucher & Baker, 2014). Rail freight has been static for some time as the rail-network capacity in many countries is utilized to a maximum while inland waterways are still under investigation and development in a large number of countries (Rushton et al., 2014).

The directives 96/53/EC and (EU) 2015/719 from the EU limit the vehicles that are allowed to conduct cross-border transportation to a maximum length of up to 16,50 m for truck-trailer combinations and 18,75 meters for articulated vehicles. The maximum gross weight is set to 40 tonnes, which could be extended to 44 tonnes when performing container transport between intermodal terminals. Furthermore, individual member states could accept LHVs for domestic freight provided that standardized EU modules are used, this is the so-called European Modular System (EMS) (Monios & Bergqvist, 2017; Sharpe & Rodríguez, 2018). The EU is considering making new regulations that would allow LHVs to conduct intra-European freight with a new maximum length of 25,25 meters and a new maximum weight of 60 tonnes (Rodrigues et al., 2015). Figure 3.1 illustrates the variety of road trains with different semi-trailer/swap-body combinations. A third carrying load unit of ISO containers are not illustrated in the figure. A large share of the goods that are being transported in Sweden are by vehicles that exceed the EU standard and are therefore defined as LHVs. (Vierth et al., 2008).

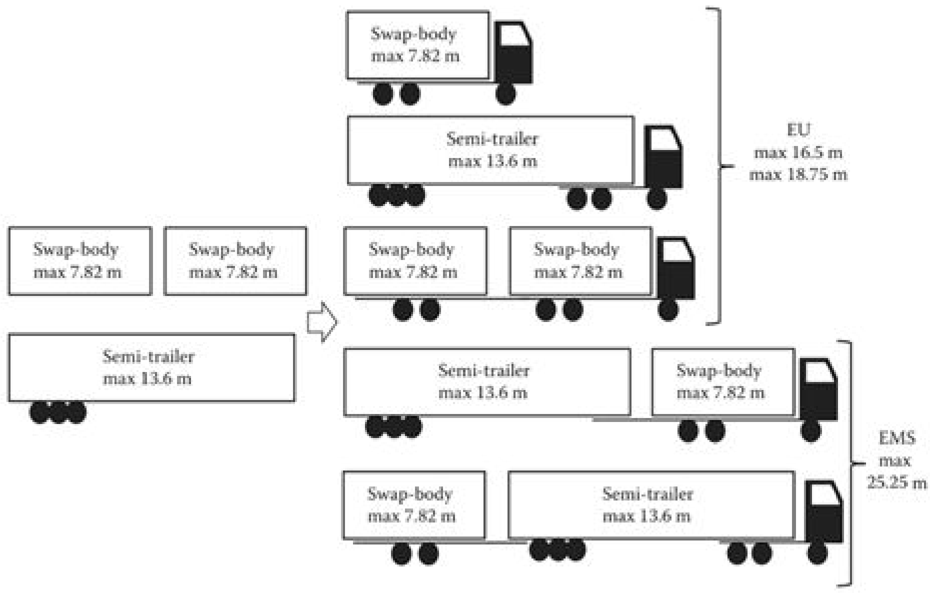


Figure 3.1: Variety of road trains with different combinations (EMS) (Monios & Bergqvist, 2017, p.105).

Sweden has a tradition of using LHVs and permitted modular vehicles to a maximum length of 25,25 meters from as early as 1997 (Pålsson et al., 2017), and the gross weight of the vehicles was extended to 64 tonnes in 2015 (Fröjd, Pettersson, Larsson, & Cider, 2017). Monios and Bergqvist (2017), discuss various studies that have presented the effect of LHVs in Sweden. The findings of the various studies have shown economic and environmental benefits and the experience is mostly positive. One of the few negative effects that is found is related to the risk of a new generation of freight traffic that responds to reductions in freight costs, which might increase the risk for accidents in the longer term.

Road freight transportation has its advantages and disadvantages just like any other mode. It can provide a very quick service with high flexibility, but has a relatively low speed limit and an even more constrained limit in the carrying capacity compared to rail freight transport or inland waterways. There are further three aspects that must be considered when choosing an appropriate vehicle on road - legality, efficiency and economy. Legality is about ensuring that the vehicles operate within the existing transport legalization with the right weights and dimensions, health, safety, and environmental features. Efficiency on the other hand is about the nature of the operations, e.g. annual mileage and terrain, characteristics of load, e.g. weight and volume, and specifications of the vehicle, e.g. body, axle configuration or engine. The economical aspect considers the operating and performance costs. This aspect includes only internal costs such as the fixed and variable costs of a vehicle, the residual value and whole life costs. Other determinants of vehicle selections involve, among other things, construction, society, environmental issues and technology. Drivers, for instance, can have a high impact on the selection of vehicles. If a company prefers to have a very high service level it might select smaller but more flexible vehicles. However, if there are not enough drivers in the market, a company must drive fewer vehicles in larger sizes. The most important factor is however to balance the operational and economic aspects to assure that trucks have a high optimization, runs efficiently, and are utilized for the right purpose. (Rushton et al., 2014)

Further aspects that must be considered in the selection of vehicle are the load types and characteristics. Rushton et al. (2014), categorize loads into four different types; (1) light, (2) heavy, (3) mixed and (4) liquid, powder and valuable load. Vehicles carrying light or mixed goods may have a low weight utilization but a high-volume utilization (Rodrígues et al., 2015). This phenomenon is described as a 'high cube factor'. Rushton et al. (2014) argues that another issue with mixed goods is that some heavier goods can't be stacked on fragile goods that have a light weight and are sensitive even though that they are short in height, and hence could become limited by the loading meters.

Vehicles conducting HCT release more emissions, have higher fuel consumption, use more energy and are more expensive per vehicle-kilometer than conventional road freight trucks (Vierth et al., 2008; Christidis & Leduc, 2009). Nevertheless, as loading capacity is greater in HCVs, fewer vehicles are needed to freight the same amount of goods that otherwise would have been freighted by conventional road freight trucks. HCVs are therefore reducing the total energy consumption, emissions, and CO2 per tonne-kilometer (De Ceuster, Breemersch, Van Herbruggen, Verweij, Davydenko, Klingender, Jacob, Arki, & Bereni, 2008; Vierth et al., 2008; Leach & Savage, 2012; McKinnon, 2016a). To enable the high potential of HCT it is important that the fill rate of the vehicles is utilized as much as possible. 3PL's can achieve satisfactory fill rates for their long-haul transport but not as high for short-haulage transport. It is hard to quantify the underused capacity because most countries do not have any systematic collection of macro-level statistics (McKinnon, 2012b). In 2010, the EU approximated that 27 % of the total truck-kilometers were empty and the average weight of each individual transport were 57 % of the maximum (Council of Supply Chain Management Professionals, 2015). However, this could be misleading as many vehicles may have conducted low-density goods which often fill the space available before the weight limit is reached (McKinnon, 2016b). Nevertheless, for 3PLs, it is hard to go above an average fill rate of 70 % because they must ensure flexibility in the transport network in order to handle fluctuations in demand (Kohn, 2005). In a transport network the consolidation of goods could be an enabler to achieve even higher fill rates (Kohn & Brodin, 2008). Some of the main constraints on the loading of freight vehicles are hard to overcome while others could be eased by changes in business practice, regulation, technical standards, and the efficient use of information technology (McKinnon, 2016b).

Factor	Effect
Market	Demand fluctuations
	Uncertainty about transport requirements
	Limited storage capacity at destinations
	Geographical imbalances in traffic flow
	Limited use of online load matching
Business practice	Just-in-time replenishment
	Poor coordination of purchasing, sales, and logistics
	Lack of supply chain visibility
	Reluctance to join collaborative load-sharing schemes
Regulation	Vehicle size and weight restrictions
	Health and safety rules
	Cabotage restrictions
Equipment	Nature of packaging and handling equipment
	Incompatibility of vehicles and products for backloading
Infrastructure	Unreliable delivery schedules
	Lack of load consolidation facilities

Table 3.1: Factors constraining the loading of freight vehicles (McKinnon, 2016b. p.12).

HCT can be applied in different ways depending on the characteristics of the goods and transportation scenario. The gross potential of using HCT varies if only the maximum weight is increased or if both maximum weight and volume is increased. The reason for this is that goods might have different limitations and is only affected when the capacity increases in the relevant aspect (Pålsson et al., 2017). For example, processed timber and cork are limited by its volume, i.e. the truck is fully loaded in terms of volume, but the weight limitation is far from reached, while round timber is limited to its weight, i.e. the truck is not fully loaded in terms of volume when the maximum weight limit is reached. The capacity for the processed timber must therefore be increased by changes in the length while the capacity for the round timber must be increased by changes in the maximum weight. HCVs may also further result in co-benefits by lowering labor requirements, vehicle-kilometers, accident levels, and pollutant emissions. Extending the limitations of trucks carrying capacity is, however, one of the most controversial ways of reducing carbon emissions from the road freight sector but in the longer term, HCVs are likely to be an important variable to decarbonize the road freight sector (McKinnon, 2016b).

3.2 Environment

The transportation sector is one of the largest negative sources regarding CO_2 emissions, local air pollutants, noise emissions and congestion that the societies of today must face and be innovative about in order to have a possibility to secure or reduce the negative impact that will otherwise occur if nothing is made for future generations (Abbasi & Nilsson, 2012). The environmental issues are calling for something to be made rapidly. One way of reducing these negative effects is to explore the possibilities with HCT as an attractive solution from a socio-economic and an environmental perspective, thus, it has potential risks of which need to be investigated further. HCT has the benefit of more efficiently utilizing existing road infrastructure and is overall a neutral choice in regards to infrastructure investments. Also, if more goods are freighted through HCT the number of trucks on the roads could be decreased. Consequently, a reduction in transport costs, fuel consumption, emissions and traffic congestion could be obtained (Ericson, Lindberg, Mellin & Vierth, 2010; Kharrazi, Aurell, Sadeghi Kati, Jacobson, Fröjd & Asp, 2014). Consolidation of goods in HCVs is accordingly to McKinnon (2012a), one of the most effective alternatives of decreasing vehicle-kilometers and thus road freight transports impact on the environment. In the last couple of years, global warming mitigation has gained increased significance for policy makers all over the world. As a result, industries are under growing pressure to evolve in an eco-efficient way (Rossi, Colicchia, Cozzolino, & Christopher, 2013), to reduce the environmental impacts of their logistics operations (McKinnon & Piecyk, 2009; Piecyk & McKinnon, 2010). Even studies that are generally opposed to HCVs do not dispute the positive impacts HCT would have on environmental performance (Fraunhofer & TRT, 2009).

McKinnon (2012b) developed a framework of efforts to reduce energy consumption and environmental impacts (see figure 3.2). The grey parameters should be improved to increase the efficiency of the operations. The first five brighter parameters relate exclusively to the transport operations while the last two darkest parameters apply to all logistical activities.

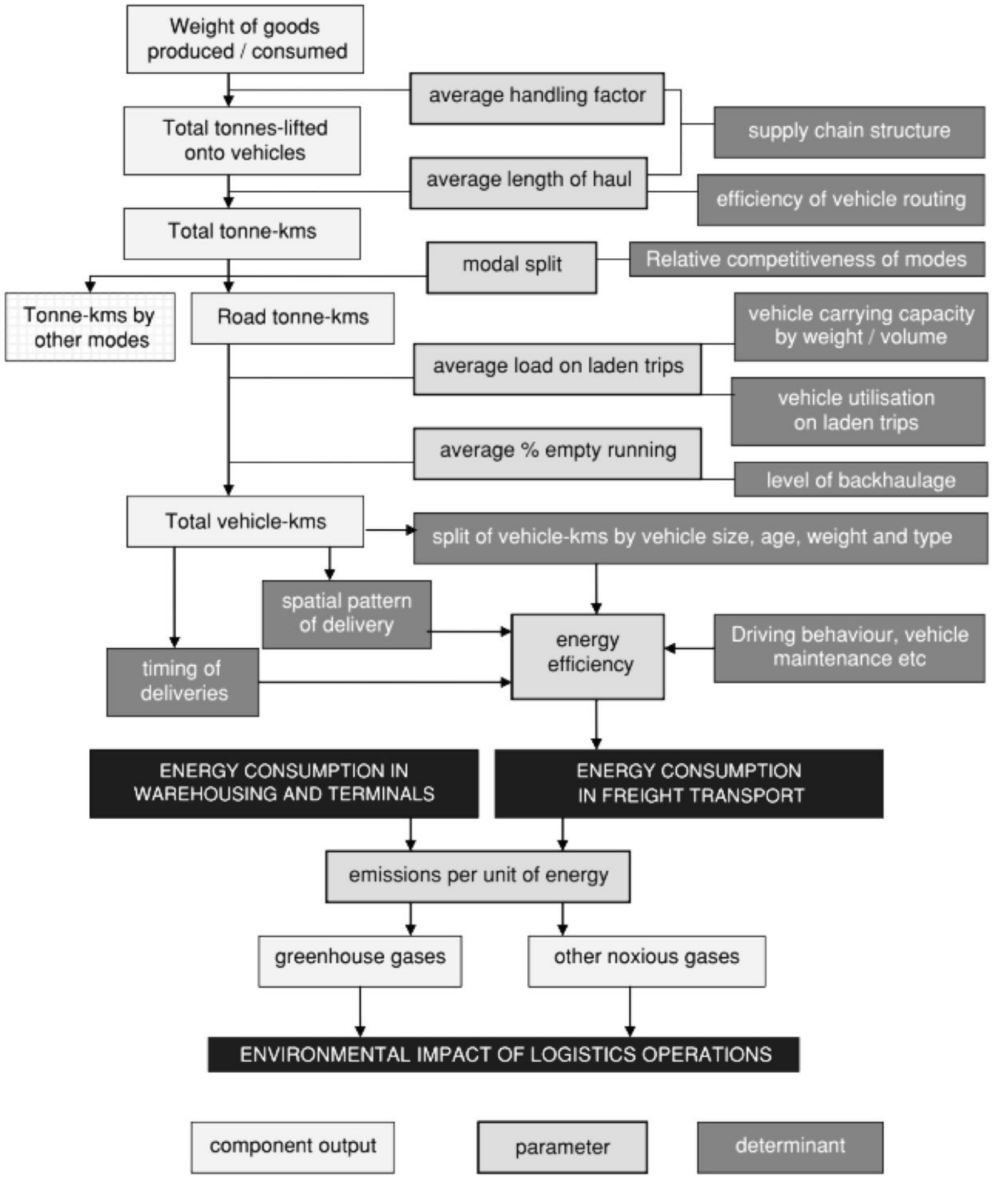


Figure 3.2: Efforts to reduce energy consumption and environmental impacts (McKinnon, 2012b. p.524).

3.2.1 Noise and Emissions

Trucking is a source of different oxides and concentrations such as CO_2, NO_X, PM, THC and SO_2 (Knight et al., 2008). These emissions are negative for the health, aggravating cardiovascular and respiratory diseases and might cause cancer of the lungs or affect the function of the lungs and other organs in different ways (OECD, 2011).

If the forthcoming growth in demand for freight transport is not as explosive as many studies suggest, it is still likely that the growth is to be robust and largely justified on the grounds of cross-sectoral decarbonization, the climate-proofing of settlements, and the economic development and infrastructure (McKinnon, 2016a).

McKinnon (2016b) further argues for a framework consisting of five sets of decarbonization initiatives for freight transportation; (1) supply chain configuration, (2) shift freight to lower carbon transport modes, (3) optimize vehicle loading, (4) increase energy efficiency of freight movement and (5) reduce carbon content of freight transport energy (see figure 3.3). The demand for freight can be reduced within the bounds of logistical management by, for example, circular economy and reduced intensity of economic activity. The second initiative is to use intermodal transportation and take advantage of the wide variations in carbon intensity and strengths of each mode. A lower carbon transport mode can, however, also be defined as strategic corridors (e.g. point-to-point versus hub-and-spoke networks). Optimizing vehicle loading does rely on freight density, space and weight related measures. There are many different aspects that can constraint loading as demand fluctuations, JIT deliveries, nature and size of packaging equipment, incompatibility of vehicles and products for backloading, poor coordination of logistics, or vehicle size and weight restrictions. HCVs can achieve higher optimizations and fill rates through load consolidations and hence accordingly also increase energy efficiency and reduce emissions per tonne-kilometer. (McKinnon, 2018)

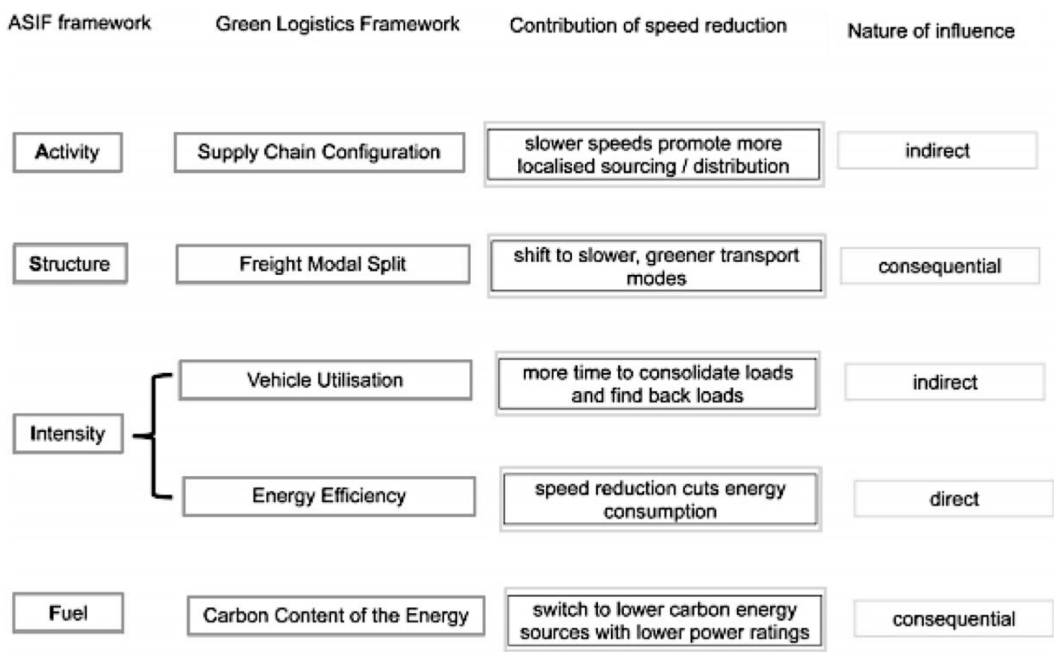


Figure 3.3: Interrelationship between decarbonization frameworks for freight transportation (McKinnon, 2016b. p.420).

Knight et al. (2008), present data that show emissions of 8 different vehicle types, all driving an average speed of 86,9 km/h which is considered typical for 4-axle and 5+ axle articulated HGVs. The data shows the heavier the vehicle, the greater the exhaust emissions and fuel consumption. However, if exhaust emissions and fuel consumption rates are considered per tonne of payload carried, the heaviest and longest vehicles produce similar or lower emissions than smaller vehicles. The consumption of fuel is, for example, determined by the technical specifications and efficiency, but also by driving patterns and the flow conditions on the transport network. Every stop and start increases the fuel consumption of heavy vehicles, and five stops is enough to double the fuel consumption on a trip of 10 kilometers for a truck of 40 tonnes. A larger truck in a terminal network could theoretically carry a load for two trucks, and bisect the amount of stops and starts and pollution accordingly. Eco-driving has furthermore the potential to immediate reduce 10 % in CO_2 emissions and fuel consumption if the management can provide continuous feedback to the drivers (OECD, 2011). To specify, if a HCV (see table 3.2 for the definitions of vehicle types) is fully loaded, it produces significantly lower emissions than vehicles of 44 or 60 tonnes if measured in emission rates per tonne of payload carried.

Vehicle Type	Emission rates						
	CO (g/km)	HC (g/km)	NOx (g/km)	PM (g/km)	CO_2 (g/km)	FC (g/km)	Payload (tonnes)
1	0.109	0.013	6.031	0.023	1081.297	340.989	29.1
2	0.110	0.013	6.237	0.023	1124.248	354.543	28.2
3	0.109	0.013	6.031	0.023	1081.495	341.055	28.1
4	0.111	0.013	6.325	0.024	1140.834	359.775	23.3
5	0.111	0.013	6.317	0.024	1139.771	359.443	23.7
6	0.140	0.017	8.011	0.030	1445.306	455.759	39.3
7	0.140	0.017	8.014	0.030	1445.172	455.759	39.7
8	0.174	0.018	9.752	0.034	1758.198	554.614	60.4

Vehicle Type	Emission rates per tonne of payload					
	CO (g/tkm)	HC (g/tkm)	NOx (g/tkm)	PM (g/tkm)	CO_2 (g/tkm)	FC (g/tkm)
1	0.004	0.000	0.207	0.001	37.146	11.714
2	0.004	0.000	0.221	0.001	39.842	12.564
3	0.004	0.000	0.214	0.001	38.445	12.124
4	0.005	0.001	0.271	0.001	48.860	15.409
5	0.005	0.001	0.267	0.001	48.191	15.198
6	0.004	0.000	0.204	0.001	36.730	11.582
7	0.004	0.000	0.202	0.001	36.447	11.494
8	0.003	0.000	0.162	0.001	29.119	9.185

Vehicle Type	Description	Maximum Length (metres)	Maximum Weight (tonnes)
1	Base case – single-deck articulated vehicle	16.50	44
2	Base case - double-deck articulated vehicle	16.50	44
3	Articulated vehicle with longer (up to 16m) steered semi-trailer	18.75	44
4	Tractive-unit, steered interlink semi-trailer, semi-trailer (B-double)	25.25	44
5	Rigid vehicle, converter dolly (A), semi-trailer	25.25	44
6	Tractive-unit, steered interlink semi-trailer, semi-trailer (B-double)	25.25	60
7	Rigid vehicle, converter dolly (A), semi-trailer	25.25	60
8	Tractive-unit, semi-trailer, converter dolly (C), semi-trailer	34.00	82

Table 3.2: Emission rates for Euro 4 vehicles with maximum laden weight (Knight et al., 2008, p.28).

Particulate filters, catalysts and other technologies are also used to reduce the toxicity of particulate emissions by DHL and other companies. Many engines of today's trucks in OECD countries have decreased the fuel consumption from 50 liters to 30 liters per 100 kilometers thanks to this development in later years. This could, however, be reduced further by minimizing the aerodynamic drag and rolling resistance, downsizing engines or improving the efficiency of auxiliary systems. As an example, 40 % of the fuel is used to overpower the drag (air resistance) and 45 % to overpower the rolling resistance (the rest is consumed by auxiliaries and powertrain losses). (OECD, 2011)

Other emissions than greenhouse gas emissions, such as noise, can be a major concern for populations living along major roads. The main sources of noise are derived primarily from the engines and friction of the wheels, but also travel speed and intensity of traffic. A level of noise above 70 dB in the close surroundings of homes is considered undesirable and this level is only allowed to be exceeded five times per average maximum-hour during the day-evening time interval 06:00 - 22:00, for the night hours it is considered that 70 dB at the walls outside the house corresponds to 45 dB inside (Naturvårdsverket, 2017).

The ETT-project (One-Pile-More) was conducted in the timber haulage industry in which trucks were permitted to be 30 meters long with a gross weight of 90 tonnes. The project presented better results than initially expected in many aspects. A 30-meter truck with a total weight of 90 tons reduced the operational costs and emissions with 20 %, and did only show an increase of 1,3 dB in noise emissions compared to a truck of 24 meters and a gross weight of 64 tonnes. The increase of 1,3 dB is considered to be small and might be difficult to perceive according to Ericson et al. (2010) and Fröjd et al. (2017). The conclusion of the noise emissions was a decreasing noise in total as there were less trucks per amount of transported freight (Ericson et al., 2010; Fröjd et al., 2017). Another study has solely compared noise emissions of HCT and traditional vehicle combinations and found that the level of noise per vehicle passage is somewhat higher for HCVs (approximately 1.5 dB) than for traditional vehicles as maximum. In the case of Sandberg et al. (2018), it was complicated to present any findings and conclude upon the effect between the HCVs and LHVs as the standards consider both maximum level while also the number of times the maximum level is exceeded. Even if it is more likely that the HCVs exceed the 70 dB limit, the number of these events is lower for the HCVs due to the reduced number of vehicles. Therefore, this study concludes that the noise emission factor does not give any of the vehicles a clear advantage over the other (Sandberg et al., 2018). Knight et al. (2008) made a similar comparison but with consideration to the number of axles, different speed and surface. The largest difference of 1,4 dB(A) was found between 6-axle and 11-axle configuration on a rough surface at the highest speed of 90 km/h. The conclusion of Knight et al. (2008) is equivalent to the compilation of the ETT-project and do also argue for a relatively small in noise emissions.

3.2.2 Congestion and Space

Research in the US suggest that the power to weight ratio, the type of road and the gradient of the road are the main factors that affect the congestion impact of HCTs. Studies in the UK on the other hand suggest that the speed (power to weight ratio expressed differently) and traffic volume are the main factors that affect the congestion impact. Nonetheless, both studies show that the impacts are great for slow-moving abnormal loads and very small when the speed exceeds 50 km/h. (Knight et al., 2008)

The overall impact does also depend on whether the number of vehicles will be reduced if HCTs are introduced. The introduction of HCTs should reduce the overall travel of HGVs, but if this leads to a modal shift or generate additional road goods traffic, the impact will be greater by the capacity increase and efficient use of road space (Steer, Dionori, Casullo, Vollath, Frisoni, & Ranghetti, 2013). Knight et al. (2008) shows that the use of a fully loaded vehicle of 82 tonnes and 34 meters is most efficient in relative use of road space measured by payload and pallet capacity (see table 3.3). Leach and Savage (2012) further argue for a decrease in fuel consumption and carbon emissions per unit of load (measured on a pallet kilometer basis) by 11-19 %.

Vehicle Case	Gross Vehicle Weight (tonnes) and number of axles	Relative use of road space (assuming full vehicle and 50m headway)	
		By Payload (tonnes per metre of road space)	By Pallet Capacity (pallets per metre of road space)
1 (base single-deck)	44 tonnes / 6-axle	1.00	1.00
2 (base double-deck)	44 tonnes / 6-axle	0.90	2.00
3 (longer semi-trailer)	44 tonnes / 6-axle	0.91	1.19
4 (B-double)	44 tonnes / 8-axle	0.71	1.36
5 (rigid + semi-trailer)	44 tonnes / 8-axle	0.72	1.36
6 (B-double)	60 tonnes / 8-axle	1.20	1.36
7 (rigid + semi-trailer)	60 tonnes / 8-axle	1.20	1.36
8 (C-train)	82 tonnes / 11-axles	1.59	1.58

Table 3.3: Relative use of road space (Knight et al., 2008, p.38).

Sweden and Finland are the two Member States in the EU that currently have LHVs or HCVs permitted on the road. There is limited evidence on what impact HCVs have on congestion and use of space. The Finnish Ministry of Transport found that HCVs are used primarily on highways and there is no evidence suggesting that the utilization of HCVs has a negative effect on congestion and traffic. As LHVs have been permitted in Sweden since 1997, it is difficult to isolate the impact they have had on the Swedish traffic flow (Steer et al., 2013). Viert et al. (2008) however consider that if LHVs were to be removed, the amount of additional traffic would increase and the financial cost for the society would be an economic loss of 7,5B SEK annually, in which 50M per year is related to the congestion. It is further notable that these numbers are considered to be underestimated in both cases according to Viert et al. (2008). Leach and Savage (2012) discuss limitations and constraints that limit the introduction of LHVs in UK with 40-60 % but still argue for annual savings of between 90-135M £ and a reduction in emissions of between 38-58 thousand tonnes per annum if the capacity in trucks is increased. Recent studies in Germany of the introduction of larger vehicles have also shown to reduce the congestion levels of 5 %. Briefly do most literature have difficulties in estimating the impacts of congestion, but a general road space can be expected to be freed up as the number of vehicles on the road is expected to be reduced with an introduction of larger vehicles (Meers et al., 2018).

3.3 Infrastructure

It is vital to consider the physical infrastructure in the development or implementation of a new transport system with HCVs as those may have an interaction with, among others, tunnels, bridges, lakes, canals and roads (e.g. road crossings, roundabouts, country roads with high accidental risks or highways with high intensity of traffic). HCVs do primarily affect roads and bridges. This section will hence focus on the vehicle's impact on roads and bridges, and other non-negligible impacts on parking spaces, roundabouts, road crossings and such are not analyzed due to the report’s limitations.

3.3.1 Roads

There are four different loading classes on the roads of Sweden that are illustrated in table 3.4. Each loading class describes the specification of a vehicle that is permitted to drive on a particular road. BK4 (Loading Class 4) was introduced in Sweden in July 2018 on approximately 11 800 kilometers, or 12 % of Sweden’s network(Swedish Transport Administration, 2019b; Swedish Transport Agency, 2019a). However, Sweden is investigating whether they can expand today's length and weight even further with BK4 and new loading classes (see for example Natanaelsson & Brandt, 2019).

Loading Class	BK1	BK2	BK3	BK4
Gross Weight (Tonnes)	64	51,4	37,5	74
Axle Load on Driving Axle	11,5	10	8	11,5
Axle Load on Non-driving Axle	10	10	8	10

Table 3.4: Loading Classes in the Road Network (Swedish Transport Administration, 2019b; Swedish Transport Agency, 2019a) .

If Sweden changed the regulation towards a decreased length and weight of trucks, it would lead to an economic loss borne by shippers and carriers in the transport sector which in turn could be passed on to their customers. In 1988, Sweden invested in increasing the road load-bearing capacity in order to adopt the standard of roads to the demands of LHVs and this was estimated at a cost of € 4,6B Euro. The Swedish society would recoup these investments after 5 years if no modal shift occurred and 12 years when transfers to rail, including rail network investment, were included. (Ericson et al., 2010)

Variables related to pavement and vehicle characteristics vary over time and space (Dodoo & Thorpe, 2005; Leduc, 2009). Types of road surface, climate conditions, axle load and configuration, suspension type, tire type and configuration, and vehicle speed are the major factors that affect road wear according to Leduc (2009). Figure 3.4 shows that the tension of a load on the road depends on many different variables, Leduc (2009) however plead the variables unequal importance and argue for the road surface properties and dynamic axle load as the most important factor. Gillespie (1993) and Atkinson, Merrill and Thom (2006) do furthermore share and confirm the view of axle load having the greatest potential to damage the roads and its fundamentality when calculating structural pavement wear from vehicles. Granlund and Lang (2016) also share this view and further argue for contact pressure under the tires to be the most crucial factor in pavement wear from freight on heavy vehicles. They explain that contact pressure under the tires is mostly affected by the wheel's configurations and axle load. Heavier vehicles are often also longer and contain more axles, which means that the load can be evenly distributed on more axles. Many studies report less pavement wear from HCVs in comparison with LHVs or HGVs, based on the principle of even distribution of axles (Aurell, Wadman & Trucks, 2007; Åkerman & Jonsson, 2007; Ogburn, Ramroth & Lovins, 2008; Koniditsiotis, Sjögren & Wandel, 2012). An example is the road freight transportation of 600 tonnes on a single vehicle combination between Horndal and Hedesunda 2011 (Granlund & Lang, 2016). The Swedish Transport Administration scanned the roads between Horndal and Hedesunda before and after the transportation to measure the wear. As the vehicle and carrying loads were extremely heavy, the speed was restricted to a lower limit. The results of the scanning on the road between Horndal and Hedesunda after the transportation did not show an abnormal pavement wear. Granlund and Lang (2016) do therefore argue that heavier vehicles, with respect to adjusted speed limits, do not have a significant effect on pavement wear. In the ETT-project there was no observation of negative impacts on either road safety or infrastructure wear which could be explained by the weight's distribution over a number of extra axles (Löfroth, Larsson, Engström, Cider, Svenson, Aurell, Johansson & Asp, 2012). DUO2 is another project that transported general cargo with the use of a double-trailer combination between the cities of Gothenburg and Malmö. The vehicle combination was 32 meters long with an allowed maximum weight of 80 tonnes (Cider & Ranäng, 2013). The two HCT projects have been conducted in parallel and the focus has been on volume and weight-limited road transport. The ETT-project has focused on weight limited transport and the DUO2-project on volume limited transport. None of the aforementioned projects had negative impacts on road wear.

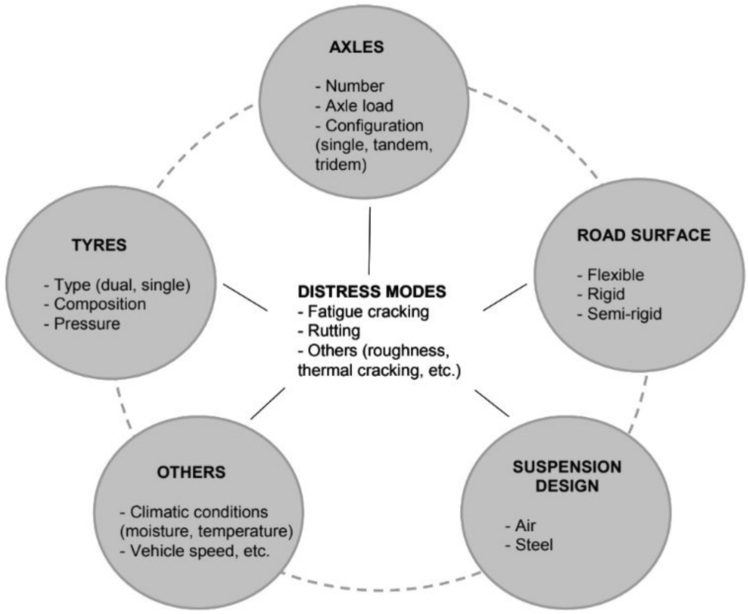


Figure 3.4: Tentative representation of driving factors affecting road wear (Leduc, 2009, p.18).

The type of traffic that tear the roads most are passenger cars with studded tires or passenger cars driving at high speed with consideration to the high number of vehicles operating on the road. Another key factor that is discussed by Granlund and Lang (2016) is the deterioration that involves much more than the actual traffic. Examples of other categories that affect the quality of the roads are the climate, age/oxidation, shortcomings in construction and maintenance. These categories do tear up on roads independent of traffic intensity. Erlingsson, Ahmed and Rahman (2018) test and compare HGV, LHV and HCV in different environments on Swedish roads through simulations in which the findings show that HCVs produce less damage per tonne of goods because of the additional axles. Pålsson et al. (2017) further analyses the HCVs effect on the carrying capacity and lifespan of the infrastructure and discuss this as a major challenge for many actors, but do argue for more loads per vehicle leading to less traffic, which means that investments in road capacity can be postponed.

3.3.2 Bridges

Bridges are, in contrast to roads, accounted by larger problems as there are more limitations on methods that can handle the issues. The main problem for HCV on bridges is the maximum gross weight traversing the bridge at the same time and the distribution of that weight. If a vehicle however is not only heavier, but also longer, the ‘aggressiveness’ on the bridge decreases. A second limitation is the fatigue of bridges as bridges have welds that are sensitive to fatigue (De Ceuster et al., 2008; Granlund & Lang, 2016).

Most bridges are designed for loads that are considerably larger than those vehicles impose today. A realization of HCTs would however mean significant differences in overloading, applied loading and dynamic effects. The bridge's ability to carry HCTs do not only depends on the axle loads and gross weight, but also on the length of the bridge span. If heavier vehicles are to access a bridge, it must be analyzed with detailed data on traffic load, traffic trend transfer functions and expected lifetime of the bridge (OECD, 2011). OECD (2011) reports that the lowest aggressiveness is found in long or very long vehicles, with a low gross weight/length ratio. This is also called for the equivalent uniformly distributed load (EUDL) and is a simple calculation used as an important parameter by the OECD to access global and semi-local load effects. It is simply calculated by the total mass divided by the total length. De Ceuster et al. (2008) have compared the effects of standard trucks and LHVs on load effects in bridge structures and show that maintaining a constant EUDL requires a total mass that is not increased by a greater proportion than its length. Other studies have shown similar results (Glaeser, Kaschner, Lerner, Roder, Weber, Wolf, & Zander, 2006; Knight et al., 2008; Vrouwenvelder, 2008), but all of these studies ignore the cumulative effects of heavy trucks side by side or a platoon of heavy trucks in one lane. Bridges with multiple lanes could therefore achieve greater effects, with respect to the bridge/span length.

3.4 Performance and Safety

Many different views and concerns can be found among researchers, politicians and the society regarding HCT safety in comparison to conventional trucks as HCVs are longer and/or heavier. Björnstig, Björnstig and Eriksson (2008) interpret the safety as one major challenge of heavy vehicles and discuss the amount of fatal accidents and the high share of these in which heavy trucks are involved. Björnstig et al. (2008) presents a decreased number of heavy vehicles as the first preventive action to reduce the number of accidents, and different separations between heavy goods- and light passenger vehicles in time and space to decrease the number of accidents.

Balint, Fagerlind, Martinsson and Holmqvist (2014) examined all accidents between 2003-2012 in Sweden in which heavy trucks have been involved. Heavy vehicles were divided into different categories. The length of the vehicle was analyzed in correlation to the accidents to see if any relationship between length of vehicle and accidercles. The longest vehicles measured (18,76 - 25,25 meters) had the lowest risk of accidents. The most common accidents during the investigated period were found to be emerging collisions from behind (25 %), single accidents (19 %) and lane change (16 %). Figure 3.5 further demonstrate the number of accidents between 2015-2018 in Sweden and the inter-relationship with heavy vehicles involved. Accidents resulting in slight injuries are not included as no data has been registered in this category (TRAFA, 2019), 1332 accidents were however represented in the slight injuries during 2001 (Flodén, 2007). The figure clearly illustrate that the most common accidents today are still related to passenger cars (see Appendix 2 for details).

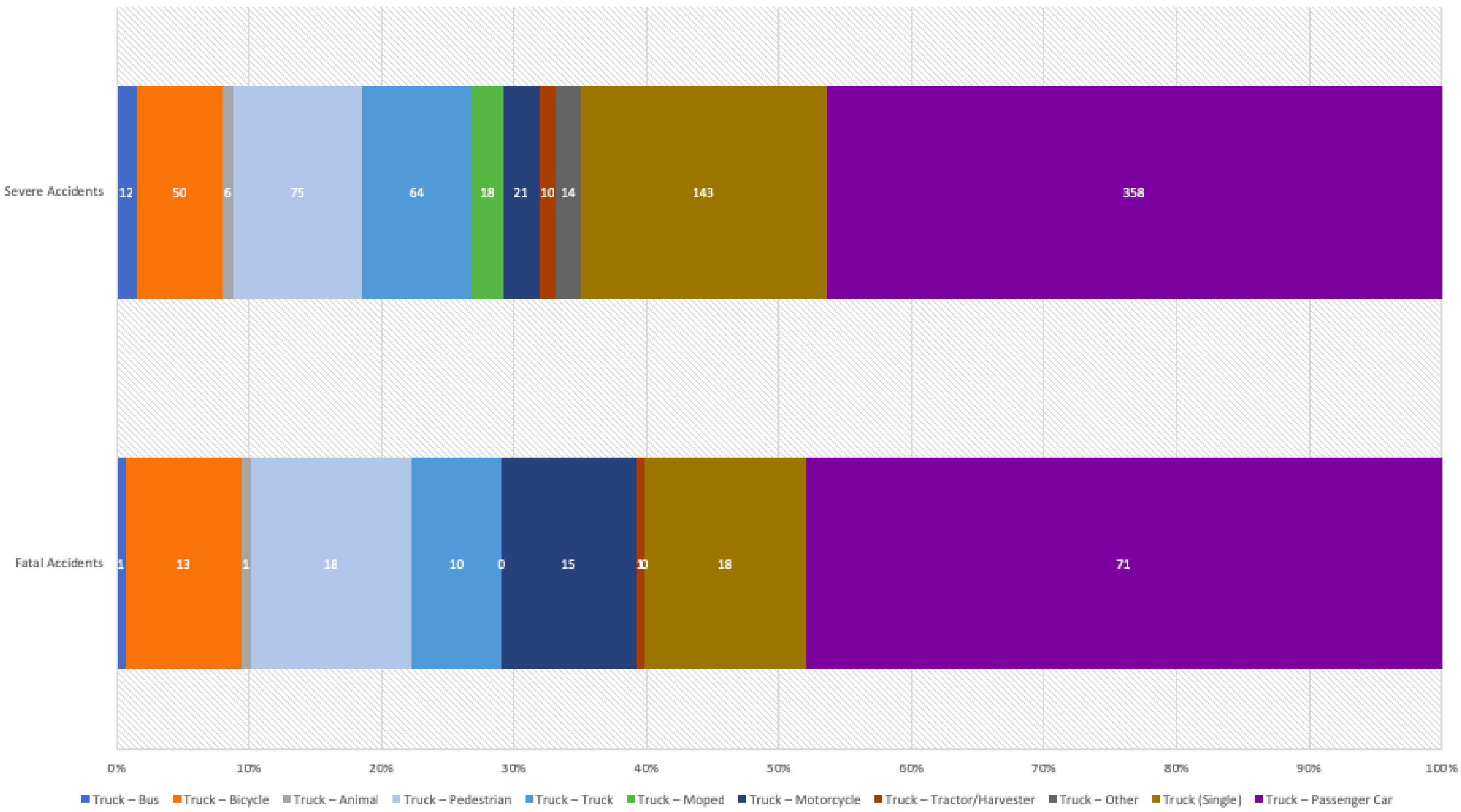


Figure 3.5: Deviation and number of accidents between 2015-18' with heavy vehicles involved (TRAFA, 2019).

Wåhlberg (2008) further presented the findings that tractor units without any carriage are more exposed to accidents. This is explained by increased carelessness in the driving behavior that is affected by the length and weight of the vehicle. Castillo-Manzano, Castro-Nuño & Fageda (2016) finds the group of medium trucks (with a load capacity of 5-15 tonnes) to be more exposed to accidents than the group of light trucks (with a load capacity under 5 tonnes). This is explained by reduced flexibility, high average speed and routes in urban cities. The group of heavy trucks (with a load capacity of over 15 tonnes) are, however, still the group with the least risk for accidents. This is explained by Castillo-Manzano et al. (2016) to depend on the roads that is used for the different categories. The group of heavy trucks do mostly run on larger and safer roads and consist of greater safety equipment. Rodrigues et al., (2015) explains additionally that the EU could save up to € 1491 million in accident costs if LHVs are introduced on European roads. Other studies that examine experienced countries in HCVs such as Canada, Finland and Australia (Montufar, Regehr, Rempel, & McGregor, 2007; Wåhlberg, 2008; Hassal, 2014) show that the largest vehicles are the group with the highest safety on the road, with considerations of serious, deadly and property injuries per 100 million kilometers. The largest vehicles in Alberta, Canada, have 58 % lower risk for accidents than standard semi-trailer combinations (Kryster-Hansen & Sjögren 2013). Similar findings are presented in a more recent study analyzing the safety of HCT traffic in Sweden and further claims that longer vehicles tend to be safer with less risk for accidents (Kulcsar, 2017), independent of any modal shift traffic safety increase due to fewer trucks in traffic (Ericson et al., 2010). There were 24 accidents in Sweden between January 2010 and July 2016 with HCVs involved. Nine of these were of 74 tonnes, 13 trucks had a weight of approximately 90 tonnes and were used for iron ore, and two accidents contained vehicles longer than 25,25 meters. According to the investigation, the added weight or length had no significant effect on the accidents (Åsman & Asp, 2018).

The apprehensions of country roads that are not separated by solid lines such as frontal collisions are the deadliest accidents. Most often it is a passenger car that drives on the opposite carriageway (see figure 3.6 for a possible scenario). A weight ratio of 10:1 does result in smaller vehicles being exposed to almost all the damage. As heavy trucks usually have a weight ratio of 10:1 in comparison to passenger cars, a collision with HGV, LHV or HCV involved is not affected by length and rarely by the weight as passenger cars practically take full damage if an accident occurs with either type. This indicates that a frontal collision with a truck of 30 tonnes is enough to create a deadly accident for a passenger car, and an increase in weight of 50 or 60 tonnes is therefore insignificant as fatalities will occur in any case. (Åsman & Asp, 2018)

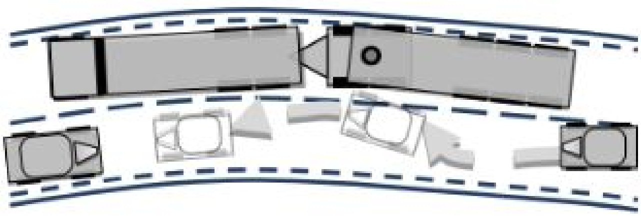


Figure 3.6: Possible scenario with overtaking crash in longitudinal traffic (Balint et al., 2014, p.32).

Many papers, studies and reports believe increased capacity gained when introducing HCVs would decrease the number of vehicles on the roads which would decrease the risks for number of accidents with heavy vehicles involved (Wåhlberg 2008; Andersson, Renner, Sandin, Fors, Strand, Hjort, Andersson Hultgren, & Almqvist, 2011; Natanaelsson, Åsman, Grudemo, & Adell, 2015; Castillo-Manzano et al., 2016). The strict requirements for permissions to use HCVs and increased carefulness when driving bigger and heavier vehicles are a possible reason behind the reduced risk for the largest vehicles (Montufar et al., 2007; Wåhlberg, 2008; Balint et al,. 2014; Hassal, 2014; Åsman & Asp, 2018). There are however also a high number of literature that reject the theory of decreasing number of HCVs on road as those argue for a decreased transport cost per tonne will alter in an increase in demand of road transport and consequently a raised number of HCVs on road. It is however important to consider the differences in, among others, geography, infrastructure, available data and network capacity in the literature (Grislis, 2010).

Kharrazi, Bruzelius, and Sandberg (2017) do nonetheless recognize six important categories that must be measured and tested in HCVs to ensure high safety and good manoeuvrability. The authors break down traction, speed tracking, speed stability and braking are in more detailed performance measurements and describe how each measurement can be tested and what standards the result should conclude. Existing regulations in Sweden are currently based on performance and with respect to environmental aspects of LHVs and HCVs.

3.5 Economic Benefits and Disadvantages

3.5.1 Internal Costs

There are a number of key aspects of road transport costing in which standing costs, running costs and overhead costs are the major categories (Rushton et al., 2014). There are further '5 Ms' that can be classified;

- Manpower: Number of drivers and salaries
- Machinery: Vehicles
- Materials: Fuel, tires and similar.
- Money: Respective cost of the resources
- Minutes: Time when resources are used for different purposes

HCVs have the possibility to decrease the number of transportations due to a higher capacity per vehicle, which would result in lowered costs. A broad effect on larger vehicles implies a lower cost per carry cargo even though the investment cost of a HCV can be up to 20 % higher compared to a LHV. (Sjöström, 2016). However, as more cargo is transported in one vehicle, the cost of salary, fuel and other costs related to the vehicle is leveled out over a larger number of cargoes. Studies of vehicles in Alberta, Canada, show cost reductions per tonne-kilometer when a HCV with a length of 26 meters or longer is used (but usually 32, 35 or 41 meters) instead of a conventional vehicle that is 23 meters. The transport costs per tonne kilometer decreased with 20-33 %, logistics costs decreased with 20-30 % and fuel consumption decreased with 25-35 %. A rough estimate of a capacity increase with 50 % can therefore be said to reduce the number of vehicles with 30 %, fuel per tonne-kilometer with 15-25 percent and transport costs with 15-20 %. (Kryster-Hansen & Sjögren, 2013)

Knight et al. (2008) compares the operating costs of eight different vehicle types and summarizes the relative costs in table 3.6. The table clearly shows that HCVs have a lower operating cost per tonne kilometer compared to all other types of vehicles. It is however important to point out that these calculations have been made on the assumptions of 100 % payload and utilization. The fill rate and utilization of LHVs and HCVs is an important factor but is in reality a challenge for many hauliers. A certain level must be filled to attain the benefits in terms of cost per tonne-kilometer in which a LHV of 25,25 m/60 t must have a payload of at least 77 % to be more beneficial than a fully loaded HGV of 40 t/18,75 m according to Christidis & Leduc (2009). Nonetheless, It is vital to obtain the volume constraints, maximum payload and empty returns to accurately calculate the operational costs. Ortega et al. (2014) investigates LHVs and HGVs in Spain and finds fuel and labor as the biggest operating costs related to the vehicles. The development of these has also been increasing rapidly. The fuel increased by 47 % and labor by 36 % between 2000 and 2010. The prices of freight transportation did at the same time increase by almost 33 % while the transportation cost for 40 tonne vehicles increased with 34 %. These figures demonstrate that efficiency and capacity gains have not grown to the same level as the increased costs in the transport sector, or more specifically heavy trucks. OECD (2011) argue for the increased price of fuel being the main reason to why transportation prices have been increasing since 2000. Ortega et al. (2014) lastly presents a reduction with 7 % of the total vehicle kilometers and 22 % of the total cost per tonnes transported if LHVs are introduced in Spain. Pålsson et al. (2017) compares the costs of current LHVs to HCVs and found a reduced cost per tonne kilometer by 14 %. Different commodity groups were compared and it was further found that some cargo groups are limited by the weight while others are limited by volume, in which grouped and mixed goods are considered to be mainly limited by volume. The HCV, with only increased weight to 74 tonnes but unchanged in length (25,25 m), is estimated to only have a net potential of 11 % in savings in total tonne-kilometers. The HCV, with both increased weight and length of 74 t/34 m, is estimated to have potential savings of 50 % in the total tonne-kilometers. The current HGV of 25,25 m /60 t have a fuel consumption of 0,43 liters per vehicle kilometer. A HCV of 34 m/74 t has a fuel consumption of 0,46 liters per vehicle kilometer. The difference might be a slight increase, but can bring large savings relative to increased capacity. It is, however, vital that fill rates and utilization are high enough to facilitate the potential for increased capacity. (McKinnon, 2005)

Vehicle Type	Gross Vehicle Weight (tonnes) and number of axles	Capital Cost	Operating cost		
			per km	per tonne-km	per pallet-km
1 (base single-deck)	44 tonnes / 6-axle	1.00	1.00	1.00	1.00
2 (base double-deck)	44 tonnes / 6-axle	1.07	1.02	1.09	0.51
3 (longer semi-trailer)	44 tonnes / 6-axle	1.10	1.01	1.05	0.82
4 (B-double)	44 tonnes / 8-axle	1.37	1.13	1.29	0.73
5 (rigid + semi-trailer)	44 tonnes / 8-axle	1.13	1.11	1.27	0.72
6 (B-double)	60 tonnes / 8-axle	1.37	1.21	0.75	0.79
7 (rigid + semi-trailer)	60 tonnes / 8-axle	1.13	1.19	0.73	0.77
8 (C-train)	82 tonnes / 11-axles	1.50	1.35	0.57	0.67

Table 3.5: Relative costs to vehicle size and loading capacity (Knight et al., 2008, p.36).

Leach and Savage (2012) compare the costs of a 44 tonne vehicle and 33 tonne vehicle and present the cost differences in table 3.7. The figures illustrate that the total cost increases (cost per km) but cost per pallet decreases if two vehicles are compared directly against each other.

	33 tonne Vehicle	44 tonne HCV	Change %
Cost per km	£0.81	£1.01	25%
Capacity (pallets)	26	40	54%
Capacity (20' containers)	2	3	50%
Cost per pallet km	£0.031	£0.025	-19%
Cost per 20' container km	£0.405	£0.337	-17%

Table 3.6: Cost Comparison 33 tonne vs. 44 tonne (Leach & Savage, 2012, p.25).

The average distribution of costs for haulers in the EU during 2008 is shown in figure 3.7 (Christidis & Leduc, 2009). This can however differ between member states, distance travelled, commodity types, vehicle models etc. However, it does provide a rough overview and breakdown of the costs. McKinnon (2007) also present a cost breakdown for EU haulers (see figure 3.8). It must be noted that the data is gathered from different periods and is considered to be impracticable due to social and technological changes, but the figures still show the distribution of costs within the road freight transportation sector.

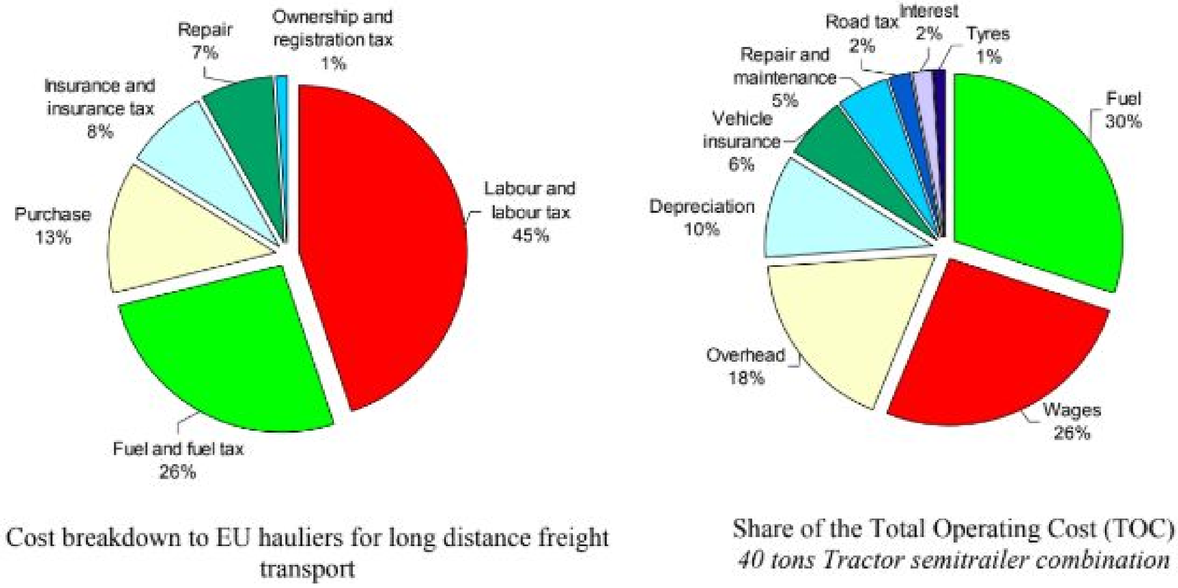


Figure 3.7: EU haulers cost breakdown in 2008 (Christidis & Leduc, 2009, p.10).

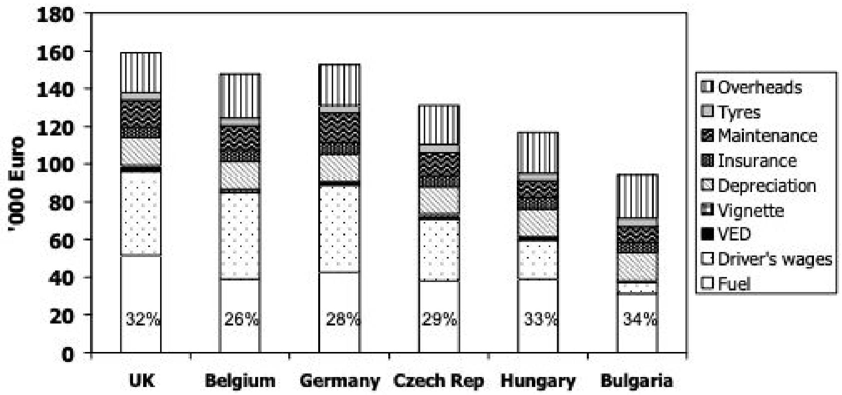


Figure 3.8: Haulers cost breakdown in six member states during 2008. (McKinnon, 2007, p.14).

Even though the majority of literature is agreed upon reduced costs per tonne kilometer and vehicle kilometers, there are some papers, reports and studies who have disagreements on how this impact the entire transportation system due to the potential risk of changes in modal split and induced transport (De Ceuster et al., 2008; Doll, Fiorello, Pastori, Reynaud, Klaus, Lückmann, Kochsiek, & Hesse, 2008; Knight et al., 2008; Vierth et al., 2008; Salet et al., 2010; McKinnon, 2012a; Pålsson et al., 2017).

3.5.2 External Costs

The activities in a transport chain can evoke negative effects such as congestion, accidents, noise, infrastructure wear and tear, air pollution, climate change and other environmental impacts (Korzhenevych, Dehnen, Broecker, Holtkamp, Meier, Gibson, Varma, & Cox, 2014). Activities in a transport chain create benefits for the shippers and carriers, but the cost of these benefits are most likely not fully borne by the transport users. External costs are defined and explained by Bickel and Friedrich (2005, p.9) as the following; "an external cost arises, when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted for, or compensated for, by the first group".

If there are no interventions from the policy makers, the external costs will not be taken into account by the transport users when they are deciding on how they will set up their transport. The users of transport are then met with misleading incentives that lead to welfare losses. The internalization of external costs means that the effects leading to welfare losses are a part of the decision-making process of the transport users. The welfare theory approach reveals that internalization of external costs with the use of market-based instruments, for example taxes, charges, emission trading etc., may lead to a more efficient use of the infrastructure, reduce negative side effects of transport activity and improve fairness between users of transport. (Korzhenevych et al., 2014)

If the total external costs of transport using LHVs are less than for using HGVs for the same transport demand, a change to use LHVs would bring social benefits. Thus, if there is a reverse modal shift from inland waterways or rail to LHVs the external costs will increase and the gains from shifting from HGVs to LHVs might be negatively impacted or neglected (Meers et al., 2018).

There has been some earlier research focused on quantifying the welfare gains that would emerge from the introduction of LHVs regarding social benefits and externalities in other countries (Ortega et al., 2014). When Sweden permitted LHVs in 1995 that were 25,25 meters in length and 60 tonnes in weight, the result was very positive in terms of social benefits and other externalities. The average consumption of fuel decreased by roughly 14 % and as a direct effect of this did the CO_2 emissions decrease substantially. If LHVs would not have been allowed, emissions of nitrogen oxides would have increased by 14 % per year (Backman & Nordström, 2002). The impact of Sweden going back to 18.75 meters and 40 tonnes LHVs would result in higher costs of transportation as both environmental and accident costs would increase (Vierth et al., 2008).

The UK increased their maximum weight for trucks in 2001 from 41 to 44 tonnes and the result after three years showed that trucks-km were increasingly saved (see figure 3.10) and it was furthermore beneficial in an economic and environmental perspective (McKinnon, 2005).

	2001	2002	2003
Reduction in annual truck-kms (million)	53	104	134
Saving in vehicle operating costs (£million) 2004 prices	44	85	110
Fuel saving (million litres) (average 0.377 litres/km or 7.5 mpg)	20.1	39.1	50.6
Reduction in emissions (tonnes)			
• Carbon dioxide	53 800	104 800	135 700
• Nitrogen oxide	351	684	884
• Particulates (PM10)	12.5	24.4	31.5

Table 3.7. Estimated savings from the increase in maximum truck weight to 44 tonnes (McKinnon, 2005, p.89).

A different study by Bereni and Jacob (2009) conducts a cost-benefit analysis regarding the implementation of LHVs in the EU. Four scenarios were studied; (1) do nothing/no changes, (2) allow standard LHVs throughout the EU, (3) allow standard LHVs only in some transportation corridors, and (4) allow trucks up to 20,75 meters in length and 44 tonnes in weight. In the first scenario the result remained unchanged but in the others the outcome was very positive. The results regarding amounts of money saved varied between roughly € 29B Euro which was the upper value in the second scenario and roughly € 1,5B Euro which was the lower value in the fourth scenario.

In a Swedish Government Official Report (2013), it is investigated how a framework for HCT should be developed, introduced, controlled and further evolved with respect to direct and indirect effects on society in the short and long term. Three potential implementation strategies were analyzed. Strategy A were implementation of HCVs on all roads currently allowed for 64 tonne in gross weight and 25,25 meters in length. Strategy B were implementation on designated roads which is around 60 % of the roads in strategy A. Strategy C were implementation on designated roads combined with a distance-based charge of 0-1,60 SEK per kilometer for all trucks. A kilometer-based charge for all road freight transport was used to promote rail and sea transport by decreasing the forces for modal shift. The cost of road transportation was recommended to be internalized at a distance-based charge of 0,55 SEK per vehicle-kilometer (Swedish Government Official Report, 2013). However, the study did also analyze the effects of higher charges: 1,00 SEK and 1,60 SEK. Two alternatives for each implementation strategy were further analyzed: heavier vehicles (74 t/25,25 m) or longer and heavier vehicles (74 t/34 m) were compared with 60 t/25,25 m vehicles. In all three implementation strategies the tonne-kilometers on road increased but the increase in the third scenario was minor on road tonne-kilometers due to the distance-based road charge. The highest distance-based charge of 1,60 SEK per kilometer will result in tonne-kilometers remaining relatively unchanged compared with the reference scenario. The charge of 1,60 SEK is positive from an environmental perspective, but does not contribute to an economic growth nor increased competitiveness of the Swedish industries. The introduction of increased weight to 74 tonnes in the two first strategies leads to a little difference in vehicle-kilometers on roads compared to the case where no HCVs are introduced. If the length is also extended to 34 meters, it is estimated that a minor reduction in vehicle-kilometers will be achieved. The results of the calculations are presented with respect to tonne-kilometers, vehicle-kilometers, CO_2 and socioeconomic effects. (Pålsson et al., 2017)

The tonne-kilometers increase with the first two implementation strategies due to induced transport and the modal shift from rail and sea. The third implementation strategy offset the road freight price decrease with the distance-based charge for all road transport and with this strategy the modal shift is negligible. With the lowest road distance-based charge of 0,55 SEK per kilometer, the effects are similar to the first two strategies and the highest road distance-based charge of 1,60 SEK will increase the road transport costs leading the modal shift from road to rail and sea. The vehicle-km decrease significantly, especially in the 74 t / 34 m formation, using any of the implementation strategies. The CO_2 emissions decrease in every scenario and implementation strategy for the 74 tonne / 34 meters vehicles (see table 3.11 and 3.12). The greatest reduction is gained if heavier and longer vehicles are allowed. Between the first two implementation strategies there is only a minor difference but the kilometer-based charge in the third implementation strategy has a significant impact.

Vehicle type	Implementation strategy A STA scenario	Implementation strategy A Climate scenario	Implementation strategy B STA scenario	Implementation strategy B Climate scenario
74 t/25.25 m	−4,655	−44	−3,820	58
74 t/34 m	−12,167	−421	−10,828	−212

Notes: Change in total CO_2 emissions (in millions kg) 2018-2058 for implementation strategies A and B in comparison to the reference scenario

Table 3.8: Change in total CO_2 emissions 2018-2058 with strategies A & B (Pålsson et al., 2017, p.616).

Vehicle type	km charge (SEK)	STA scenario	Climate scenario
74 t/25.25 m	0.55	−7,140	−230
	1.00	−10,300	−470
	1.60	−13,520	−695
74 t/34 m	0.55	−15,308	−586
	1.00	−18,135	−834
	1.60	−21,050	−1,069

Notes: Change in total CO_2 emissions (in millions kg) 2018-2058 for implementation strategy C with a km charge of SEK 0.55, SEK 1.00 and SEK 1.60 per km in comparison to the reference scenario

Table 3.9: Change in total CO_2 emissions 2018-2058 with strategy C (Pålsson et al., 2017, p.616).

The socioeconomic cost calculation illustrates the total effect of improving the efficiency of road transport, transfer of transports from sea and rail and changes in the demand for road transport. The analysis of implementation strategies A and B shows that there is more to gain for heavier and longer vehicles rather than for only heavier vehicles (see table 3.13).

Present value, SEK millions		Implementation strategy A 74 t/25.25 m	Implementation strategy A 74 t/34 m	Implementation strategy B 74 t/25.25 m	Implementation strategy B 74 t/34 m
Producer/consumer benefits	Vehicle owner or transport buyer	77,973	177,963	67,008	161,122
Budget benefits (indicates cost due to reduced tax revenues)	Diesel tax and VAT	−8,709	−30,733	−7,533	−27,881
External costs/benefits	Road wear (excl. bridges)	1,191	2,910	995	2,609
	Air pollution	107	538	87	486
	CO_2	3,152	8,382	2,552	7,426
	Accidents	1,155	3,040	943	2,701
	Time delay	311	835	251	739
Sum benefits – cost		75,180	162,935	64,303	147,202
Investment cost		13,425	13,425	10,705	10,705
NNK		4.60	11.14	5.01	12.75

Table 3.10: Socio-economic cost calculation for the STA scenario (Pålsson et al., 2017, p.617).

3.6 Alternative Modes and Risks for Transmodal Shift

There are diverse attitudes and points of view of HCT. Those who favor the use of HCVs claim it will contribute to an increased transport efficiency per tonne-kilometer with reduced operational costs for haulers as well as environmental impacts. Those who disagree claim that a potential increase in transport efficiency will be neglected because of a greater demand for transport, a modal shift to road and needed infrastructure investments (Transport and Environment, 2013).

It has been found that there is a theoretical potential of transfer between the transportation modes from road to rail in Sweden that is considerable (with a potential of a decrease with 20 % of the total transportation systems emissions). Still, the biggest efficiency potential is within each individual mode of transport. An issue in this context is that even if today's rail system is not utilized optimally, there is still a need of investments in the rail network infrastructure to make this transmodal transfer possible (Vierth et al., 2008). However, it is expensive to reduce CO_2 emissions by investing in necessary upgrades in the rail network infrastructure at a cost of almost 5 SEK per reduced kilogram of CO_2 (Flodén & Bergqvist, 2008). In a Swedish context it has been stated that the competition between rail and road transport is limited. Historically, when the maximum weight of trucks was raised from 37 to 51,4 tonnes in 1974, the rail freight transportation-work measured in tonne-km was reduced 9 % until 1978. During the same period of time the road freight's transportation-work increased with only 1 %. The conclusion from the Swedish National Road and Transport Research Institute (VTI) was that the minor increase in road transportation made it hard to prove that it did increase at the expense of the railroad. Nor did the changes in the maximum gross weight of trucks that occurred in 1990 and 1993 to 56 and 60 tonnes respectively seem to result in any transfer between the modes of road and rail (Vierth et al., 2008; Vierth et al., 2018). This is also supported by the fact that even if Sweden and Finland have unique and generous rules when it comes to LHVs and HCVs, these countries have at the same time had among the highest shares of domestic freight of goods on railway in Europe (Vierth et al., 2008; Steer et al., 2013; Berndtsson & Åsman, 2014; Rodrigues et al., 2015; Meers et al., 2018). The historical levels of tonne-km for each mode in Sweden is compiled in figure 3.10. The figure also includes the tonne-km index for road and rail which illustrates the percentage change in transport performance for each mode relative to the baseline year 1990, note that both rail and road represents index 100 on the tonne kilometer-axle during 1990 and not before (Vierth et al., 2018).

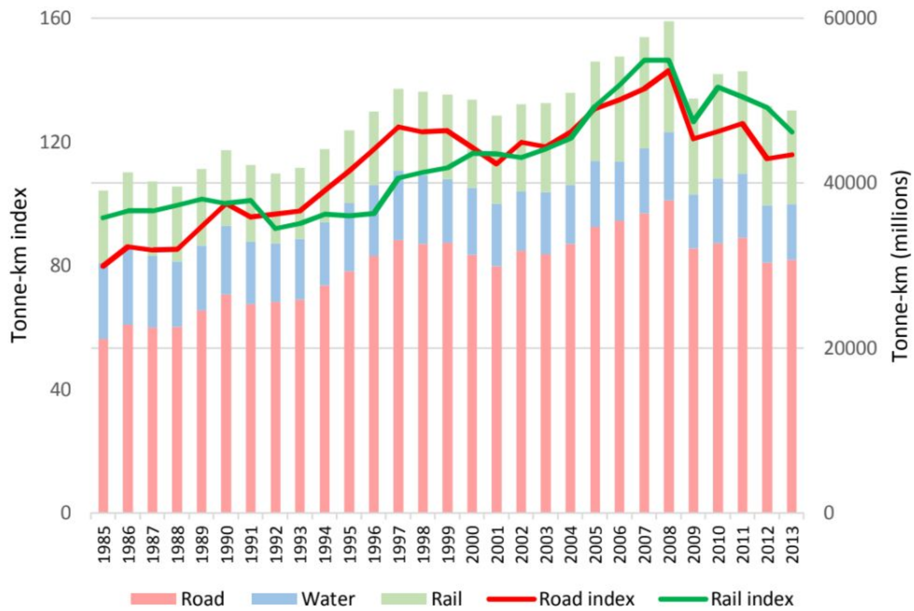


Figure 3.9: Domestic transport performance and tonne-km index (1990 = 100). (Vierth et al., 2018, p.8).

While different studies on the effect of LHVs or HCVs are warning of a considerable reverse modal shift, it is still rare to find reported evidence for a reverse modal shift in countries that have introduced larger vehicles (Meers et al., 2018; Vierth et al., 2018). Even if LCVs or HCVs conducting freight transportation were to be removed, no modal shift would occur due to the lack of spare capacity for more freight by rail (Steer et al., 2013). The Netherlands' Ministry of Infrastructure and Environment (2011), studied the modal shift to the road after larger vehicles were introduced and concluded that even if the costs for road freight transportation were reduced, no modal shift to the road could be noticed and nothing neither indicated that it would occur in the near future.

An introduction of HCVs in Sweden would affect companies conducting freight transportation in various ways. The structure of the haulage sector might be affected in the short term because of investment capabilities between small and large haulers. Also, given that HCVs increase road transportation efficiency, the road's market share could increase at the expense of rail and sea, as previous literature suggests. Nevertheless, this modal shift would not lead to a decrease in terms of freight volumes for rail and sea, there would thus be a slower increase as it is assumed that the total freight transport volumes will increase (Adell et al., 2016). The Swedish rail network is strained today and there is a high level of traffic on the rail network. The capacity of the Swedish rail network is highly utilized and many routes could be classified as overloaded (Transport Administration, 2011). Excessive capacity utilization contributes to difficulties in keeping time punctuality, both for passenger- and goods-traffic. The largest problems are found at the goods-traffic and these problems are expected to grow due to an increase in traffic in combination with limited capacity expansion, lagging operation and maintenance of an aged infrastructure. Capacity limitations need to be handled with tuning measures and re-investments in the short-term, while fundamental capacity increases are needed in the long-term (Berndtsson & Åsman, 2014). In the report TRV 2011/10161 (Transport Administration, 2011), suggestions on how to improve the condition in the Swedish rail network are mentioned, however, these suggestions are limited to actions within the rail network and do not affect cooperation between other modes of transportation. Capacity constraints are mostly concentrated around the bigger cities but are also northbound from Stockholm to Sundsvall. A reasonable conclusion is that there will only be a very limited extent of free capacity within the Swedish rail network for the next decade that can meet the increased freight demand on rail transportation (Berndtsson & Åsman, 2014). In Sweden, LHVs freight 90 % of the road tonne-kilometers but no modal shift to rail will occur even if LHVs were removed due to the lack of spare capacity for extra rail freight (Steer et al., 2013).

The competition between rail and road transportation is not always comparable as rail in some contexts is not the best available solution for freight capacity even if rail under some conditions could be efficient and competitive (Bryan, Weisbrod, & Martland, 2007). It is further argued that the cost structure of LHVs are not very suitable when conducting transport over shorter distances and there are limited possibilities to combine a 20 ft with a 40 ft container or three 20 ft containers because of the imbalances in container flows and weight restrictions (Meers et al., 2018).

Using HCVs will reduce the cost per tonne-kilometer for road transportation and this is predicted to have a rebound effect on tonne-kilometers and vehicle-kilometers due to the modal shift and induced transport (McKinnon 2012a; Steer et al., 2013). If a modal shift is to occur, it will depend on the relative cost shift between modes of transport as long as no counter-action is taken. A major effect on modal splits is predicted in some studies (De Ceuster et al., 2008; Knight et al., 2008). Others predict a less excessive effect (Salet et al. 2010). The lower operational costs for transport are hypothesised to stimulate or induce demand for transport (Pålsson et al., 2017). It is, however, argued that price elasticities for the increased demand for transport are lacking in accuracy and reliability (McKinnon, 2012a). Nevertheless, the effects of reduced transportation costs will also be an enabler for the pre- and post-haulage in an intermodal transport chain (Bergqvist & Behrends, 2011; Jourquin, Tavasszy, & Duan, 2014), as the competitiveness of intermodal transport with rail transport as base to a large extent depends on the cost of the pre- and post-haulage (Kreutzberger, Konings, & Aronson, 2006). The competitiveness of intermodal rail transport depends on the cost for transhipment and pre- and post-haulage of which accounts for 25-40 % of the total cost (Ballis & Golias, 2002; Ballis & Golias, 2004). In some cases, for an intermodal rail-road transport, the cost of pre- and post- haulage sums up for more than 70 % of the total cost over a distance of 300 km (Resor, Blaze & Morlok, 2004).

If pre- and post-haulage were to be performed by HCVs rather than the regular haulage setup there is a potential to decrease the total cost for intermodal transport for the shipper by about 5 to 10 % when the haulage accounts for about 20 % of the total cost of the transport chain. This change has the potential to create a substantial modal shift as the break-even point is relocated and intermodal rail-road transport becomes more competitive. If regulations for HCT were more generous regarding vehicle length, this may contribute to better cost efficiency for intermodal transport by addressing the problem of the last mile efficiency (Bergqvist & Behrends, 2011; Bergqvist & Monios, 2016). The use of HCVs in pre- and post-haulage creates a large potential for intermodal rail-road transport in terms of increased efficiency, reduced need for investments, lower total energy consumption, and reduced emissions (Ye, Shen & Bergqvist, 2014).

The modes of freight transport vary a lot seen to the average carbon intensity. Going from the modes with the highest intensities to the ones with lower intensities is seen as one of the most efficient ways to decarbonize logistics but the potential for each mode varies depending from country to country (McKinnon, 2016a). The European Commission strives to shift 30 % of the freight tonnage for transports going 300 km or more to rail or water by 2030 (European Commission, 2011). The European rail network's infrastructure must increase its capacity in order to handle the growth in rail tonne-kilometers together with the growth in rail passenger volumes. Expansion of the infrastructure is a relatively expensive solution for carbon mitigation and also carries a significant penalty that will arise as a direct effect of the construction and maintenance of the infrastructure (McKinnon, 2016a).

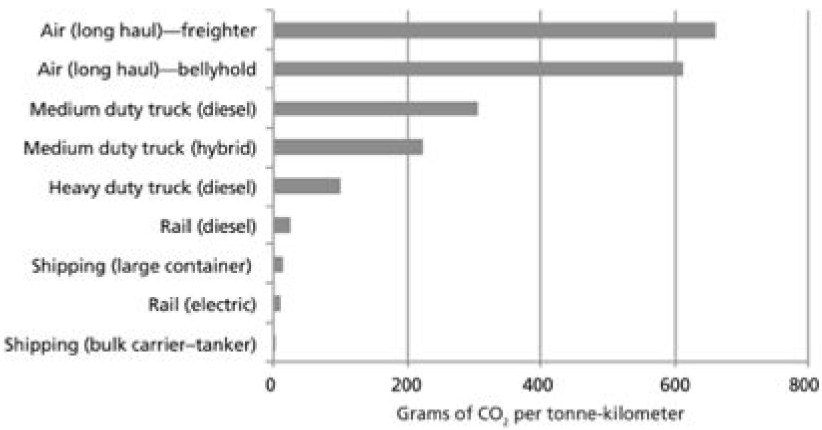


Figure 3.10: Average carbon intensity of freight transport modes (McKinnon, 2016a, p.11).

3.7 Proposed Cost Benefit Model

The proposed model calculates the relative costs from a system perspective in which the operational costs for DHL and the external costs for the society are covered in the equations and functions of the model. The operational cost calculations are derived from performed transports within the terminal network of DHL during the period 01/01-2018 to 12/10/2018. The external costs are derived from the outcome of the operational premises fuel consumption and distance between the terminals in the model, and thereafter used in combination with theoretical findings which describe the externalities in absolute numbers. To gain a transparency, a sensitivity analysis approach is applied and calculated upon as a foundation of the analysis which result in the three scenarios (see section 2.1.2).

The proposed model is built from a number of different fundamental parameters for both the LHVs and HCVs. The fundamental parameters used in the model's operational cost section are vehicle dimensions (length, width, and height), volumetric weight factor (kg), kilo per LDM, average fill-rate, utilized hours per year and average speed. The variables used in the external cost section are the amount of emissions (kg/l), the cost of emissions (cost/kg), the relative cost of emissions (cost/km), the cost of accidents (cost/km), and road wear (cost/km). The calculations and formulas used are hereafter explained in detail to provide required reliability to the developed model. Each of the calculations and formulas is performed for each relationship and day for the respective terminal in the network.

The volumetric weight is firstly converted to volume capacity. The volumetric weight between the two different terminals on a certain day was the only data that was initially gained from DHL regarding traffic intensity. The formula for volumetric weight is:

$$Volumetric\ weight = (length * width * height) * 280$$

To break out the volume from the volumetric weight, only a simple division is needed with 280 kg that is the equivalent for a cubic meter:

$$Volume\ (M^3) = \frac{Volumetric\ weight}{280}$$

As the volume in cubic meters may not be best suitable to use as it is hard to fill the vehicles capacity in terms of volume, this parameter is used mainly as a comparison to the parameter chosen to use through the calculations which is the LDM.

The volumetric weight is then converted to LDM. This is the parameter that all calculations will be based upon as this gave a more faithful picture of how the transportation of freight is planned and handled in the context of DHL Freight's line-haul operations. The average weight per loading meter during 2018 was 1300 kg. The amount of required loading meters is therefore calculated based on the value of 1300 kg:

$$Loading\ meters = \frac{Volumetric\ weight}{Kg\ per\ loading\ meter\ (1300\ kg)}$$

It is now possible to calculate the number of vehicles needed for the transport, as the required capacity to saturate the demand for freight transportation is given when the volumetric weights is recalculated to LDMs. The next step calculate the demand for vehicles needed for each relationship and day on the terminal network. This is calculated for both LHVs and HCVs.

$$LHV_N = \frac{Daily\ demand\ in\ loading\ meters}{LHV\ trailer\ length * average\ fill\ rate}$$

$$HCV_N = \frac{Daily\ demand\ in\ loading\ meters}{HCV\ trailer\ length * average\ fill\ rate}$$

The number of engines that can be reduced during a certain transportation is then calculated as a part in identifying how the environmental premises is affected by an introduction of HCT.

$$Reduced\ Engines\ per\ trip = Demand\ LHV - Demand\ HCV$$

Above calculation will result in non-absolute numbers as the demand for LHV could be 4,39 and for HCV 3,15 but as it is impossible to use 4,39 LHVs, these numbers must be rounded to the upper absolute value which in this case would be 5 LHVs and 4 HCVs. A formula applied to roundup the numbers systematically is therefore added to the model:

$$Vehicles\ needed\ in\ absloute\ numbers = Roundup\ (Demanded\ vehicles; 0)$$

The upcoming step is to calculate the costs of the capacity for both vehicle types. Costs for LHV and HCV occurring in other scientific studies and reports were chosen as a foundation for the cost structure with adjustments to the inflation. As the cost variables were found to be diverse in different academia, a minimum, maximum and average value is calculated. However, as the real costs from DHL has been obtained, these could be applied directly in the model and be compared to the theoretical findings of the LHVs cost structure. As the costs of DHL is found to be low and very similar to the theoretical minimum value, it is logical to be compared with the HCVs minimum value. The cost structure parameters is divided into fixed costs, distance-based variable costs and time-based variable costs with consideration to the key aspects that were discussed by Rushton et al., (2014). The parameters are;

- Fixed costs
    - Price of procurement
    - Life span
    - Yearly depreciation
    - Average tied up capital
    - Cost of capital
- Distance based variable costs
    - Tires (SEK/km)
    - Repair and maintenance (SEK/km)
    - Fuel consumption (L/km)
    - Fuel costs (SEK/L), and depreciation (SEK/km)

- Time based variable costs
    - Salary and payroll tax (SEK/hour)
    - Other, i.e. taxes, insurance, equipment etc. (SEK/hour)

The total cost per hour, with the aggregated fixed and variable costs, for each vehicle type are calculated as:

$$FC_h = \frac{(Yearly\ depreciation + Cost\ of\ capital)}{Utilised\ hours\ per\ year}$$

$$VC_{km} = \left((Tires + Repairs + Depreciation) + \left(Fuel_{\frac{l}{km}} * Fuel_{\frac{SEK}{l}} \right) \right)$$

$$TVC_h = Salary_{SEK/h} + Other_{SEK/h} + (VC_{km} * Average\ speed_{\frac{km}{h}})$$

$$TC_h = FC_h + TVC_{/h}$$

The total cost of a transportation, if operated by LHV or HCV, is now calculated by including the number of vehicles needed in obsolete numbers with the total cost per hour to obtain the total cost per relationship and day:

$$TC = FC_h + \left(\left(\frac{Distance}{Average\ speed_{\frac{km}{h}}} \right) * TVC_h \right)$$

The environmental calculations related to emissions are based on the data of Adell et al. (2016) and their estimates of external costs, whilst the calculations related to safety are based on the data of Flodén (2007). The parameters of emissions are presented in kg/l and cost/kg and recalculated to cost/km to be applied on each transport by simply being multiplied to the needed number of vehicles and distance. The cost of accidents is re-calculated upon the amount of accidents in 2018 with a deduction of the risk valuation cost as the reviewed literature suggests almost 50 % lower risk of accidents in HCT.

In the end, a logical test is applied through an IF-function in Excel, which checks whether a condition is met and returns a value reliant on the falseness or trueness of that condition. This function is primarily used to acquire the data of the optimal vehicle type for Scenario C. The value of HCV is returned when the value of total costs for HCV are less than for LHV, but the value of LHV are returned if this is false.

$$IF\ (logical\_test; value\_if\_true; value\_if\_false)$$

$$IF\ (TC_{HCT} < TC_{LHV}; value\_if\_true\_TC_{HCT}; value\_if\_false\_TC_{LHV})$$

4. Result

The fourth chapter presents the empirical result. The data is primarily collected from DHL and the Swedish Transport Administration. Calculations based on the proposed cost benefit model are presented and the findings are further discussed from the perspective of the different scenarios.

4.1 Cost Calculations

The costs for three different scenarios have been calculated. The first calculations are based on an average fill rate of 70 % and 100 % in both LHVs and HCVs (see table 4.1). If all data is calculated based on an average fill rate of 70 % in LHVs and HCVs, the savings in an optimal HCT introduction would have the most potential in which costs could be reduced by over 52M SEK annually with the condition that the demand for freight transport is unchanged. If the demand for freight transport were to increase accordingly to the forecasts, the potential annual cost savings would increase even further. If a 100 % theoretical fill rate is calculated upon, the potential cost reductions would however only become 28M SEK.

Average Fill Rate	Scenario A (As is / Soley LHV)	Scenario B (Soley HCT)	Scenario C (Optimal Setup)	Potential Savings
70%	1 036 704 000 kr	1 118 320 000 kr	984 266 000 kr	52 438 000 kr
100%	953 133 000 kr	1 059 885 000 kr	924 963 000 kr	28 170 000 kr

Table 4.1: The total cost based on fill rates of 70 and 100 % in Scenario A, B and C

Table 4.2 illustrates the costs if goods representing a certain percentage in a LHV, would be transferred to a HCV without any consolidation with other goods. The table do furthermore show how different levels of intensities affect the costs in the different scenarios. For example, 16,64 LDM resemble 80 % in a LHV but 61 % in a HCV. 61 % is hence the breaking point were HCV becomes more profitable to use if it is assumed that 80 % is the average loading space utilization in LHVs. A second example is the 100 % fill rate of a LHV that corresponds to an HCV with a fill rate of 76 %.If a HCV is loaded with less than a 76 % fill rate, the transportation will hence be more costly compared to a LHV that is fully loaded.

Average Fill Rate		Scenario A	Scenario B	Scenario C	Potential Savings
LHV	HCV				
70%	53%	1 036 705 000 kr	1 199 065 000 kr	1 036 705 000 kr	0 kr
80%	61%	999 395 000 kr	1 153 581 000 kr	999 395 000 kr	0 kr
90%	69%	972 857 000 kr	1 121 559 000 kr	972 857 000 kr	0 kr
100%	76%	953 133 000 kr	1 100 801 000 kr	953 133 000 kr	0 kr
100%	84%	953 133 000 kr	1 083 276 000 kr	941 352 000 kr	11 781 000 kr
100%	91%	953 133 000 kr	1 071 499 000 kr	933 138 000 kr	19 995 000 kr
100%	99%	953 133 000 kr	1 060 996 000 kr	925 748 000 kr	27 385 000 kr

Table 4.2: Examples of breaking points for optimization of HCV with respect of the fill rates.

Table 4.3 is developed as an advancement of table 4.2 to show how the cost structure is allocated seen to the number of engines saved in the different scenarios. The first example shows that if a fill rate of 100 % is used in LHVs and 84 % in the HCVs, the cost would be higher for HCVs when no engines are saved or reduced in the transportation, but the cost would be lower for HCVs in the scenarios when one or more engines is saved. In this example there are no relation in the terminal network that will save more than 2 engines in the same transport. It has been assumed, in the last example, that if no engines are saved the transports with HCVs are more expensive than to solely use LHVs and therefore has these relations been eliminated to identify the location of the potential regarding a more rational economic utilization of the HCVs.

			Cost Engines Saved = 0	Cost Engines Saved = 1	Cost Engines Saved = 2	Cost Engines Saved = 3	Total Costs	Potential Savings HCV
Fill Rate 1	LHV	100%	919 195 000 kr	33 938 000 kr	-	-	953 133 000 kr	-130 143 000 kr
	HCV	84%	1 061 232 000 kr	22 044 000 kr	-	-	1 083 276 000 kr	
Fill Rate 2	LHV	100%	894 169 000 kr	58 896 000 kr	68 000 kr	-	953 133 000 kr	-118 367 000 kr
	HCV	91%	1 032 340 000 kr	39 096 000 kr	64 000 kr	-	1 071 500 000 kr	
Fill Rate 3	LHV	100%	875 126 000 kr	77 808 000 kr	168 000 kr	30 000 kr	953 132 000 kr	-107 864 000 kr
	HCV	99%	1 010 374 000 kr	50 458 000 kr	138 000 kr	26 000 kr	1 060 996 000 kr	
Optimal	LHV	100%	-	77 808 000 kr	168 000 kr	30 000 kr	78 006 000 kr	27 384 000 kr
	HCV	99%	-	50 458 000 kr	138 000 kr	26 000 kr	50 622 000 kr	

Table 4.3: Breakdown of table 4.2.

The current average fill rate in DHL of 75 % has been used in the calculations of costs for the LHVs in Scenario A and C. A fill rate of 80 % in HCVs has been used in the calculations of the costs for HCVs in Scenario B and C. The logic and motivation to why 75 % and 80 % respectively have been chosen as a foundation have been discussed in the methodology and are further explained in the analysis. Based on this foundation, a yearly cost savings of almost 56M SEK can be achieved throughout the terminal network. The costs in the current system (Scenario A) are approximately 1 016M SEK. If HCT is introduced between all 25 terminals and all relationships, it would result in an increased cost to 1 091M SEK. However, the total costs in Scenario C were HCV are only used when profitable, the total costs would decrease with approximately 5,5 %, to 960M SEK.

Average Fill Rate		Scenario A	Scenario B	Scenario C	Potential Savings
LHV = 75%	HCV = 80%	1 016 478 000 kr	1 091 332 000 kr	960 594 000 kr	55 884 000 kr

Table 4.4. Optimal fill rate for potential savings.

Based on the period during 01/01-2018 and 12/10-2018 could costs and vehicle kilometers between several relationships be reduced by the use of HCVs. Out of 600 relationships did 102 had a potential during the total period of savings reaching minimum 1 SEK. If all relationships consider the reversed routes and are based on a total two-way communication, imbalances can be found. For example, an introduction of HCT from Helsingborg to Västberga can reduce the costs with 700 000 SEK annually, whilst the trip from Västberga to Helsingborg can reduce the costs with 400 000 SEK resulting in savings of 1,1M SEK per year if a two-way communication is considered. However, this could be compared to the relationship between Sundsvall and Luleå. The transportation from Sundsvall to Luleå can reduce the costs with 810 000 SEK, but nonetheless a a trip from Luleå to Sundsvall increase the costs by 180 000 SEK if HCVs are used instead of LHVs. Appendix 6 furthermore illustrate the balances and relationships between all terminals in the network. Relationships marked in green have a potential on both routes, whilst relationships marked in yellow do only have a potential on one-way in the routes and an imbalance do therefore exists in these relationships.

This aspect is further illustrated in table 4.7. It is clearly shown that Sundsvall should be considered as an interesting relation if HCT is introduced. However, the terminal in Sundsvall do not require any HCVs in the outbound to the other six large terminals in the network. The red relationships do not have any potential for HCT at all, independent on origin and destination. Table 4.8 further present the two alone relations with the highest potential of cost savings. Västberga-Gothenburg and Västberga-Helsingborg are the terminals that would reduce the costs most. If only one HCV are permitted to operate, it should perform on one of these routes.

		Destination							
		Gothenburg	Helsingborg	Jönköping	Malmö	Rosersberg	Sundsvall	Västberga	Total Costs
Origin	Gothenburg		2 064 000 kr	1 145 000 kr	2 183 000 kr	4 077 000 kr	3 468 000 kr	5 284 000 kr	18 221 000 kr
	Helsingborg	3 048 000 kr		1 688 000 kr	629 000 kr	5 188 000 kr	4 705 000 kr	6 916 000 kr	22 174 000 kr
	Jönköping	1 624 000 kr	1 815 000 kr		2 585 000 kr	2 481 000 kr	2 965 000 kr	2 692 000 kr	14 162 000 kr
	Malmö	2 888 000 kr	582 000 kr	1 257 000 kr		4 701 000 kr	4 618 000 kr	6 279 000 kr	20 325 000 kr
	Rosersberg	4 291 000 kr	3 288 000 kr	1 198 000 kr	3 700 000 kr		1 639 000 kr	354 000 kr	14 470 000 kr
	Sundsvall	3 077 000 kr	3 083 000 kr	2 356 000 kr	3 241 000 kr	1 254 000 kr		1 467 000 kr	14 478 000 kr
	Västberga	4 666 000 kr	3 676 000 kr	1 838 000 kr	3 856 000 kr	290 000 kr	1 498 000 kr		15 824 000 kr
									119 654 000 kr

Table 4.5 Total operational costs in Scenario A.

		Destination							
		Gothenburg	Helsingborg	Jönköping	Malmö	Rosersberg	Sundsvall	Västberga	Total Costs
Origin	Gothenburg		1 807 000 kr	1 079 000 kr	2 061 000 kr	3 855 000 kr	2 953 000 kr	4 690 000 kr	16 445 000 kr
	Helsingborg	2 695 000 kr		1 555 000 kr	588 000 kr	4 893 000 kr	4 598 000 kr	6 215 000 kr	20 544 000 kr
	Jönköping	1 438 000 kr	1 693 000 kr		2 312 000 kr	2 248 000 kr	2 810 000 kr	2 499 000 kr	13 000 000 kr
	Malmö	2 546 000 kr	532 000 kr	1 237 000 kr		4 413 000 kr	3 886 000 kr	5 651 000 kr	18 265 000 kr
	Rosersberg	3 882 000 kr	2 667 000 kr	1 345 000 kr	3 103 000 kr		1 492 000 kr	320 000 kr	12 809 000 kr
	Sundsvall	3 140 000 kr	3 457 000 kr	2 682 000 kr	3 723 000 kr	1 359 000 kr		1 546 000 kr	15 907 000 kr
	Västberga	4 112 000 kr	3 268 000 kr	1 612 000 kr	3 508 000 kr	268 000 kr	1 469 000 kr		14 237 000 kr
									111 207 000 kr

Table 4.6: Total operational costs in Scenario B.

		Destination							
		Gothenburg	Helsingborg	Jönköping	Malmö	Rosersberg	Sundsvall	Västberga	Total Costs
Origin	Gothenburg		257 000 kr	66 000 kr	122 000 kr	222 000 kr	515 000 kr	594 000 kr	1 776 000 kr
	Helsingborg	354 000 kr		133 000 kr	41 000 kr	295 000 kr	107 000 kr	701 000 kr	1 631 000 kr
	Jönköping	186 000 kr	122 000 kr		273 000 kr	234 000 kr	155 000 kr	193 000 kr	1 163 000 kr
	Malmö	342 000 kr	50 000 kr	21 000 kr		288 000 kr	732 000 kr	628 000 kr	2 061 000 kr
	Rosersberg	408 000 kr	621 000 kr	-146 000 kr	596 000 kr		147 000 kr	35 000 kr	1 661 000 kr
	Sundsvall	-63 000 kr	-374 000 kr	-326 000 kr	-483 000 kr	-105 000 kr		-79 000 kr	-1 430 000 kr
	Västberga	553 000 kr	407 000 kr	226 000 kr	348 000 kr	22 000 kr	29 000 kr		1 585 000 kr
									8 447 000 kr

Table 4.7: Cost differences when exchanging Scenario A with Scenario B.

Origin	Destination: Gothenburg	Helsingborg	Jönköping	Malmö	Rosersberg	Sundsvall	Västberga	Total Costs
Gothenburg		1 718 000 kr	987 000 kr	1 886 000 kr	3 539 000 kr	2 699 000 kr	4 514 000 kr	15 343 000 kr
Helsingborg	2 634 000 kr		1 401 000 kr	547 000 kr	4 498 000 kr	4 094 000 kr	5 974 000 kr	19 148 000 kr
Jönköping	1 392 000 kr	1 570 000 kr		2 182 000 kr	2 082 000 kr	2 519 000 kr	2 331 000 kr	12 076 000 kr
Malmö	2 447 000 kr	498 000 kr	1 101 000 kr		4 021 000 kr	3 560 000 kr	5 377 000 kr	17 004 000 kr
Rosersberg	3 641 000 kr	2 461 000 kr	1 171 000 kr	2 852 000 kr		1 346 000 kr	301 000 kr	11 772 000 kr
Sundsvall	2 775 000 kr	3 008 000 kr	2 330 000 kr	3 227 000 kr	1 192 000 kr		1 359 000 kr	13 891 000 kr
Västberga	3 923 000 kr	2 965 000 kr	1 496 000 kr	3 180 000 kr	244 000 kr	1 308 000 kr		13 116 000 kr
								102 350 000 kr

Table 4.8: Optimal cost setup in Scenario C.

The seven terminals in table 4.8 are the ones identified with the greatest potential in total cost savings with consideration to an optimal setup relative to each individual transport. To ensure that these designated relationships have a sufficient freight demand to saturate over the whole year in the use of HCVs a freight demand analysis (see Appendix 7), and an average freight demand allocated over the weekday's analysis (see Appendix 8) have been performed on each of the highlighted terminals. The freight demand analysis is reaching over the whole period investigated to see the daily fluctuations over each terminal's departing freight volumes. The average freight demand allocated over the weekday's analysis is illustrating each terminal's average freight demand allocated over Mondays, Tuesdays, Wednesdays, Thursdays and Fridays. Saturdays and Sundays are excluded due to a low workload on the weekends. A summary of appendix 8 is illustrated in figure 4.1. The summary shows that the terminals in Gothenburg and Jönköping are the ones with the highest average freight demand over the investigated period from the first of January until the 12th of October 2018.

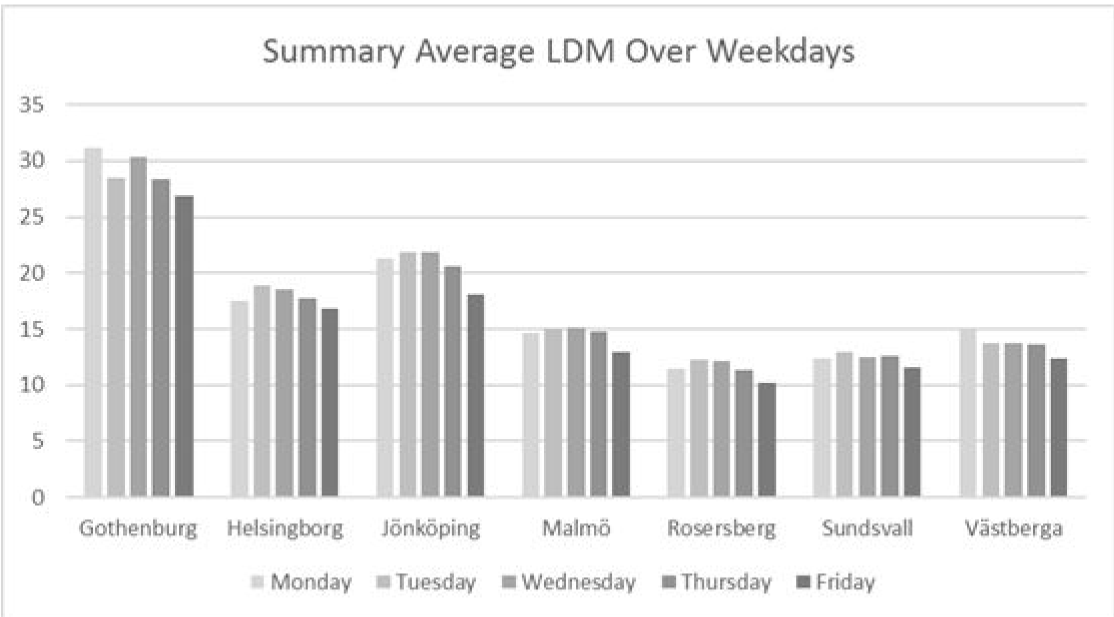


Figure 4.1: Variations during the weekdays in the highlighted terminals.

4.2 Environmental Effects

The environmental savings is presented in table 4.10. Scenario A shows the highest amount of fuel needed to saturate the demand for freight in the terminal network as this scenario require more vehicles relative to the amount of goods subject to transportation. Scenario B shows less fuel needed as there will be fewer vehicles needed to saturate the total demand for goods transportation but as the vehicles in this scenario need more fuel per vehicle kilometer the difference between Scenario A and B are relatively small. Scenario C, however, will require the lowest amount of fuel as this is the optimal allocation of the vehicle setup. The amount of emissions is directly derived from the consumption of fuel and Scenario C can consequently approximately reach almost 7 % in emissions savings.

	Scenario A (As is / Soley LHV)	Scenario B (Soley HCT)	Scenario C (Optimal Setup)
Fuel (L)	28 779 000	28 666 000	26 962 500
Co2 (kg)	73 792 220	71 367 440	68 910 600
Nox (kg)	28 160	27 230	26 300
HC (kg)	2 160	2 090	2 020
PM (kg)	325	315	304
SO2 (kg)	116	114	108

Table 4.9: Fuel used and amount of emissions released in each scenario.

The release of emissions has an external cost that society must cover. The costs are related to the fuel usage in the vehicle fleet. Table 4.11 divides the costs for greenhouse emissions, pavement wear and accident costs. The total external costs can be reduced by almost 16M SEK annually, or 8 %, in Scenario C. However, Scenario B alone is the plot with lowest external costs. Even though HCV consumes a higher amount of fuel, fewer vehicles are required in Scenario B compared to A, and with the increased length and decreased weight per axle the road pavement damage and accident cost is greatly decreased.

	Scenario A	Scenario B	Scenario C
Co2	81 909 000 kr	79 218 000 kr	76 491 000 kr
Nox	2 402 000 kr	2 323 000 kr	2 243 000 kr
HC	100 000 kr	97 000 kr	93 000 kr
PM	286 000 kr	276 000 kr	267 000 kr
SO2	6 200 kr	6 100 kr	5 800 kr
Total Cost (Emissions)	84 703 200 kr	81 920 100 kr	79 099 800 kr
Road Wear Cost	40 930 000 kr	36 873 000 kr	37 938 000 kr
Accident Cost	74 979 000 kr	51 761 000 kr	67 841 000 kr
Total External Costs	200 612 200 kr	170 554 100 kr	184 878 800 kr

Table 4.10: Summary of the external costs for each scenario.

4.3 Routes for High Capacity Vehicles Within the Terminal Network

There are 25 terminals in the terminal network of DHL (see Appendix 3). Gothenburg, Helsingborg, Rosersberg (Stockholm) and Jönköping are further connected to international shipments. Much of the goods are transported via other terminals for consolidations to enhance the vehicles fill rates. There are also terminals that are close by geographically. For example, Rosersberg and Västberga are located 40 kilometers from each other, whilst Helsingborg and Malmö are 65 km apart. Theoretically, all terminals that are within 80 kilometers (equal to one hour) apart could be grouped and goods consolidated to achieve higher volumes and fill rates resulting in higher optimization of HCT with decreased operational and external costs as a consequence. There are seven terminals of special interest to investigate for an introduction of HCT: Gothenburg, Helsingborg, Jönköping, Malmö, Rosersberg, Sundsvall and Västberga. Rosersberg and Västberga are both located in Stockholm, and Helsingborg and Malmö are located close by in the same county, Skåne. These seven terminals can hence be divided to five regions; Skåne, Stockholm, Sundsvall, Jönköping and Gothenburg.

The intensity of traffic work between these regions is illustrated on Appendix 5. A wider marking on the map presents a higher intensity on the roads. The traffic work between Skåne, Gothenburg, Stockholm and Jönköping does have the largest intensity in Sweden. An introduction of HCT on these roads must therefore be carefully analyzed as longer vehicles might affect the flow of traffic and the behaviors of passenger cars. In 2018 did the Swedish Transport Administration receive an assignment from the government to analyze if and where HCT vehicles can be permitted to increase the efficiency of the transportation and decrease its greenhouse gas emissions. Natanaelsson and Brandt (2019) presents the findings of the Swedish Transport Administration and found that HCT can operate on 9000 kilometers of road theoretically, but these are not all connected and it is therefore difficult to introduce HCT on all roads. The authors consider therefore only 4500 kilometers that should be acknowledged when granting a national permission for HCVs. Appendix 9 presents an illustration of the report in which green markings demonstrate roads that could be available for longer vehicles within a year, while blue markings demonstrate roads that could be available after a reconstruction. The roads between Skåne, Jönköping, Gothenburg, Stockholm and Sundsvall are all marked green which mean that HCVs could operate between these terminals. The map and illustrations are based on different criteria that are, among others, (1) containing a lane width of at least 3,5 meters and road with of at least 7 meters, (2) roads must be separated from pedestrians and cyclists, (3) crossings must be able to hold longer vehicles, (4) entrance and exit ramps must be at least 34,5 meters to hold one HCV without disturbing the remaining traffic, (5) lanes for overtaking's with good standards must be available, (6) accessible service areas for HCT, (7) layby's that are longer than 34,5 meters, (8) traffic signals providing the time needed for a longer vehicle to accelerate.

Large parts of road E4, E6, E16, E18, E20, E22, 23, 25, 40, 44, 56, 70, 73 and 75 are able to carry HCVs (Natanaelsson & Brandt, 2019). Some minor parts of road 23 and E22 might be able to carry HCVs in 2025. These routes that connect the seven largest terminals can hence be used when goods are transported in the network. Table 4.9 shows the most optimal roads to operate on between the different terminals based on distance, time and the analysis of roads that are able to carry HCVs.

	Gothenburg	Helsingborg	Jönköping	Malmö	Rosersberg	Sundsvall	Västberga
Gothenburg		Route E20	Route 40	Route E20	Route E4/40	Route E20/E4	Route E4/40
Helsingborg	Route E20		Route E4	Route E20	Route E4	Route E4	Route E4
Jönköping	Route 40	Route E4		Route E4	Route E4	Route E4	Route E4
Malmö	Route E20	Route E20	Route E4		Route E4	Route E4	Route E4
Rosersberg	Route E4/40	Route E4	Route E4	Route E4		Route E4	Route E4
Sundsvall	Route E20/E4	Route E4	Route E4	Route E4	Route E4		Route E4
Västberga	Route E4/40	Route E4	Route E4	Route E4	Route E4	Route E4	

Table 4.11: Routes for HCT between the different terminals.

A route between the terminals of interest often includes a third terminal of interest in between. Examples are given below:

- A vehicle between Stockholm and Gothenburg driving on route E4/40 drives past the terminal of Jönköping.
- A vehicle driving between Jönköping/Gothenburg and Malmö drives past the terminal of Helsingborg.
- A vehicle driving between Stockholm and Malmö drives past the terminal in Helsingborg.
- A vehicle driving between Gothenburg and Sundsvall could drive on E4 alone without changing to E20, to drive past Jönköping and Stockholm. This detour would however be increasing the trip with over 1 hour.

A trip between Rosersberg and Västberga would use E4. However, as this route has a high traffic intensity, it should be considered if HCVs could operate on this road during rush hour traffic with a high congestion. It is vital to understand that the report by Natanaelsson and Brandt (2019) does not consider the smaller roads between the highways and terminals. Because of this, the last miles, or kilometers, must be considered and added to the data. The analysis of roads, from and to the highlighted terminals, is focused on the strip between the terminals and highways. Due to this setup - each terminal is only mentioned in detail in the last mile to a highway network that links each terminal from and to a different terminal in table 4.9.

The upcoming descriptions are of the routes from and to the terminals from the highway and need further investigation from municipalities and the Transport Administration. All seven terminals are located in industrial areas at the outer boundaries of the cities with near accessibility to the highways. The overviewing illustrations below are extended with street views in Appendix 10 as a complement for the last mile. All junctions, roundabouts, crossings and other intersections are currently capable of carrying LHVs of 25,25 meters. These must, however, be examined to ensure capabilities of carrying HCVs of 34,5 meters and some bridges must be examined to ensure a capability of carrying HCVs with extended gross weight of 10 tonnes. The terminals of Jönköping and Västberga have a large number of interactions, with the latter also having an intensive traffic in closeby roads, these two are therefore specifically considered to be in a high risk zone of being inadequate for HCT.

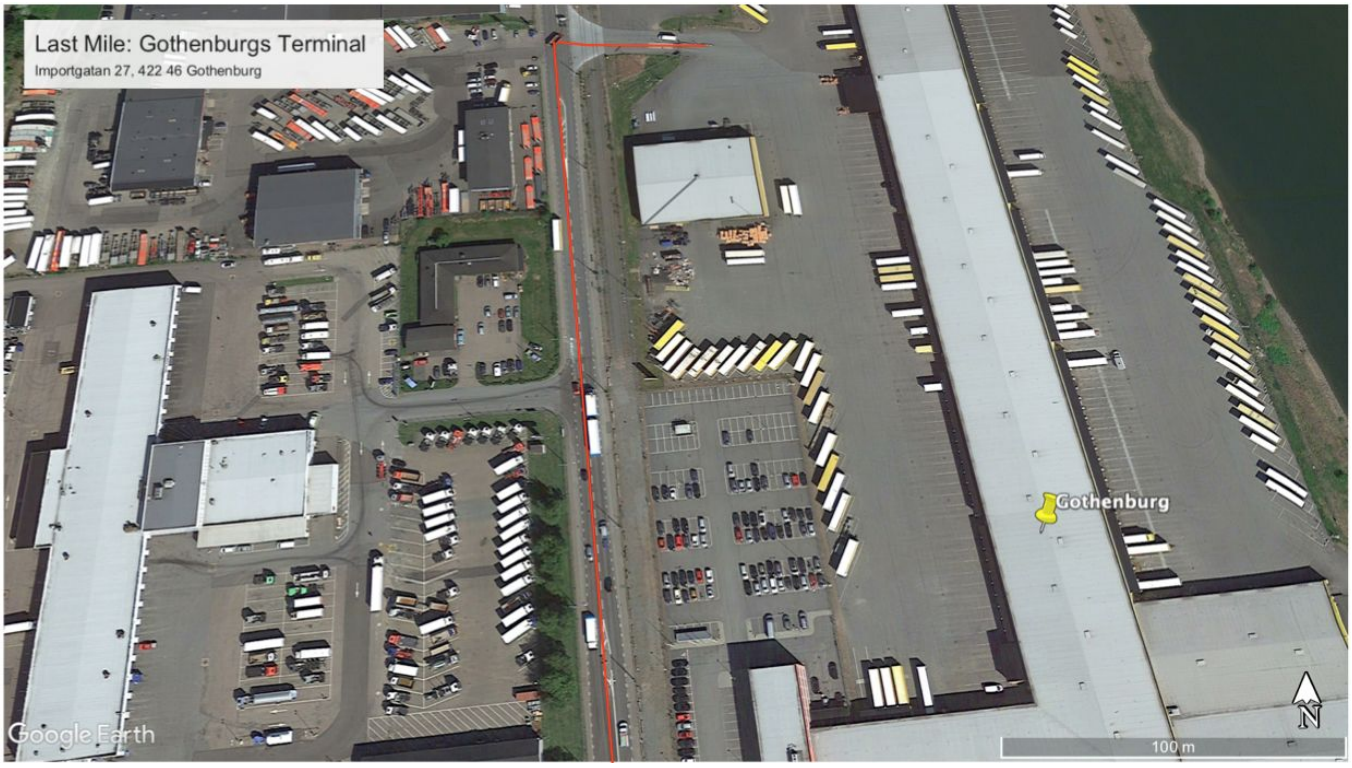


Figure 4.2: Route from and to the terminal of Gothenburg (continued in figure 4.3)

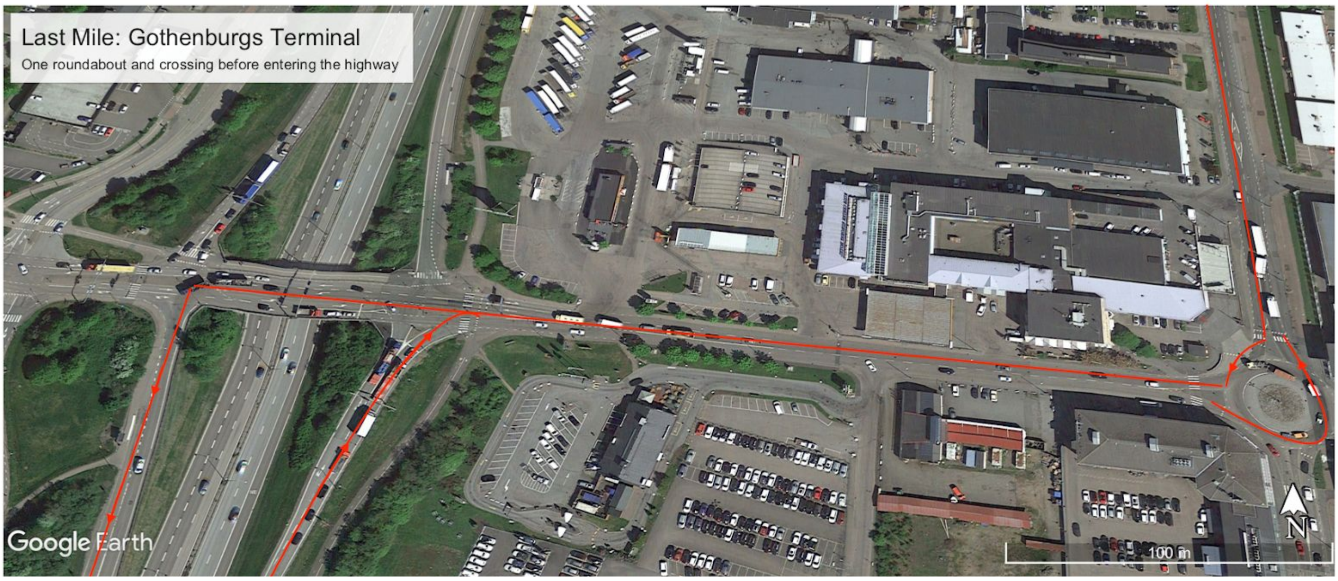


Figure 4.3: Cont. route from and to the terminal of Gothenburg.

Figure 4.4: The route between Helsingborg and the other terminals (the dashed highway is southward direction).

Figure 4.5: Routes to and from the terminal of Malmö.

Figure 4.6: Route to and from the terminal of Jönköping.

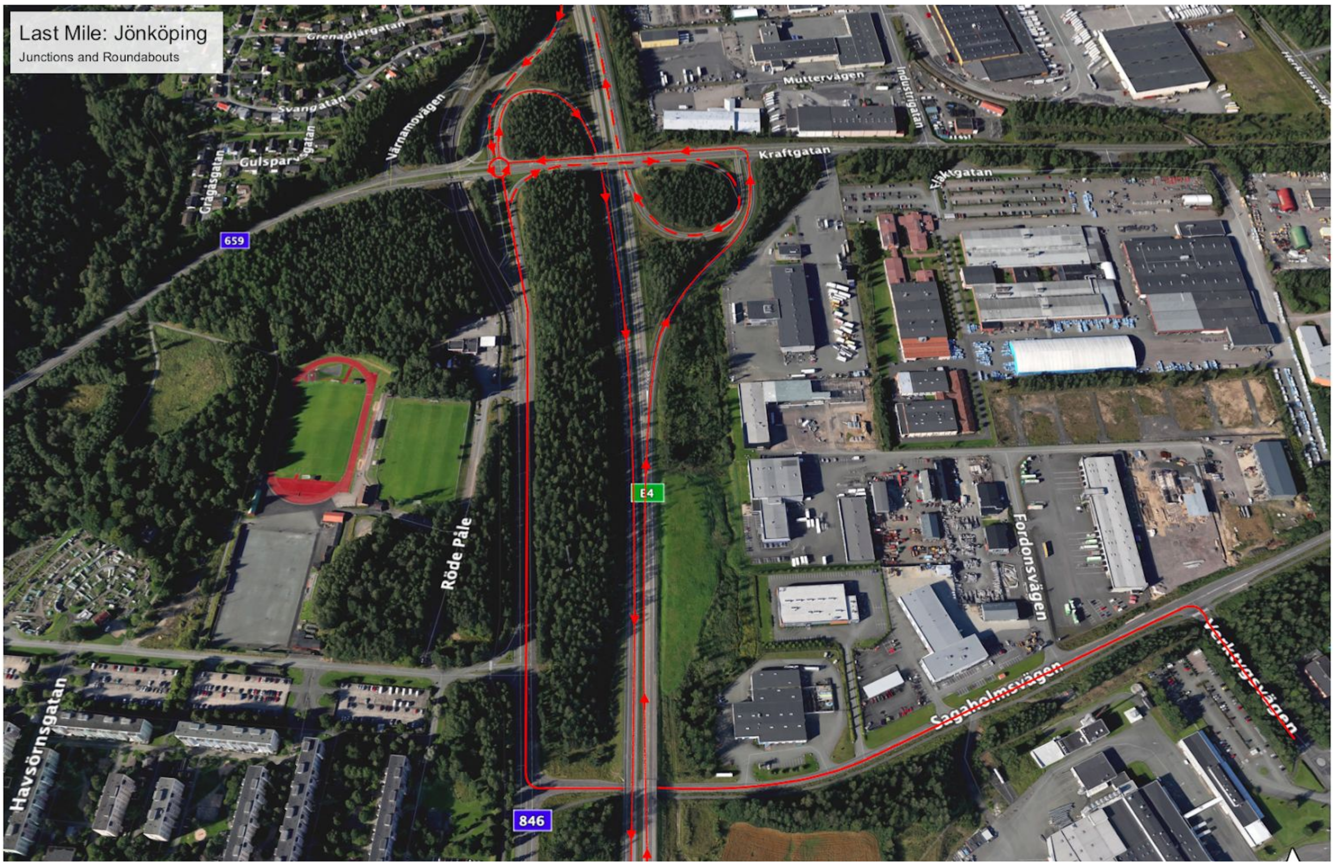


Figure 4.7: Highways to the northward (dashed line to Stockholm or Sundsvall) and southward (filled line to Gothenburg or Malmö) directions.

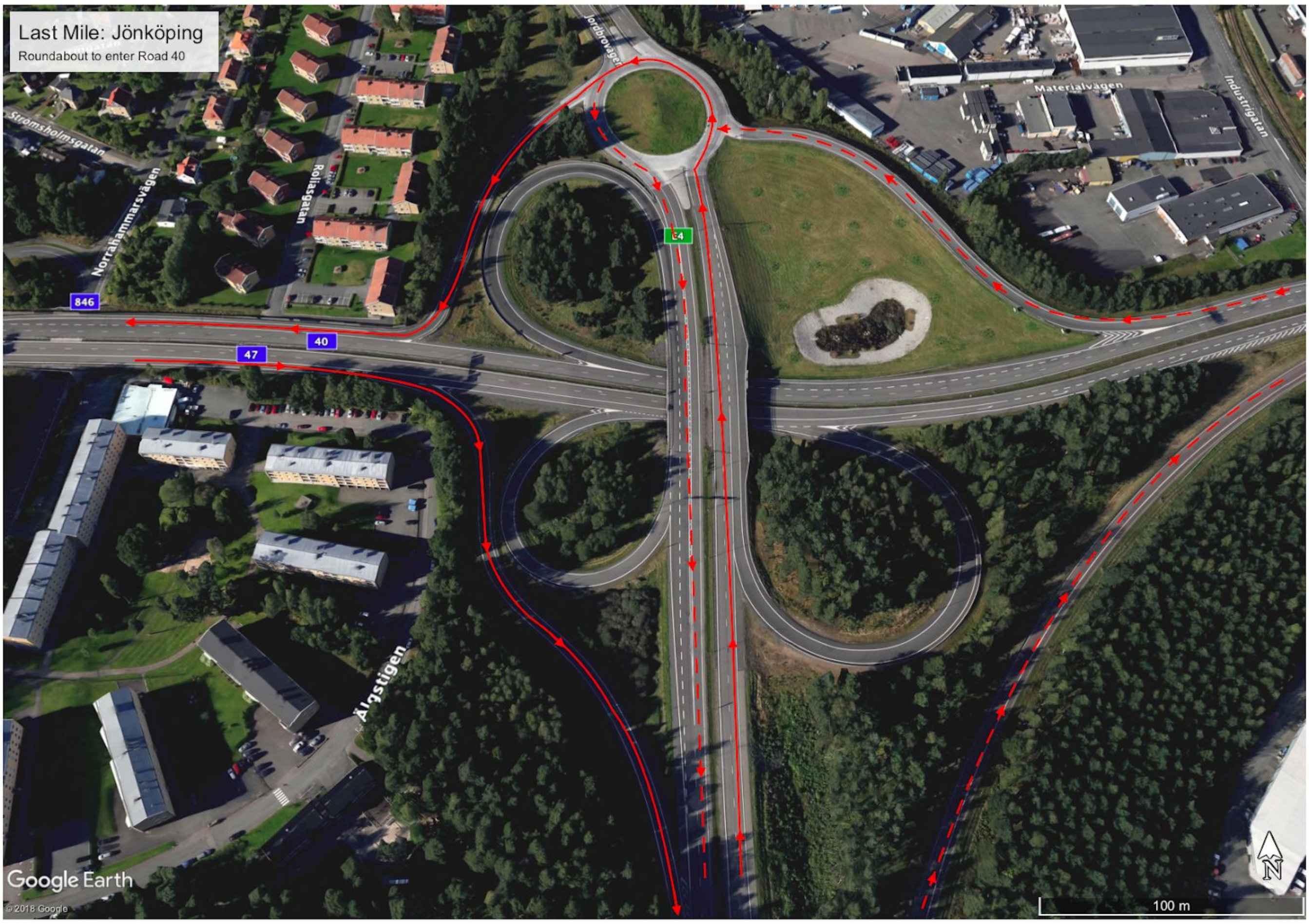


Figure 4.8: Cont. Highways to the northward (dashed line to Stockholm or Sundsvall) and southward (filled line to Gothenburg or Malmö) directions.

Figure 4.9: Route to and from Sundsvall.

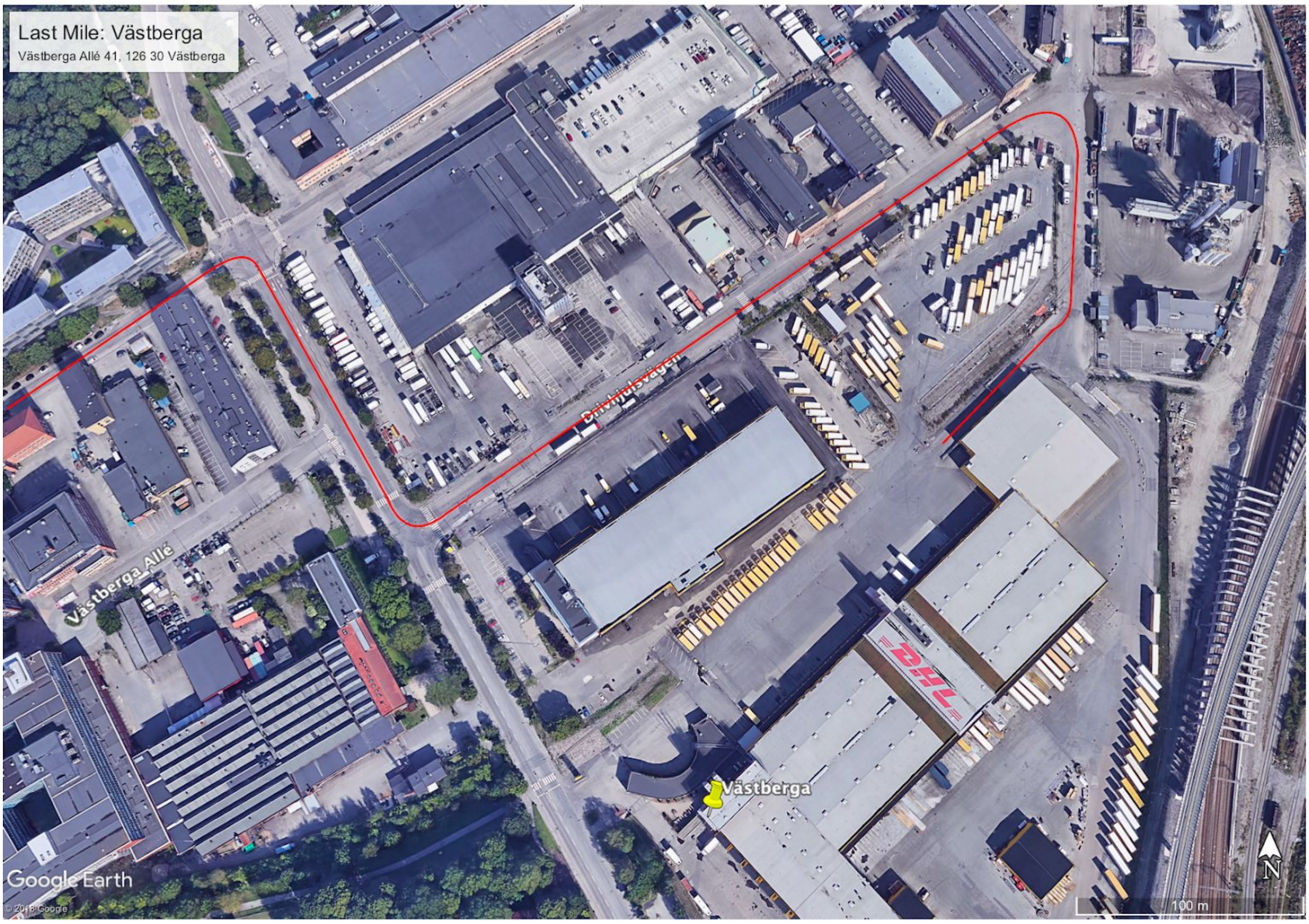


Figure 4.10: Route to the southward direction.

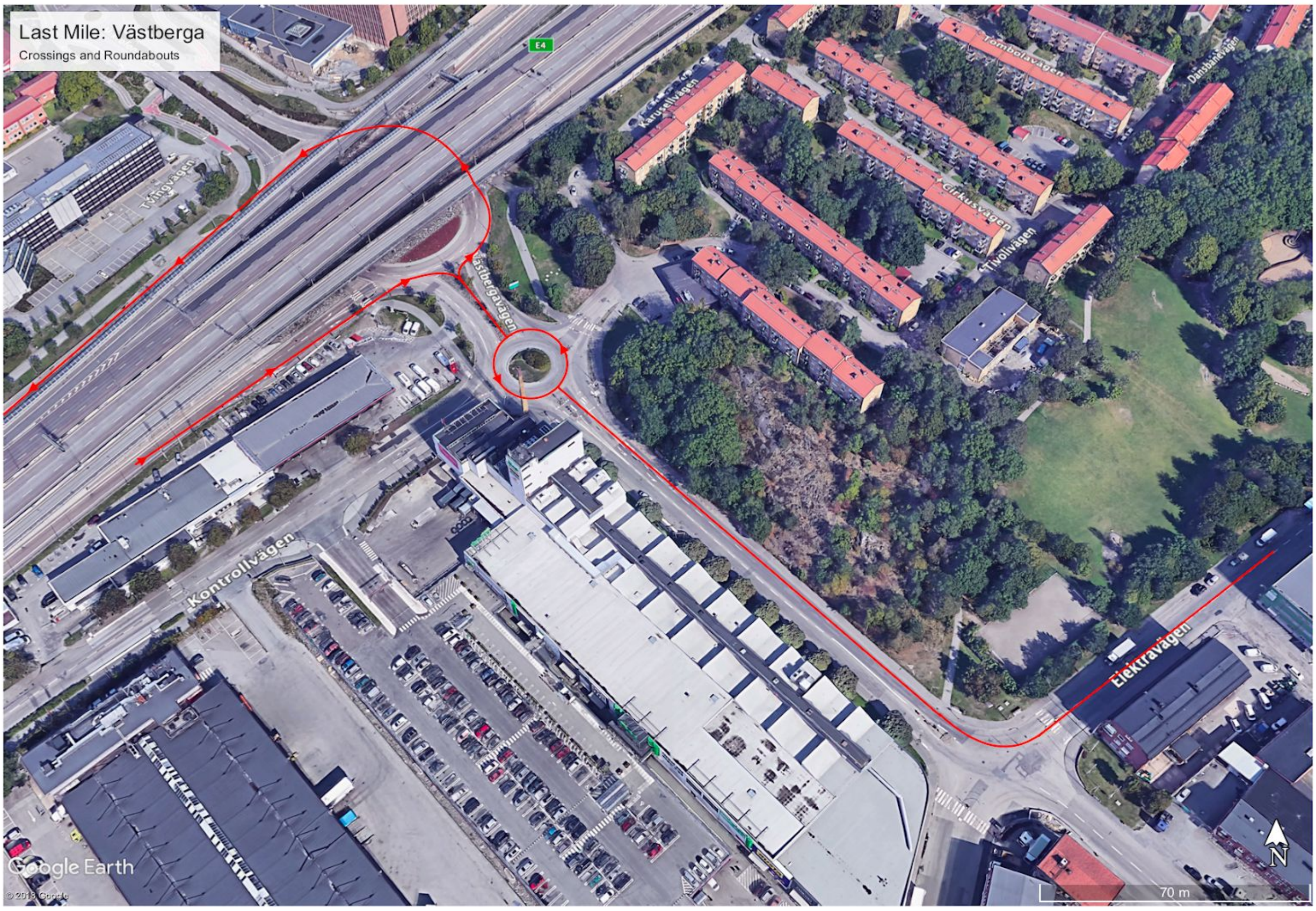


Figure 4.11: Route to the southern terminals (Gothenburg, Helsingborg, Jönköping and Malmö).

Figure 4.12: Route to a northward direction avoiding junctions, crossings and roundabouts.

Figure 4.13: Routes to both southward and northward directions.

4.4 Performance

The Swedish Transport Agency does issue permits for pilot activities of HCT only if there is a new technology and/or construction that is to be tested. It is therefore vital that the application of a permit includes an innovative technological solution that is new or developed. Another vital score in the application is to not create any risks in the aspect of safety. The vehicle must, for example, have at least the same braking and acceleration performance as current LHVs, a marking clearly stating “Extra Long Vehicle”, and the carriage units can be coupled to achieve a total length of 34,5 meters (Natanaelsson & Brandt, 2019). The tractor unit must however be able to turn in a circle of an outer radius of 12,5 meters and an inner radius of 5,3 meters while the coupled combination must be able to turn with an outer radius of 12,5 meters and inner radius of 2 meters (Swedish Transport Agency, 2019a). As the carriage unit is coupled with the tractor through a link, more links can allow a better turning radius, this however also increases the difficulties in reversing. A link is a semi-trailer but equipped with a ‘fifth wheel’ coupling that connects the towing truck with the carriage units. The drivers usually drive deep past the lane they attempt to turn into before making a late turn. The vehicles need this extra distance due to their length to not cut off the front of a passenger vehicle in the opposite lane. To drive in reverse is however difficult with multiple links and fifth wheels and the drivers are usually required to “straighten up” the vehicle by driving a few extra meters before putting in reverse. If the fifth wheel has a longer distance to the tractor, the slower the rear will turn as the trailer responds more slowly to the steering input. Nonetheless, once the trailer does start to turn, it will turn very quickly, hence the difficulties in the reversed driving. There is also other coupling equipment that is different. A drawbar is, for example, a coupling that is not to be confused with a fifth wheel. A fifth wheel is in contrast to a drawbar designed to transmit a major proportion of the load’s weight to the hauling vehicle (Jeschke, Isenhardt, Hees, & Henning, 2016; Treiber & Bark, 2016).

A fully loaded HCV with 44 tonnes has a higher fuel consumption than a fully loaded LHV with 44 tonnes that operates under the exact same conditions. This is a consequence of the additional aerodynamic drag and rolling resistance caused by the extra axles (Leach & Savage, 2012). Many HCV variants also have an additional point of discontinuity, i.e. the gap between the trailers and vehicle body, which adds friction zones and air recirculation (Leduc, 2009). The additional air recirculation, friction zones and increased number of axles all contribute to an increased aerodynamic drag. The size of the aerodynamic drag is further dependent on the vehicle shape and square of the speed. A decreased speed decreases the drag and the use of energy as a result. It is, however, not likely that lower speed limits are to be introduced. As a general rule speeds above 55 km/h cause the aerodynamic to become a dominant force opposing the vehicle motion (King, 2012), and 40 % of the fuel consumption is used to overcome the drag and 45 % to overcome the rolling resistance when driving at a constant speed. The design of the vehicle can hence reduce the aerodynamic losses, as an example from the UK where the best-selling truck reduced its drag coefficient with 10 % resulting in a decreased energy use per kilometer by 4 % (McCulloch, Bishop & Doucette, 2012). Villalobos and Wilmsmeier (2016) and further argue for a potential of a decrease in the drug coefficient with 25 % is possible, whilst Ang-Olson and Schroeer (2002) also encourage improved design on both trailers and tractors by arguing for almost 8 % in reduced fuel savings as a potential consequence. However, the extent to reduce the drag is constrained by economic, functional and aesthetic preferences (McCulloch et al., 2012).

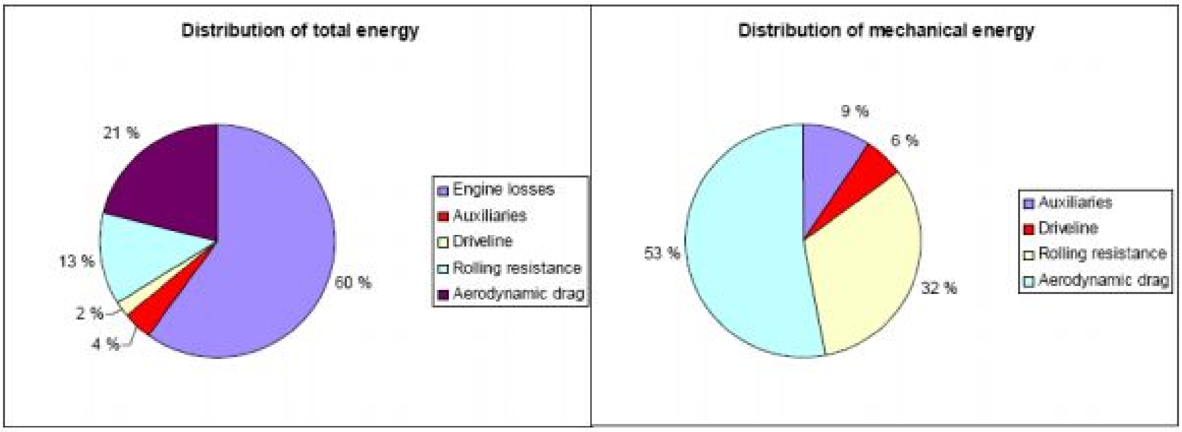
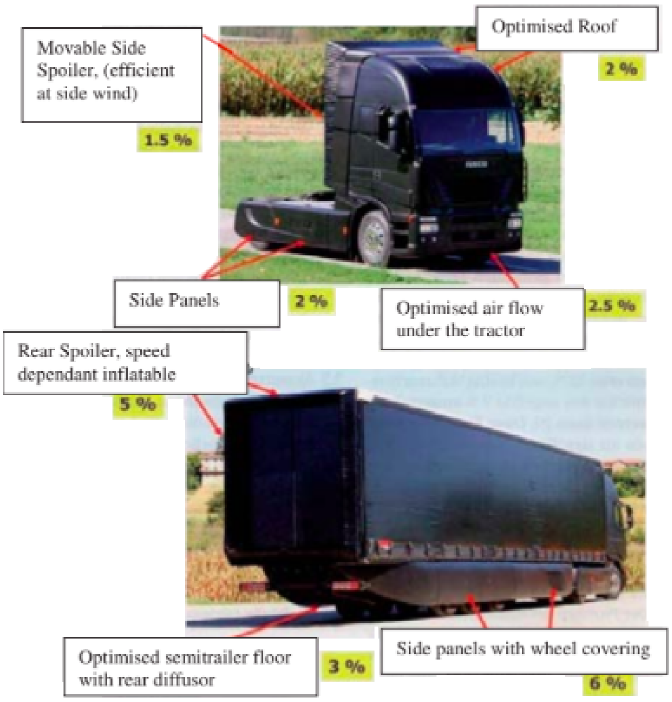


Figure 4.14: Example of relative distribution of energy for a semi-trailer combination with an average speed of 104 km/h (Leduc, 2009).



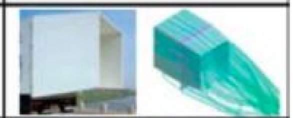
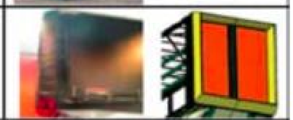
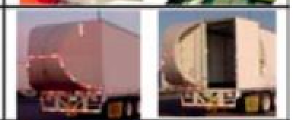
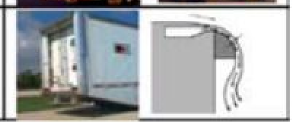
Device	approx. additional dimension required	best suiting trailer type	approximate CO2 reduction long haul	Image / working principle
Open cavity tails	1.0 - 1.5 m	box, curtain, refridgerated box (reefer)	6%	
Inset open cavity tails	0.6 m - 0.8m	box, curtain, refridgerated box (reefer)	5-8%	
Inflatable open cavity tails	0.4 - 0.6 m	box, curtain, refridgerated box (reefer)	3-4%	
Inflatable closed cavity tails	1.0 - 1.5 m	box, curtain, refridgerated box (reefer), chassis	5%	
Active Flow Control / Difusors	0.3 m	box, curtain, refridgerated box (reefer)	7%	

Figure 4.15: How aerodynamic design and optimisation can decrease the drag coefficient (OECD, 2011).

Vehicle control technologies may also be a solution that can be tested during the pilot activity. Vehicle control technologies such as intelligent access control (Intelligent Tillträdes-Kontroll in Swedish) has been discussed and tested on HCVs in Sweden (Asp, Wandel & Rydén 2018). IAC is a management system installed in the vehicles for authorities to audit if violations are suspected. The authorities have through the IAC system access to, among other things, routes, weight, vehicle configurations, load type, engine and fuel type. This also provides a more accurate data for authorities related to matching traffic, roads and vehicles and can hence provide better utilization of the existing infrastructure, decreased amount of accidents and congestion and more accurate investments in capacity expansions (Kryster-Hansen & Sjögren, 2013; Asp et al., 2018). Other control technologies that might be tested include curve speed warning systems or an intelligent speed adaptation system (OECD, 2011).

There are also other technologies that can be tested such as rear cameras on the trailers, automated coupling, active steering or technologies that research further into the effects of HCT on the road. The rear cameras can be tested to investigate upon the number of accidents can be decreased and driving time when reversing can be decreased by using rear cameras. As coupling is a large part of the handling in the terminals, automated coupling might also save time in the operations and can hence be tested. Active steering is a different technological and constructional solution that can be tested to investigate the possibility of active steering on longer vehicles. Lastly, the effects of HCVs on road can be investigated in cooperation with the Swedish Transport Administration.

5. Analysis

The result is pursued with a comprehensive discussion and are both motivated and criticized from different aspects and perspectives. The analysis does further lift the results to a general level and discuss the results and HCV's significance in DHL's system and terminal network in relation to the theoretical framework.

5.1 Cost Benefit Analysis

In an initial stage the effects for each of the three scenarios were calculated. The costs of Scenario A, for example, only represent conventional vehicles (LHVs) performing within the terminal network. The costs of Scenario B illustrate a situation in which HCVs are introduced and used alone (i.e. no LHVs operating) within the terminal network. The calculations of Scenario C represent the optimal setup of vehicles based on every singular transportation between two terminals. The optimal setup was based on the required LDMs and not the weight nor volume of the goods. The main reason for the choice of LDMs as a variable is because of the type of goods, that are mostly bulk goods that cannot be stacked, and the loading meters become therefore the limit in the capacity. The number of LHVs and HCVs are determined based on the required capacity and the vehicles with the lowest total operational cost becomes the optimal option.

The developed model in this report is simple but yet accurate. A user can easily add supplementary variables or equations to calculate additional costs and benefits. The model does however require a large amount of data with high quality in the sense of validity, consistency, timeliness and accuracy. If the amount of data is inadequate, the result may become unjustifiable. It is therefore vital to remember that the data gathered is only from the period of 01/01-2018 – 12/10-2018 and thus missing the months of December, November and partly October- months that usually have large traffic during periods such as Christmas, Black Friday and the End-Year Sales which can affect the numbers and calculations. The model is consequently just as good as its empirical data. The result of the model does however provide an understanding of the potential of high capacity transport, and the result is underestimated due to the missing data that do cover large volumes of goods and therefore an even larger demand for HCVs.

The first calculations were based on an average fill rate of 70 % respectively 100 % in both types of vehicle. In the case of an average fill rate of 70 %, Scenario C showed the largest potential savings per year resulting in roughly 52 439 000 SEK. In the case of an average fill rate of 100 %, Scenario C showed the largest potential savings once again, however this time the savings per year resulted in roughly 28 169 000 SEK. The difference between the two outcomes could be explained as due to the fact that HCVs are more expensive to run than a conventional vehicle per vehicle-kilometer and many of the relations within the terminal network don't have a need of excess capacity to perform the transports. Furthermore, a conventional vehicle that is cheaper to run is assumed to also be more profitable than a HCV. This explains why Scenario A is more profitable through lower costs than Scenario B in both of the calculated average fill rates. However, the conventional vehicles in Scenario C are only used when they are more suitable and profitable to perform the transportation. As an example, if one HCV is used were the demand for freight exceed one LHV and thus would need two

LHVs to perform the transportation, there is a more profitable solution to use only one HCV for the same amount of goods. Scenario C is therefore to be explained as an optimal choice of vehicle type per transportation, leading to the lowest cost possible based on the required capacity to please the demand for freight.

When the calculations for the initial stage was completed, a comparison was made between the different scenarios to see how the total cost was allocated if it was assumed that the amount of goods subject for transportation in a conventional vehicle were directly transferred to a HCV instead. Firstly, an average fill rate of 70 % were used in the conventional vehicles of which is equal to an average fill rate of 53 % in a HCV. The costs for each scenario was calculated according to this average fill rate setup between the both vehicles and in Scenario A did the total cost result in roughly 1 036M SEK, in Scenario B did the total cost result in roughly 1 199M SEK, and in Scenario C did the total cost result in the same cost as in Scenario A. Thus, no cost savings was found in the terminal network if this setup would be chosen. This is because the two vehicles are carrying the same amount of goods, and the same number of vehicles are needed to transport the same amount of goods. As conventional vehicles are less costly to run per vehicle kilometer, these vehicles will be the most profitable compared with the HCVs.

The same calculations were made on different average fill rates for both vehicles, i.e. 80 % in a conventional vehicle which is equal to 61 % of a HCV, 90 % in conventional vehicles which is equal to 69 % of a HCV, and 100 % of a conventional vehicle which is equal to 76 % of a HCV. All these comparisons present the same total cost in Scenario A and Scenario C. The conclusion shows that as long as the HCVs have an average fill rate that corresponds to the capacity of less than a conventional vehicle, the conventional vehicle will always be more profitable and this also support the earlier findings with respect of the same average fill rate used in both vehicles. If a theoretical fill rate of 100 % in the conventional vehicles is assumed, this corresponds to a fill rate of 76 % in a HCV. Accordingly, the HCVs should be starting to become more profitable once transporting an amount of goods exceeding the capacity of a conventional vehicle. This could sound quite logical, but in order to validate this logic there were additional average fill rate comparisons between the two vehicles. The average fill rate of conventional vehicles is still 100 % as it is not possible to fill the vehicles with more goods. However, the compared average fill rates of a HCV were 84 %, 91 %, and 99 %. Yet again, when 100 % of a conventional vehicle and 76 % of a HCV were used, it was still less costly to operate with a conventional vehicle, but when 100 % of a conventional vehicle and 84 % of a HCV is compared to Scenario A and C do not present an equal result any more. Scenario C is now less expensive and is therefore supporting a yearly cost saving of roughly 11 780 000 SEK. This does in an easy sense show that a HCV must be filled more than 76 % in order to start becoming profitable compared with the use of a 100 % filled conventional vehicle, and support the findings of Christidis and Leduc (2009), which argue for a payload of at least 77 %.

There should also be given some attention to the potential savings in relation to the added fill rate of the HCV. In the first comparison there is a leap from 76 % to 84 % fill rate in the HCV and this resulted in a potential saving of over 11M SEK. In the second comparison there is a relatively equal leap from 84 % to 91 % fill rate in the HCV and this did result in potential savings of over 19M SEK. In the third and last comparison there is once again a relatively equal leap from 91 % to 99 % fill rate in the HCV and this resulted in potential savings of roughly 27M SEK. If there would be the same relative linear increase between fill rate and potential savings this should in the second comparison be equal to potential savings in the first comparison times two (11 780 000 x 2 = 23 560 000) as the fill rate is increased with the same amount. The same conditions seen from this perspective should also be applied in the third comparison (11 780 000 x 3 = 35 340 000). The reason for the non-linear relationship between the variables of fill rate and potential savings is because each relation of transport between all of the terminals in the network have been handled and calculated separately, and as the gap between the overlapping intervals regarding the actual demand of vehicles needed to perform the transportation is larger when going from a fill rate of 76 % to a fill rate of 84 %, the reduced amount of engines or vehicles during the period is larger in this interval, whilst some smaller in the second and further less in the third comparison. A cost structure breakdown was made to validate these findings (see table 4.3).

As there was a proposition that the non-linear relationship between average fill rate and potential cost savings was dependent on the gaps in total reduced engines between conventional vehicles and HCVs, the cost breakdown was divided over different fill rates linked to total cost per engine. There were four different fill rates analyzed for the LHV and HCV and the LHV had a 100 % fill rate in all comparisons while the HCV in the first comparison had a fill rate of 84 %, in the second 91 %, in the third and fourth 99 %. In the fourth comparison however, there was an assumption made regarding all relations in the terminal network not including any reduced engines or when the demand for freight could be met by an LHV there would be no potential cost savings, therefore were these relations eliminated from the data. This is to see the potential savings in which HCVs have a clear advantage over LHVs in terms of increased efficiency in freight of goods. The cost structure breakdown table (table 4.3) illustrates and concludes the findings that earlier were believed to be the reason for the non-linear relationship between an average fill rate and potential savings made.

DHL has an average fill rate of 75 % in their transportation of goods seen to LDM in today's terminal network performed by LHVs. This fill rate has therefore been used when calculating the total cost in Scenario A and in Scenario C were LHVs is most efficient from a cost and capacity perspective. The fill rate of 75 % in LDMs in an LHV is equal to 15,6 (20,8 x 0,75 = 15,6), thus there are 5,2 LDMs still available (20,8 – 15,6 = 5,2). If examining at what fill rate a HCV would have if available space is equal to 5,2 LDMs instead, this would be roughly 80 % ((27,3 – 5,2) / 27,3 = 0,809). This was used as a foundation to the calculations going forward based on Kohn's (2005) argument in which he stated that 3PLs cannot have an average fill rate of 100 % or even close to it in practice, as haulers must be able to ensure flexibility and secure available extra capacity in order to handle fluctuations in demand and variations during the season. Therefore, a fill rate of 80 % is used when calculating the total cost in Scenario B and in Scenario C for HCVs. The total cost in Scenario A would approximately become 1 016M SEK, in Scenario B 1 091M SEK, and in Scenario C 960M SEK. Hence, the potential cost reductions with this logic would result in almost 56M SEK per year. This is a decrease in the total operational costs over the whole terminal network of 5,5 %.

Based on LDM, a high capacity vehicle of 34,5 meters increases the capacity with 31 %. Kryster-Hansen and Sjögren (2013) roughly estimated a capacity increase with 50 % to reduce transport costs by 15 - 20 %. This is not true based on the calculations of this report as the calculated costs are reduced with only 5,5 % by an increase in the capacity of 31 %. Kryster-Hansen and Sjögren did however not base or limit their calculations to the loading meters, which is a possible reason for the differences between the findings.

Some variables in the cost calculations are underestimated while others are considered to be overestimated. For example, in rough numbers are 80 % of the freight transportations outsourced to external haulers, whilst 20 % are DHL's organic haulers. Fixed and variable costs can therefore differ depending on the hauling company used in DHL's operations for a certain transport. The costs used as a basis in the cost calculations are derived from DHL's owned haulage. The calculations are based on the costs of LHVs in comparison to the costs of HCVs. HGVs and smaller vehicles are however used as a standard vehicle between certain relationships, and also additionally between relationships if excess capacity is needed. If a transportation is of 5 LDMs, the calculations are currently based on the costs of a LHV even though this type of vehicle is not used in reality. The cost of handling activities at the terminals is, however, underestimated. HCVs could probably not drive with ease to some terminals such as Västberga and Jönköping which result in increased handling costs. The costs of coupling within the terminals are also not included in the calculations and must be considered. The coupling operations can be handled by a tugmaster, a terminal employee with a CE-driving license or by the vehicle driver. The coupling will take longer time and therefore affect the lead-times which can have an effect on the system. HCT could be tested only between two terminals in an early phase of the project to find the ideal operational methods for the coupling and handling and from there on duplicate the method to the other terminals to ensure carrying as low costs as possible related to the coupling and handling operations. Furthermore, a simple sensitivity analysis of cost differences has been calculated and applied. The calculations present how the total cost and annual savings are affected by differences in lone variables. Below table (5.1) present how the total costs in Scenario C changes when different parameters are decreased with 30 and 10 %, or increased with 30 and 10 %. For example, if the cost of fuel would increase by 10 %, the findings show that this would result in an increase of 3,3 % in the total costs. The higher fuel prices would mean 3,4 % in Scenario A and 3,1 % in Scenario B. If the costs would increase in some parameters, the difference in the total cost would often be small. The parameters of fuel and average speed, however have a significant effect on the total costs, if these would increase by 30 %. It is, however, believed that an increase of 30 % in fuel nor average speed is not realistic in practice. These findings are further presented in Appendix 11 with the total cost in SEK and the differential ratio in percentage displayed to provide a better understanding and stronger validity of the findings. The environmental effects would not be affected by price adjustments in different parameters and thus not accounted for in the calculations.

Scenario C		Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent			
		-30 %	-10 %	+10 %	+30 %
Adjusted Parameter	Tires	-0,9%	-0,3%	0,3%	0,9%
	Repair	-2,2%	-0,7%	0,7%	2,2%
	Fuel	-10,0%	-3,3%	3,3%	10,0%
	Depreciation	-3,6%	-1,2%	1,2%	3,6%
	Salary	-9,7%	-3,2%	3,2%	9,7%
	Other	-1,1%	-0,4%	0,4%	1,1%
	Averge Speed	18,9%	4,9%	-4,0%	-10,2%
	Utalized Hours	3,5%	0,9%	-0,7%	-1,9%

Table 5.1: Sensitivity analysis of cost differences in the different parameters

DHL has expressed an interest in investigating upon what a permit of 34,5 meters / 74 tonnes vehicle combination could have for effects on whole system. Nevertheless, the vehicles are currently loaded with maximum weight only a few times per year, and it should therefore be considered if an application for 74 tonnes is necessary. If a permit of 64 tonnes would be sufficient, the loading meters and volume capacity would not be affected as it only limits the weight capacity, which is rarely the restriction the operations in DHL Freight. If 64 tonnes are just as applicable and convenient as 74 tonnes, the potential cost savings have been underestimated. The savings are mainly underestimated regarding the costs of investment for the HCV. This is because the costs of the HCV are based on 74 tonnes and not 64 tonnes. The reason that the investment costs between both vehicle types differ rather much is because a 74 tonne HCV needs more customization and parts dimensioned to the excess weight regarding breaks, wheel suspension, and solidity of other components of which elsewhere might compose a risk of vehicle malfunction. This would then become a hazardous risk while the HCV is in traffic and could hence lead to accidents or destruction of public property which indirectly would increase the external costs for the society. Other operational costs would be overestimated if a 64 tonnes / 34,5 meters vehicle is appointed as it, for example, requires more energy and fuel to drive a heavier vehicle (cf. King, 2012; McCulloch et al., 2012; Skogforsk, 2015; Adell et al., 2016). Nonetheless, if DHL would prefer to set the weight-limit to 64 tonnes, which is today's prevailing weight-limit for LHVs in Sweden, this would be equal to less investment costs of vehicles at the same time as the process of permit most likely would become easier as the Swedish Transport Administration has no need to investigate if the extra weight from 64 tonnes to 74 tonnes somehow will affect the roads regarding their loading class. Furthermore, the Swedish Transport Administration has released a report that analyzed the Swedish road network and concluded that all larger highways are sufficient to enable freight transportation with HCVs (Natanaelsson & Brandt, 2019). It would therefore only be necessary to examine the last mile and minor roads from the departing terminals, which is until the HCV has reached the highway entrance ramp and from the highway exit ramp until the HCV has reached the receiving terminal. This report has only analyzed and marked out these intervals of roads briefly for the terminals identified as the ones with the highest potential for applying HCVs.

DHL Freight currently has a total of 25 terminals in their Swedish network. The latter step after investigating the total costs for the different scenarios was to identify the relations for each terminal to see examine if an introduction of HCV usage would be feasible from a financial perspective. In the gathered data from January to October 2018, all 25 terminals are transporting goods to each other, resulting in a total of 600 relations or ways of communication ($\sum (N \times N) - N) = ((25 \times 25) - 25)$. The use of HCVs was found to be cost efficient in both communication ways (departure and return included) in 92 of 600 relations, which is roughly 15 % of the terminals, with no imbalance. It was profitable to use HCV one way, even with imbalance between the terminals in one communication way, in additionally 110 out of the 600 relations which is roughly 18 %. Hence, HCV was concluded to be unprofitable in 398 of the 600 relations equal to roughly 66 %. Therefore, it could be clarified that the use of HCVs is cost effective in 1/3 of the relationships and not beneficial in 2/3 of the 600 relations.

The terminals with the highest potential for implementation of HCVs prior to the analysis given on request from DHL Freight were examined as DHL had noticed the largest potential in the terminals of Stockholm, Malmö, Jönköping, Gothenburg and Sundsvall based on their activities and traffic. The matrix developed based on this (see table 4.5, 4.6, 4.7 and 4.8) presented the total costs in the different Scenarios between the different relationships. Two departing terminals that showed negative numbers to the other six terminals were found to be Sundsvall and Rosersberg. All of the costs were summarized which resulted in illustrating the optimal cost setup. The optimal cost setup in Scenario C compared to Scenario A and B between the largest seven terminals is illustrated below (table 5.1) given in rounded numbers.

	Scenario A (As is / Current situation)	**Scenario B (Solely HCT)**
	119 654 000	111 207 000
Scenario C (Optimal setup)	102 350 000	102 350 000
Total cost savings with HCVs	*17 304 000*	*8 857 000*

Table 5.2: Comparison of each scenario's costs in highlighted terminals and potential savings if HCVs are available.

An additional analysis was made to examine if the highlighted terminals had volumes of goods subject for transportation sufficient enough to saturate the yearly demand for freight. To do this, an initial freight demand analysis was made (see Appendix 7) to illustrate the demand for freight with respect of the LDMs over the period investigated. This was made in order to see the stability of the demand and also to identify fluctuations caused by seasonal variations or other reasons. An analysis of the average freight demand allocated over the week was made for each of the highlighted terminals as a complement. The total demand on Mondays was divided by the number of weeks and gave the average demand on Mondays over the period investigated, and this was made for each weekday and highlighted terminal respectively (see Appendix 8). The summary of the analysis shows each terminals distribution of average demand for LDM were the variance differ between 18 and 3 %, and provide a full overview of the variation in the seven largest terminals (see table 5.2).

	Gothenburg	Jönköping	Helsingborg	Malmö	Västberga	Sundsvall	Rosersberg
Monday	31,1	21,3	17,5	14,7	15,1	12,4	11,4
Tuesday	28,5	21,9	18,9	15,0	13,7	12,9	12,2
Wednesday	30,3	21,9	18,5	15,1	13,8	12,5	12,1
Thursday	28,3	20,6	17,7	14,8	13,6	12,6	11,3
Friday	26,9	18,1	16,9	13,0	12,4	11,6	10,2
Total	145,1	103,8	89,4	72,6	68,6	62,0	57,3
Average	29,0	20,8	17,9	14,5	13,7	12,4	11,5

Table 5.3: Average demand for freight transportation in the highlighted terminals.

As the result shows, Gothenburg and Jönköping are well suitable to perform HCTs and this could also be argued for Helsingborg if an aspect of fill rate utilization is taken into consideration. Malmö, Västberga, Sundsvall and Rosersberg however show that the demand for freight seen to LDMs would be sufficient enough to saturate with a conventional LHV based on the above table. This aspect is important to have knowledge about as the prerequisites to enable an efficient use of HCVs both from an economically and environmentally perspective as an efficient use of HCVs in a terminal network could be characterized as a need to rely on stabile and continuous flows or volumes of goods.

However, better possibilities could exist to achieve economies of scale in the transportation network by consolidating more than one terminal in one freight transport divided in each of the larger highways connecting many of the terminals in southern and middle parts of Sweden. To exemplify, if a transport is going from Malmö to Gothenburg the vehicle will go northbound on E20. The vehicle will pass through both Helsingborg and Halmstad before continuing towards Gothenburg. For instance, if an assumption is made that there one day is a demand to transport one trailer from Malmö to Gothenburg but also one trailer from Helsingborg to Gothenburg. DHL Freight can, if a permit of 64 tonnes is achieved rather than 74 tonnes, use the tractor unit regularly used in an LHV as a flexible solution as the 64 tonnes weight restriction doesn't put many prerequisites on the construction of the tractor unit due to the standardized components. A vehicle starting from Malmö with a length of maximum 25,25 meters carrying unit could stop by Helsingborg and add a second trailer to the equipage. In other words, if there are possibilities to gather an extra trailer the LHV becomes an HCV by just adding an extra trailer. This would improve the flexibility and decrease the lead-time by improved allocation of capacity by the dividing and coupling of the trailers. If there are no such possibilities due to the required capacity in Helsingborg, the LHV just runs continuously as normal with a length of 25,25 meters. This idea can, if setup correctly and carefully, leverage the potential cost savings and also the efficiency of the terminal network seen from an environmental perspective. This can reduce the costs considerably and increase the quality of the service level. The extra interlinks located at some terminals also have the possibility to be reallocated to handle fluctuations. Thus, this strategy of implementation requires carefully performed capacity planning between each of the terminals of interest but also efficient flows of information between the terminals, hauliers, and management. Another example would be Malmö to Rosersberg or Västberga, going from Malmö through E20 passing Helsingborg before entering E4 passing Värnamo, Jönköping, and Norrköping before reaching Rosersberg or Västberga in the Stockholm region. However, this would add another level of complexity regarding capacity planning and realization of execution in the terminal network. A deeper investigation would be required to understand, illustrate and discuss this complexity and its benefits. This appearance and structure are however identified and believed to add an extra level of flexibility in the terminal operating network to some extent.

Another aspect that however requires a more complex discussion but could nonetheless create economies of scale with the use of HCT is consolidation or structure of specific terminals. If, for example, the terminal in Helsingborg is merged with the terminal in Halmstad, could the total demand subject to freight transportation be combined and hence be more appropriate to perform in HCT. A consolidation of the terminals would also reduce the operational and external costs further due to a higher fill rate and optimization. As the average fill rates would increase, it is also natural that the need and potential of HCT increase further as a consequence. An example of how the costs would be if Rosersberg and Västberga were consolidated is illustrated in table 5.3. The total annual savings in

Scenario C would be 5,8M SEK, which is a decrease with 24 % compared with the prior calculations made for Scenario C. Scenario B would however decrease 27 % and this could support earlier thoughts mentioned regarding a larger demand for freight transportation that is better suited for HCT as the potential for further consolidation becomes a possibility, thus reducing vehicles and furthermore operational costs.

Consolidation Stockholm	Scenario A	Scenario B	Scenario C
Total Cost (As is)	29 648 000 kr	26 458 000 kr	24 344 000 kr
Total Cost (Consolidation)	21 855 000 kr	19 347 000 kr	18 536 000 kr
Total Cost Savings	7 793 000 kr	7 111 000 kr	5 808 000 kr
Total Cost Savings (%)	26%	27%	24%

Table 5.4: The effect of a consolidation of Västberga and Rosersberg on operational costs.

This is however not a concept that can be easily realized as there are complicated questions that are difficult to answer that must be resolved. Because of the effects on different aspects of interest in DHL. company structure would be affected to a great extent, e.g. this would affect and increase the last-mile deliveries with smaller vehicles to the stores and collection points. Some variables would hence increase while others would decrease in the cost structure and the economy of scale might not result in synergies due to the increased cost variables. Nevertheless, as the government is strongly indicating that HCT can be introduced in the near future (cf. Natanaelsson & Brandt, 2019), DHL must investigate how a permit on a national level affects the operations and how the corporation can benefit and adjust to such change.

5.2 Environmental Effects and Performance

HCT is an attractive solution from an environmental perspective as it is believed to have the potential to minimize the total fuel consumption, emissions and traffic congestion (Kharrazi et al., 2014). The findings of this report show that this is true, with all types of oxides reduced between 6-7 % in Scenario C. If HCT are introduced on the whole network, the emissions would still be reduced- however with only 3 %. These decreases would more specifically be 1 816 464 liters of fuel, 4 881 tonnes of CO_2, 1,8 tonnes of NO_X, 142 kg of HC, 21 kg of PM and 7,4 kg of SO_2. To understand exactly what these numbers mean for the society, the estimated cost of Adell et al. (2016) was applied to these deductions. The external costs of these emissions would decrease by almost 7 % or 5,6M SEK annually. It should however be noted that the emission releases in grams per liter of fuel in the report of Adell et al. (2016) have minor differences from Knight et al. (2008) as the different author's calculations are based on among others a diverse average speed, carrying weight and different EMS vehicle types.

Emissions such as noise are more difficult to present any findings for. The ETT-project did however show that noise emissions did not increase as initially expected and if totality is seen, the number of decreased vehicles resulted in an overall decrease in noise emissions in general. The HCVs will most likely have an increased noise emission (cf. Knight et al., 2008; Sandberg et al., 2018). However, as the goods in DHL are currently limited by volume and the weight is usually what affects the noise emissions (cf. Vierth et al., 2008; Ericson et al., 2010; Fröjd et al., 2017), it is believed that the increased noise emissions of an introduction of HCT will not be any issue for DHL.

The vehicle kilometers and tonne-kilometers are reduced greatly if HCT are introduced over the whole terminal network in Scenario B. However, as it is not cost beneficial to introduce HCT on the full network, the improved numbers of vehicle kilometers and tonne-kilometers are reduced in Scenario C, but are still an improvement in comparison to Scenario A. The consumption of fuel is further determined by technical specifications, driving patterns and the flow conditions of the network. Figure 3.2 presents different efforts that can reduce the energy consumption and environmental impact. The weight of goods consumed is increasing by 20 % per year which increases the need for larger capacities due to higher volumes. The supply chain structure and efficiency of vehicle routing can be improved through HCVs and consequently decrease the total tonne-kilometers through a larger capacity. The average load per trip increases and the number of trips can hence be reduced. Some researchers (cf. McKinnon 2005; Knight et al., 2008; McKinnon, 2012a; Adell et al., 2016) argue that consolidation of goods is the most efficient method to decrease vehicle-kilometers and hence the transportation's impact on the environment. If the vehicle utilization of HCVs can further be enlarged from an average of 80 %, the number of trips can be reduced even more. By driving past other terminals and consolidating goods, it is not impossible to achieve a 100 % fill rate in many trips. For example, a trip from Gothenburg to Stockholm could stop by Borås if there are goods that can be consolidated. However, if Borås have a large volume of goods that are to be delivered to Stockholm, it might still need an extra vehicle, carefulness is therefore vital in the planning.

The driving behavior is a different parameter that can reduce the use of energy and environmental impact, through aerodynamic drag can the fuel consumption be reduced by 4-8 % per kilometer (this reduction is not included in the calculation of table 4.10). The behavior can also be concerned by IAC and a more careful driving when handling larger vehicles. Montufar et al. (2007), Wåhlberg (2008), Balint et al. (2014), Hassal (2014), and Åsman and Asp (2018) do all argue for a higher carefulness when driving larger vehicles. This carefulness can include a smoother driving with less stops and starts and a lower average speed. These are all different elements that influence the energy and environmental impact on both indirect and direct ways.

To achieve the maximum potential of HCT related to emissions and fuel consumption, it is important that HCT is not used on extremely long distances. For instance, to transport goods between Malmö and Sundsvall with HCT will result in lower operational costs. However, the distance between Malmö and Sundsvall is more suited for an intermodal mode of rail-road than solely road and the transporter must therefore be careful with not replacing shares from the rail with road. The operational cost reduction of 5,5 % is not considered to be high enough to create a transmodal shift from rail to road. The specific relationships related to Sundsvall did also present imbalances, Sundsvall could therefore be examined further before being introduced to HCT. The geographical and triangular relationship between Gothenburg, Jönköping, Stockholm, Malmö and Helsingborg shows the most promising potential in both operational and external cost reductions while these relationships do not obtain any imbalances. Furthermore, the short distance between these terminals may be better suited for road then for rail to achieve a higher level of flexibility and reliability between these terminals.

According to several studies (cf. Knight et al., 2008; Leach & Savage, 2012) the impact of congestion and space capture is greater when the speed falls behind 50 km/h on road freight. As many studies covered in Sweden argue for an average speed of 80 km/h or 60 km/h as minimum (cf. Flodén, 2007; Adell et al., 2016) the speed will mostly exceed the limit of 50 km/h. Furthermore, the location of the terminals is all near a highway and could therefore have an average speed above the calculated 60km/h. As the amount of transportations in the terminal network would decrease with 14 522 vehicles with an optimal introduction of HCT (Scenario C), the space capturing on the roads would decrease with 141 232 meters in total annually. The presented data from DHL shows that congestion levels would decrease with almost 4 %, a similar amount to the German studies which present findings that speak of 5 % (cf. Meers et al., 2018). As Vierth et al. (2008) present findings of increased costs for society if LHVs were to be removed and congestion would be increased to a higher number of vehicles on the road, it can be argued that the opposite effect could arise, i.e. a decreased cost for the society when HCT are introduced as a general road space are freed up. A common example of accidents related to the vehicles use of space arises in the overtaking (see figure 3.6). As the number of vehicles and space capturing decreases, the risk decrease as well. Nonetheless, when a certain passenger car however still chooses to overtake a HCV, it is vital to acknowledge the particular vehicle's extended length, which increases the risk of an accident in this specific overtaking. The Swedish Traffic Administration can further investigate rush hour traffic and, if necessary, only permit HCVs on the roads under certain hours during the day or night. This can further be controlled by technologies such as IAC-systems or other information systems that share data with the Swedish Traffic Administration.

Such technologies can further provide a deeper understanding of the phenomena of high capacity transports and gather new data for the government's future investigations of HCT. An IAC system can also present data related to the load type, routes, configurations and fuel type. With this type of data, together with other parameters, DHL and government can achieve a better understanding of the fuel consumption per vehicle, tonne kilometers, LDM or cubic weight. Performance, technology and safety are three vital aspects to consider when requesting a permit to operate with HCT. Different technologies and performance standards have been discussed briefly that can be tested during the pilot period.

The components are currently standardized for 64 tonnes as it is currently the maximum permitted weight on the road by law and regulation even though there are some roads that recently opened up for 74 tonnes (BK4). As DHLs goods are limited by LDMs and volume due to the type of goods, a request to use 74 tonnes on roads can be criticized. This request would require an investigation on the effect of not only roads, but also bridges and the investigation would hence become more demanding for DHL as well as the Swedish Transport Administration/Agency. Nonetheless, all performance measures in table 3.4 must be examined independently if the maximum weight would be of 64 or 74 tonnes. If standard components can be used, the handling could become less costly and easier. In a theoretical sense, each terminal could always strive to have 1-2 extra trailers available. A tractor driving from Jönköping to Västberga could, for example, carry a semi-trailer and a swap-body with a total length of 25,25 meters. However, the volume that needs to be carried in the return journey, from Västberga to Jönköping might be high and the semi-trailer could in this case just be substituted by another semi-trailer. This method and flexibility could even reduce the number of tonne-kilometers and trips even in addition.

The report by Natanaelsson and Brandt (2019) published by the Swedish Transport Administration was used as a supporting document for the examination of available roads for high capacity transportation. The smaller roads (also called the last mile in this report) have been examined through Google Maps. The local roads tend to be smaller and those have been observed until the smaller local road becomes a highway. The roads from Jönköping and Malmö to the highway include driving by two recently introduced roundabouts. A permit for HCVs is only for a certain and very specific roads, it is therefore vital to advise with the municipalities, counties and the Swedish Traffic Administration regarding the roads. If there are any new roads built or if a crossing would be reconstructed to a roundabout, it could cause large problems to the HCVs performance. The terminals of Jönköping and Västberga are two terminals that can interfere with challenges. Västberga is heavily trafficked during rush hours and there are multiple roundabouts and crossings that the HCVs must be able to turn within in a safe manner, e.g. within an outer radius of 12,5 meters. Natanaelsson and Brandt (2019) confirm that large highways such as the E4, E20 and 40 can carry high capacity vehicles. The smaller roads from and to the terminals must however be examined further by the public actors.

6. Conclusion

The final chapter concludes the interpretations and findings, answers the research questions, summarizes the effects of high capacity transport and is finalized with recommendations for further investigation and research.

The purpose of this report was to describe the effects of an introduction of high capacity transport from a system analysis to provide comprehensive findings and create a holistic understanding of how HCT would affect the established network of DHL Freight Sweden. The findings present capabilities in the aspects of cost structure, environmental effects, performance and safety, and operational structure. There is an adequate amount of information and evidence presented for the effects of HCT even though the opposite is mentioned often in reports published by both the Swedish Traffic Administration and the Swedish Traffic Agency. Sweden is however currently one of the countries that carries the largest freight transport vehicles seen from a global perspective and only a few other countries permit larger vehicles, see for example Finland. Even though many academia present numbers and result from different simulations, there are not many case studies in the specific environment of Sweden that are available. Previous studies and research however agree upon the potentials of HCT in the aspects of emissions, socio-economy and in some cases a need for investments in the infrastructure, but the exact benefits can slightly differ between different studies and countries. The theoretical framework, however, diverges upon the risks of transmodal shifts because of the geographical state of Sweden and the strengths and weaknesses of rail and road respectively.

The developed model and calculations present similar findings to the suggestions from the theoretical framework with identical savings in the socio-economy, internal cost structure and greenhouse gas emissions. An introduction and implementation of HCT in the terminal network of DHL are indeed interesting with high potential, not only by creating the increased capacity that is required from the company to cope with the growth seen in demand of freight transportation.

Table 6.1 summarizes the findings and results of the system analysis that has been examined. Scenario A is the current situation of LHV's operating between all relationships and is illustrated as the index. Scenario B and C present the findings relative to Scenario A. The operational costs are calculated in respect to the number of vehicles needed for each transportation and LDMs. The fixed cost for HCVs have a great difference between Scenario B and C, as HCVs only become more profitable when more than two engines are saved in one trip. If one LHV were to be compared with one HCV, the fixed cost of an HCV would be greater with 53 %, whilst the cost per kilometer would increase with 19 % and the 2 % per hour.

Table 4.9 summarize the potential of reduction in different oxides and the findings show that CO_2 can be reduced with almost 5 000 tonnes or 6,6 %. The overall environmental cost in table 6.1 is based on the total external cost and could strongly be reduced when HCVs are operating alone. This scenario, however, is not considered to have high credibility, as this would be very costly for DHL, which would gain an increased total cost of 7,4 % throughout their terminal network. The overall environmental cost includes all external costs except the cost of congestion and relative use of space.

This is not included as no literature can be identified that presents a cost per meter or vehicle during this project. The emissions in table 6.1 have further been calculated based on the aggregated weight of all types of emissions and are not weighed in any matter on the effects inherited from the different types of oxides. Costs related to infrastructure only include the cost of pavement wear and do not include the wear of bridges as DHL is only limited by LDM's and volume.

The logistics quality has only been discussed with supporting theory and literature and has not been calculated. A '+' does indicate a potential, '+ +' indicate on a strong potential, whilst '-' indicate on an unpromising consequence and '- -' on a stronger unpromising consequence. The logistics quality is affected negatively in Scenario B as HCVs are limited to only drive on a certain road and have a lower average speed. The value decreases further as the goods do not always require larger vehicles. There is however large potential in Scenario C that arises with increased capacity resulting in improved flexibility and reliability in the transportation.

	Scenario A	Scenario B	Scenario C
Total Operational Costs	0	7%	-5%
Fixed Costs	0	42%	-2%
Distance Based Costs	0	10%	-5%
Time Based Costs	0	-5%	-7%
Overall Environmental Cost	0	-15%	-8%
Emissions	0	-3%	-7%
Congestion	0	23%	-4%
External Costs Related to Emissions	0	-3%	-7%
External Costs Related to Infrastructure	0	-10%	-7%
External Costs Related to Safety	0	-31%	-10%
Overall Logistics Quality	0	- -	+ +
Reliability	0	- -	+ +
Lead-Time	0	- -	+ +
Frequency	0	0	+
Flexiblity	0	- -	-
Value	0	- -	+ +

Table 6.1: Summary of the findings.

The potential benefits of HCT are reduced operational and socio-economic costs for both DHL and the society. The operational costs can be reduced by almost 56M SEK or 5,5 % annually. The emissions releases can be reduced 6,6 % and the total external costs by approximately 25M SEK annually. The amount of CO_2 alone can be reduced with almost 5 000 tonnes annually. The calculations have been based on 2018's average fill rate of 75 % in conventional vehicles. The available capacity of 25 % is required to manage fluctuations and flexibility and is equivalent to a HCV with the fill rate of 80 %. The 80 % fill rate has therefore been used as a foundation in the calculations for HCVs with respect to the current service rate and quality that is offered to the customers of DHL Freight. The potential in all aspects can grow further if consolidations are considered, this can however influence the structure of DHL's established terminal network. HCVs, however, do not result in a positive outcome between all 600 relations between the 25 terminals in the system, and should therefore only be considered between the suggested relationships (see Appendix 6).

The aggregated relationship with the most potential in reducing costs is summarized and illustrated in figure 6.1 based on table 4.8. Västberga - Gothenburg and Helsingborg - Västberga are the relationships with the highest volumes and hence most potential for HCT. Figure 6.1 do however consolidate the terminals of Malmö and Helsingborg, and Västberga and Rosersberg to create a clear illustration without too many lines. The overall structure of figure 6.1 is broken down in table 6.2, however, as Malmö - Helsingborg and Västberga - Rosersberg are grouped, the freight transport within these areas, equivalent to 1,5 %, is eliminated in table 6.2. This is the reason for the slight total cost difference compared with table 5.1. The red-marked line between Malmö and Stockholm are thickest and hence the highest freight transportation intensity, followed by the orange, yellow, green and lastly the blue-marked line between Jönköping and Stockholm.

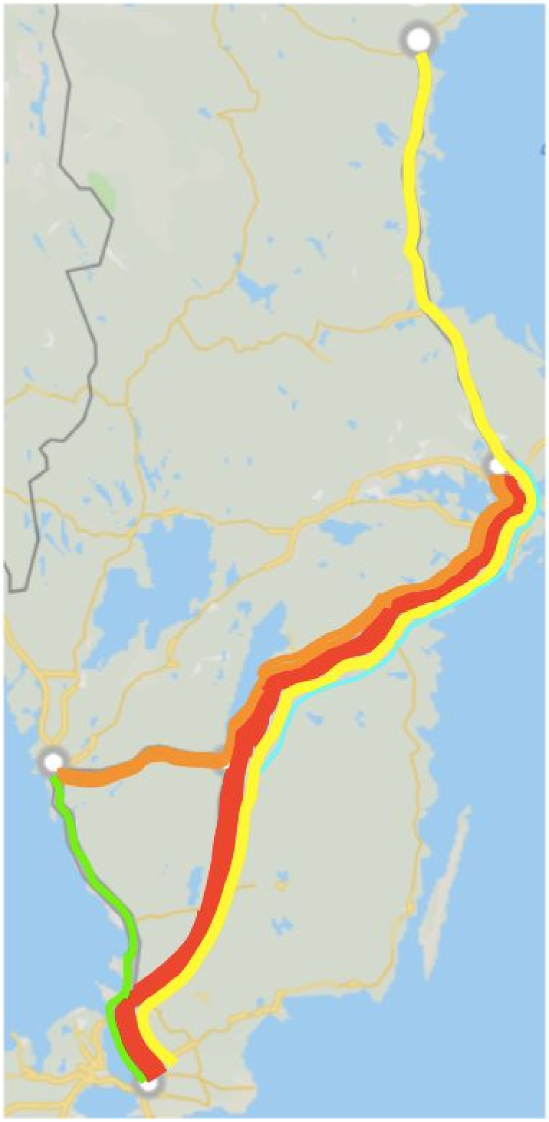


Figure 6.1: The relationships with the largest transportation intensity.

Top 10 Relations	Optimal Cost	Relative %	Accumulated %	Line Color
Malmö - Stockholm	31 333 000 kr	31,1%	31,1%	Red
Gothenburg - Stockholm	15 619 000 kr	15,5%	46,6%	Orange
Malmö - Sundsvall	13 891 000 kr	13,8%	60,4%	Yellow
Gothenburg - Malmö	8 688 000 kr	8,6%	69,0%	Green
Jönköping - Stockholm	7 082 000 kr	7,0%	76,0%	Blue
Jönköping - Malmö	6 256 000 kr	6,2%	82,2%	Red/Yellow
Gothenburg - Sundsvall	5 474 000 kr	5,4%	87,7%	Orange/Yellow
Sundsvall - Stockholm	5 207 000 kr	5,2%	92,8%	Yellow
Jönköping - Sundsvall	4 850 000 kr	4,8%	97,6%	Yellow
Gothenburg - Jönköping	2 380 000 kr	2,4%	100%	Orange
Sum:	100 780 000 kr	100%		

Table 6.2: Top 10 relations suitable for HCT within the terminal network of DHL

By acknowledging the research questions, justifying the findings and clarifying the data in table 6.1, the purpose of this report has been accomplished. The findings of this report also support the superiority of the literature and presents evidence of the effects related specifically to the third-party logistics company DHL. The findings are therefore considered to contribute to a holistic understanding for the Swedish Transport Administration and the Swedish Transport Agency in the examined aspects to provide a decision basis for the business case. However, there is still much room for further research on the subject. The calculations are, for instance, underestimated as data from October, November and December are missing and not included in the calculations of cost and emissions savings. Also, as DHL is limited by the volume and LDMs due to the type of goods, it should be carefully considered if a request of 74 tonnes is needed. If so, a deeper analysis of the affected bridges wear must be examined and included in the calculations. As HCT is currently being investigated upon by the government in-depth, and the latest report by Natanaelsson and Brandt (2019) also suggest HCT to be permitted on many roads, an introduction of HCT is recognized on national level and may in the near future be realized. DHL may therefore look into decreasing the number of relationships of 600 to have a better utilization of high capacity vehicles if these are permitted on a national level. There are also further aspects in the phenomenon of HCT that can be clarified more specifically for Sweden, such as the risks for transmodal shifts if HCT is introduced by the government.

6.1 Recommendations for future research

This report has not thoroughly investigated different technical and constructional solutions. It is therefore recommended that DHL Freight examine this aspect more deliberately and precisely. There are a number of solutions that have been mentioned and discussed in a larger sense that can be further explored as a starting point if needed. It is further recommended to investigate in an intelligent traffic planning system with respect and consideration for HCVs. The development of the current system that considers HCVs can in a smart manner illustrate exactly when HCVs are needed and ensure that only trips where HCVs have a lower cost than LHVs are used. This could extract the risks of using HCVs when it is not necessary and only obtain the HVCs trips that are profitable. Such system could also plan the trips with consideration of imbalances between different terminals and calculate the most suitable vehicle based on a total. For example, if a trip of 16 LDMs are needed from Gothenburg to Jönköping, a LHV is required. However, there is a transportation planned on the same day of 6 LDMs from Borås to Jönköping. If these are consolidated, an extra vehicle is not needed if a HCV is used.

Also, if the trip back from Jönköping was of 5 LDMs the next day, the HCV would then be empty and unused. An intelligent system would calculate automatically how and where to use it exactly to ensure the highest possible profitability.

An analysis of the affected road network that are topical and relevant for HCT is also recommended to be analyzed in detail. It is recommended that the Swedish Traffic Administration and regional organizations (i.e. municipalities and counties) examine the exact roads to establish the full certainty of longer vehicles' ability to operate on all curves, lay-bys, roundabouts, T-junctions, tunnels, bridges and carriageways. For example, there might be a curve that needs to contain a solid line that separates two lines from am overtaking due to the risks of a longer vehicle according figure 3.6.

A fourth recommendation for DHL is to examine the handling and coupling in the terminals. The handling of a HCV requires more time and consequently costs more in relation to the handling of a conventional vehicle. There are, however, different possible solutions for fast and easy handling of terminal tractors or remotely controlled dollies. There are however pros and cons with different methods that should be considered with respect for the internal handling process.

The last recommendation for future research in the phenomena of HCT in general is to investigate further upon the risks for a transmodal shift in Sweden if HCT would be introduction in the whole road network of Sweden. Much of the literature do genuinely indicate of a minimal risk for a transmodal shift and reveal a full capacity or low flexibility in rail and inland waterways as one of many arguments. Previous regulation modifications of permitted weight and dimensions do also show a very limited or no percentage of a transmodal shift (see Belgium for instance), and historical events in Sweden likewise present a very small shift that might hail from the long geography of Sweden that provides a strong advantage for rail due to heavy goods on long haulage. Historical investments have also been large on expanding the network of roads while the rail network is only recently being modernized and extended, a process that will take many years to accomplish.

Reference list

Abbasi, M., & Nilsson, F. (2012). Themes and challenges in making supply chains environmentally sustainable. Supply Chain Management: An International Journal, 17(5), 517-530.

Adell, E., Khan, J., Hiselius, L., Lund, E., Nelldal, B. L., Pettersson, F., ... & Wandel, S. (2016). Systemanalys av införande av HCT på väg i Sverige. Environmental and Energy Systems Studies: Miljö-och energisystem, LTH, Lunds universitet.

Adell, E., Ljungberg, C., Börefelt, A., & Hanander, M. (2013). 1-årsutvärdering av projektet ETT coil till (ECT). Trivector, report PM, 37.

af Wåhlberg, A. E. (2008). Meta‐analysis of the difference in accident risk between long and short truck configurations. Journal of Risk Research, 11(3), 315-333.

Åkerman, I., & Jonsson, R. (2007). European Modular System for road freight transport: Experiences and possibilities. TFK-TransportForsK AB.

Andersson, J., Renner, L., Sandin, J., Fors, C., Strand, N., Hjort, M., ... & Almqvist, S. (2011). Trafiksäkerhetspåverkan vid omkörning av 30-metersfordon. Statens väg-och transportforskningsinstitut.

Ang-Olson, J., & Schroeer, W. (2002). Energy efficiency strategies for freight trucking: potential impact on fuel use and greenhouse gas emissions. Transportation Research Record, 1815(1), 11-18.

Arnäs, P. O., Arvidsson, N., Börjesson, F., & Liljestrand, K. (2013). Behov och nyttor av transporter med hög kapacitet (HCT) inom olika branscher och för olika varuslag-En förstudie inom ramen för FoI-programmet High Capacity Transports. Chalmers University of Technology.

Åsman, P., & Asp, T., (2018). Annual Report of High Capacity Transport 2017. The Swedish Transport Administration.

Asmoarp, V., Jonsson, R., & Funck, J. (2015). Monitoring fuel consumption of a 74-tonne chip truck in the ETT project. Skogforsk.

Asp, T., Wandel, S., & Rydén, P. (2018). Demonstration Intelligent Tillträdes-Kontroll.

Atkinson, V., Merrill, D., & Thom, N. (2006). Pavement wear factors.

Aurell, J., Wadman, T., & Trucks, V. (2007). Vehicle combinations based on the modular concept. NVF-reports, Report, 1.

Backman, H., & Nordström, R. (2002). Improved performance of European long haulage transport (No. 2002: 6E).

Bálint, A., Fagerlind, H., Martinsson, J., & Holmqvist, K. (2014). Accident analysis for traffic safety aspects of High Capacity Transports.

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.

Ballis, A., & Golias, J. (2004). Towards the improvement of a combined transport chain performance. European journal of operational research, 152(2), 420-436.

Ben Jebli, M., & Hadhri, W. (2018). The dynamic causal links between CO2 emissions from transport, real GDP, energy use and international tourism. International Journal of Sustainable Development & World Ecology, 25(6), 568-577.

Bereni, M., & Jacob, B. (2009). A look into the likely consequences of adapting weights and dimensions of heavy commercial vehicles in Europe. Transportation Research Board, Washington.

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.

Bergqvist, R., & Monios, J. (2016). The last mile, inbound logistics and intermodal high capacity transport-the case of Jula in Sweden. World Review of Intermodal Transportation Research, 6(1), 74-92.

Berndtsson, A., & Åsman, P. (2014). Ökad energieffektivitet genom High Capacity Transports.

Bickel, P., & Friedrich, R. (2005). Externalities of energy methodology 2005 update. European Commission EUR, 21951.

Björnstig, U., Björnstig, J., & Eriksson, A. (2008). Passenger car collision fatalities–with special emphasis on collisions with heavy vehicles. Accident analysis & prevention, 40(1), 158-166.

Boland, A., Cherry, G., & Dickson, R. (Eds.). (2017). Doing a systematic review: a student's guide. Sage.

Bryan, J., Weisbrod, G., & Martland, C. D. (2007). Rail freight as a means of reducing roadway congestion: feasibility considerations for transportation planning. Transportation Research Record, 2008(1), 75-83.

Castillo-Manzano, J. I., Castro-Nuño, M., & Fageda, X. (2016). Exploring the relationship between truck load capacity and traffic accidents in the European Union. Transportation research part E: logistics and transportation review, 88, 94-109.

Christidis, P., & Leduc, G. (2009). Longer and Heavier Vehicles for freight transport. JRC European Commission, 1-40.

Cider, L., & Ranäng, S. (2013). Slutrapport Duo2-Trailer. FFI (Fordonsstrategisk Forskning och Innovation).

Clarke, G. (2014). Task A: Collection and Analysis of Data on the Structure of the Road Haulage Sector in the European Union.

Council of Supply Chain Management Professionals (2015). Event report improving transport capacity utilization. http://cscmpbenelux.org/event-report-improving-transport-capacity-utilization/ [Accessed 01/03-2019].

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

Creswell, J. W., & Poth, C. N. (2017). Qualitative inquiry and research design: Choosing among five approaches. Sage publications.

Danish Ministry of Transport (2011). The Danish-Eco Combi Trial. Transportministeriet.

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.

Debauche, W. (2008). Working Group on longer and heavier goods vehicles: A multidiciplinary approach to the Issue. In Proc. of the International Conference on Heavy Vehicle–HVTT10 (pp. 111-122).

DHL Freight Sweden (2019). https://www.dhl.se/sv/country_profile.html [Accessed 2019-02-30].

DHL, Deklaration av emissionsberäkning , 2018. https://www.logistics.dhl/content/dam/dhl/local/se/dhl-freight/documents/pdf/se-freight-emissionsdeclaration-se.pdf [Accessed 9/2-2019].

Dodoo, N. A., & Thorpe, N. (2005). A new approach for allocating pavement damage between heavy goods vehicles for road-user charging. Transport Policy, 12(5), 419-430.

Doll, C., Fiorello, D., Pastori, E., Reynaud, C., Klaus, P., Lückmann, P., ... & Hesse, K. (2008). Long-term climate impacts of the introduction of mega-trucks. Study for the Community of European Railways and Infrastructure Companies (CER) co-ordinated by Fraunhofer ISI, Karlsruhe.

DPDHL. (2017). DHL Freight reducerar CO2-utsläpp med 54 % per tonkm, DHL Freight Sweden. http://news.cision.com/se/dhl-freight-sverige/r/dhl-freight-reducerar-co2-utslapp-med-54--per-tonkm,c2271930 [Accessed 2019-02-24].

EC-European Commission. (2011). Roadmap to a Single European Transport Area-Towards a competitive and resource efficient transport system. White Paper, Communication, 144.

Ericson, J., Lindberg, G., Mellin, A., & Vierth, I. (2010). Co-modality—The socio-economic effects of longer and/or heavier vehicles for land-based freight transport. Proceedings of the 12th WCTR, Lisbon, Potugal, 11-15.

Erlingsson, S., Ahmed, A.W. and Rahman, M.S. (2018). "Impact of heavier and longer vehicles on the performance of asphalt pavements". In proceedings of the 7th Transport Research Arena TRA 2018, Vienna, Austria.

Eurostat (2017). Road freight transport by type of goods. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Road_freight_transport_by_type_of_goods [Accessed 1/3-2019].

Fang, B., & Han, X. (2000). Relating Transportation to GDP: Concepts, Measures, and Data. Integrated Transport Economy Modelling─ Top European and North American Models.

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

Floden, J., & Bergqvist, R. (2008). Överföringspotential för gods till kombinerade transporter och hamnpendlar: rapport till VTI inom uppdraget Kartläggning av potentialen för överflyttning av person-och godstransporter mellan transportslag, VTI Projekt 92268.

Fraunhofer, I. S. I., & TRT, N. (2009). Long-Term Climate Impacts of the Introduction of Mega-Trucks. Study for the Community of European Railway and Infrastructure Companies (CER): Karlsruhe, Germany.

Frey, B. B. (Ed.). (2018). The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation. SAGE Publications.

Fröjd, N., Pettersson, E., Larsson, L. and Cider, L. (2017). "HCT Typfordonskombinationer, Dnr: 2015-02327". Vinnova FFI slutrapport.

Garcia, C., Levy, S., Limão, S., & Kupfer, F. (2008). Correlation between transport intensity and GDP in European regions: A new approach. In STRC: 8th Swiss Transport Research Conference, Monte Verità, Ascona, October 15-17, 2008 (pp. 1-18).

Gillespie, T. D. (1993). Effects of heavy-vehicle characteristics on pavement response and performance (Vol. 353). Transportation Research Board.

Glaeser, K.P., R. Kaschner, M. Lerner, C.K. Roder, R. Weber, A. Wolf, and U. Zander (2006), Effects of new vehicle concepts on the infrastructure of the federal trunk road network, Final report, Federal Highway Research Institute (BAST), Bergisch-Gladbach, November.

Government Offices of Sweden. (2017). The climate policy framework https://www.government.se/articles/2017/06/the-climate-policy-framework/ [Accessed 27/2-2019].

Granlund, J., & Lang, J. (2016). Förkortad väglivslängd. Borlänge: WSP.

Grislis, A. (2010). Longer combination vehicles and road safety. Transport, 25(3), 336-343.

Hassall, K. (2014). Quantifying the benefits of high productivity vehicles (No. AP-R465/14).

Hellung-Larsen, M. (2012). Evaluation of trial with European Modular System: Danish experience. In HVTT12: 12th International Symposium on Heavy Vehicle Transport Technology.

Inderwildi, O., & King, D. (Eds.). (2012). Energy, transport, & the environment: addressing the sustainable mobility paradigm. Springer Science & Business Media.

Jeschke, S., Isenhardt, I., Hees, F., & Henning, K. (Eds.). (2013). Automation, communication and cybernetics in science and engineering 2011/2012 (Vol. 2013, pp. 548-549). Berlin: Springer.

Johansson, F., von Hofsten, H. (2017). HCT-kalkyl - an interactive cost calculation model for comparing trucks of different sizes. Skogforsk.

Jourquin, B., Tavasszy, L., & Duan, L. (2014). On the generalized cost-demand elasticity of intermodal container transport. European Journal of Transport and Infrastructure Research, 14(4).

Kharrazi, S., Aurell, J., Sadeghi Kati, M., Jacobson, B., Fröjd, N., & Asp, T. (2014). Towards performance based standards in Sweden. In 13th International Heavy Vehicle Transport Technology Symposium, San Luis, Argentina, 2014.

Kharrazi, S., Bruzelius, F., & Sandberg, U. (2017). Performance based standards for high capacity transports in Sweden-FIFFI project 2013-03881-Final report. VTI report A, 948.

King, D.A. (red.) (2012). Energy, transport, & the environment - addressing the sustainable mobility. Springer London Ltd.

Knight, I., Newton, W., Barlow, T., McCrae, I., Dodd, M., Couper, G., ... & Ramdas, V. (2008). Longer and/or longer and heavier goods vehicles (LHVs): a study of the likely effects if permitted in the UK (No. PPR 285). UK: TRL.

Kohn, C. (2005). Centralisation of distribution systems and its environmental effects (Doctoral dissertation, Ekonomiska institutionen).

Kohn, C., & Brodin, M. H. (2008). Centralised distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics. International Journal of Logistics: Research and Applications, 11(3), 229-245.

Koniditsiotis, C., Sjögren, J., & Wandel, S. (2012). HIGH CAPACITY TRANSPORTS (HCT) IN SWEDEN AND AUSTRALIA–EXPERIENCES AND ROAD MAP TO THE FUTURE. In HVTT12: International Symposium on Heavy Vehicle Transport Technology, Stockholm, Sweden.

Korzhenevych, A., Dehnen, N., Bröcker, J., Holtkamp, M., Meier, H., Gibson, G., ... & Cox, V. (2014). Update of the handbook on external costs of transport. European Commission DG MOVE.

Koskinen, O. H., & Sauna-aho, J. (2002, June). Nordic VS. Central European Vehicle Configuration–Fuel Economy, Emissions, Vehicle Operating Costs and Road Wear. In 7th International Symposium on Heavy Vehicle Weights & Dimensions. Delft, The Netherlands, June 16-20, 2002 (pp. 241-254).

Kreutzberger, E., Konings, R., & Aronson, L. (2006). Evaluation of pre-and post-haulage in intermodal freight networks. Towards better performing transport networks, 256-284.

Kulcsar, B., (2017). SAEFFLOW – Safety and efficiency analysis of HCT-Traffic flow indicators. Rapport för FFI-projekt 2014- 03933, 2017.

Kyster-Hansen, H., & Sjögren, J. (2013, April). Roadmap High Capacity Transports on road in Sweden. In Forum for Innovation in the Transport Sector, Lindholmen Science Park, Gothenburg.

Leach, D. Z., & Savage, C. J. (2012). Impact assessment: High capacity vehicles.

Leduc, G. (2009). Longer and Heavier Vehicles. JRC Scientific & Technical Reports, European Communities, Luxembourg.

Liddle, B., & Lung, S. (2013). The long-run causal relationship between transport energy consumption and GDP: Evidence from heterogeneous panel methods robust to cross-sectional dependence. Economics Letters, 121(3), 524-527.

Liimatainen, H., & Nykänen, L. (2017). Impacts of increasing maximum truck weight—Case Finland. Transport Research Centre Verne, Tampere University of Technology: Tampere, Finland.

Löfroth, C., & Svenson, G. (2012). ETT–Modulsystem för skogstransporter–En trave Till (ETT) och Större Travar (ST). Arbetsrapport från Skogforsk 758. 158 s.

Löfroth, C., Larsson, L., Enström, J., Cider, L., Svenson, G., Aurell, J., ... & Asp, T. (2012). ETT-a modular system for forest transport. In HVTT12: 12th International Symposium on Heavy Vehicle Transport Technology.

McCulloch, M. D., Bishop, J. D., & Doucette, R. T. (2012). Using electric vehicles for road transport. In Energy, Transport, & the Environment (pp. 223-252). Springer, London.

McKinnon, A. (2012a). Improving the Sustainability of Road Freight Transport by Relaxing Truck Size and Weight Restrictions. In Supply Chain Innovation for Competing in Highly Dynamic Markets: Challenges and Solutions (pp. 185-198). IGI Global.

McKinnon, A. (2016a). Freight transport in a low-carbon world: Assessing opportunities for cutting emissions. TR News, (306).

McKinnon, A. (2018). Decarbonizing logistics: distributing goods in a low carbon world. Kogan Page Publishers.

McKinnon, A. C. (2005). The economic and environmental benefits of increasing maximum truck weight: the British experience. Transportation Research Part D: Transport and Environment, 10(1), 77-95.

McKinnon, A. C. (2007). Increasing fuel prices and market distortion in a domestic road haulage market: the case of the UK.

McKinnon, A. C. (2012b). Reducing energy consumption and emissions in the logistics sector. In Energy, transport, & the environment (pp. 521-537). Springer, London.

McKinnon, A. C. (2016b). Freight transport deceleration: Its possible contribution to the decarbonisation of logistics. Transport Reviews, 36(4), 418-436.

McKinnon, A. C., & Piecyk, M. I. (2009). Measurement of CO2 emissions from road freight transport: A review of UK experience. Energy policy, 37(10), 3733-3742.

Meers, D., van Lier, T., & Macharis, C. (2018). Longer and heavier vehicles in Belgium: A threat for the intermodal sector?. Transportation Research Part D: Transport and Environment, 61, 459-470.

Ministry of Infrastructure and the Environment. (2011). Monitoring Modal Shift. Longer and Heavier Vehicles. The Follow-up Measurement. The Hague.

Monios, J., & Bergqvist, R. (2017). Intermodal freight transport and logistics. CRC Press.

Montufar, J., Regehr, J., Rempel, G., & McGregor, R. V. (2007). Long combination vehicle (LCV) safety performance in Alberta: 1999-2005. Montufar & Associates Transportation Consulting.

Natanaelsson, K., & Brandt, J. (2019). Längre lastbilar på det Svenska vägnätet – För mer hållbara transporter. (publikationsnummer: 2019:076). Trafikverket. Borlänge.

Natanaelsson, K., Åsman, P., Grudemo, S., Adell, E. (2015). Rapport Systemanalys av införande av HCT på väg Slutversion – Underlagsrapport till regeringsuppdraget ”Fördjupade analyser av att tillåta tyngre fordon på det allmänna vägnätet” (Rapport 2015:234). Borlänge: Trafikverket.

Naturvårdsverket (2017), “Riktvärden för buller från väg- och spårtrafik vid befintliga bostäder”, Naturvårdsverket, report ÄNR NV-08465-15, October 2016, rev. June 2017.

http://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/buller/vagar-och-jarnvagar/vagledn-riktv-buller-vag-spar-befintliga-bostader-rev-juni2017.pdf [Accessed 13/3-2019].

NIER, (2018). Forecast on Swedish and International Economy https://www.konj.se/publikationer/konjunkturlaget/prognosjamforelse.html [Accessed 05/02-2019].

OECD (2011). Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability, OECD Publishing.

Ogburn, M., Ramroth, L., & Lovins, A. B. (2008). Transformational trucks: determining the energy efficiency limits of a class-8 tractor-trailer. Snowmass, CO: Rocky Mountain Institute. Publ. T08-08.

Ortega, A., Vassallo, J. M., Guzman, A. F., & Pérez-Martínez, P. J. (2014). Are longer and heavier vehicles (LHVs) beneficial for society? A cost benefit analysis to evaluate their potential implementation in Spain. Transport reviews, 34(2), 150-168.

Pålsson, H., Winslott Hiselius, L., Wandel, S., Khan, J., & Adell, E. (2017). Longer and heavier road freight vehicles in Sweden: Effects on tonne-and vehicle-kilometres, CO2 and socio-economics. International Journal of Physical Distribution & Logistics Management, 47(7), 603-622.

Piecyk, M. I., & McKinnon, A. C. (2010). Forecasting the carbon footprint of road freight transport in 2020. International Journal of Production Economics, 128(1), 31-42.

Resor, R. R., Blaze, J. R., & Morlok, E. K. (2004). Short-haul rail intermodal: can it compete with trucks?. Transportation Research Record, 1873(1), 45-52.

Rodrigues, V. S., Piecyk, M., Mason, R., & Boenders, T. (2015). The longer and heavier vehicle debate: A review of empirical evidence from Germany. Transportation Research Part D: Transport and Environment, 40, 114-131.

Rossi, S., Colicchia, C., Cozzolino, A., & Christopher, M. (2013). The logistics service providers in eco-efficiency innovation: an empirical study. Supply chain management: an international journal, 18(6), 583-603.

Rushton, A., Croucher, P., & Baker, P. (2014). The handbook of logistics and distribution management: Understanding the supply chain. Kogan Page Publishers.

Salet, M., Aarts, L., Honer, M., Davydenko, I., Quak, H., de Bes van Staalduinen, J., & Verweij, K. (2010). Longer and Heavier Vehicles in the Netherlands: facts, figures and experiences in the period 1995-2010. Netherlands Ministry of Transport, 1-71.

Sandberg, U., Kharrazi, S., & Mioduszewski, P. (2018). Comparison Of Noise Emission Of HCT And Classic Vehicle Combinations For Timber Transportation In Sweden. In 15th International Symposium on Heavy Vehicule Transport Technology: HVTT 15, Oct 2018, ROTTERDAM, Netherlands.

Schramm, W. (1971). Notes on case studies of instructional media projects. Academy for Educational Development, Washington, DC.

Sharpe, B., & Rodríguez, F. (2018). Market Analysis of Heavy-Duty Commercial Trailers in Europe.

Sjöström, T. (2016). Potentialen i ny teknik i godssystemet. Sweco.

Statistics Sweden, (2019). Statistics Database. http://www.scb.se/ [Accessed 05/02-2019].

Steer, J., Dionori, F., Casullo, L., Vollath, C., Frisoni, R., Carippo, F., & Ranghetti, D. (2013). A Review of Megatrucks—Major Issues and Case Studies. Directorate general for internal policies, Policy Department B: Structural and cohesion policies, Transport and tourism.

Stockhammar, P., and Brusewitz, U. H. (2018). Utvärdering av makroekonomiska prognoser. Rapportnr: KI-NR 2018:11. NIER. Stockholm.

Stridsberg, M., & Sundin, J. (2017). Transportmarknaden i siffror 2017. Transport administration. Dnr: TSG 2017-4166.

Swedish Environmental Protection Agency, (2018a), National Inventory Report Sweden, Greenhouse Gas Emission Inventories 1990-2016. United Nations Framework Convention on Climate Change and the Kyoto Protocol.

Swedish Environmental Protection Agency. (2018b). Fördjupad analys av svensk klimatstatistik 2018, Swedish Environmental Protection Agency, Rapport 6848.

Swedish EPA. (2017). Sweden's Climate Act and climate policy framework http://www.swedishepa.se/Environmental-objectives-and-cooperation/Swedish-environmental-work/Work-areas/Climate/Climate-Act-and-Climate-policy-framework-/ [Accessed 27/2-2019].

Swedish Government Official Report. (2013). Fossilfrihet på väg.

Swedish Transport Administration, (2019a). https://nvdb2012.trafikverket.se/SeTransportnatverket. [Accessed 20/3-2019].

Swedish Transport Administration, (2019b). Loading Class BK4 - Roads for traffic up to 74 tonnes https://www.trafikverket.se/for-dig-i-branschen/vag/barighetsklass-bk4/ [Accessed 22/2-2019].

Swedish Transport Agency, (2019a). Permissible Axle and Truck Load https://www.transportstyrelsen.se/sv/vagtrafik/Yrkestrafik/Gods-och-buss/Matt-och-vikt/ [Accessed 22/2-2019].

Swedish Transport Agency, (2019b). https://www.transportstyrelsen.se/en/road/ [Accessed 15/3-2019].

Tapio, P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. Transport policy, 12(2), 137-151.

The Dutch Ministry of Infrastructure and the Environment, (2011). Longer and Heavier Vehicles in Practice. The Hague.

TRAFA, Transport Analysis (2019). Transport Statistics. https://www.trafa.se/. [Accessed 12/3-2019].

Transport Administration (2011). Situationen i det svenska järnvägsnätet. Publikation TRV 2011/10161A.

Transport Administration (2018). Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.1. https://www.trafikverket.se/contentassets/4b1c1005597d47bda386d81dd3444b24/asek-6.1/asek_6_1_hela_rapporten_180412.pdf [Accessed 2/4–2019].

Transport and Environment (2013), “Longer and heavier lorries in the EU”, available at: https://www.transportenvironment.org/sites/te/files/publications/T%26E%20position%20paper%20megatrucks%202013_final.pdf [Accessed 28-02-2019].

Treiber, A., Bark, P. (2016). Energieffektiva transporter av massgods i stora tätortsområden och storstäder. Transportforskning (TFK) Stockholm.

Vierth, I., Berell, H., McDaniel, J., Haraldsson, M., Hammarström, U., Yahya, M. R., ... & Björketun, U. (2008). The effects of long and heavy trucks on the transport system: Report on a government assignment. Statens väg-och transportforskningsinstitut.

Vierth, I., Lindgren, S., & Lindgren, H. (2018). Impact of higher road vehicle dimensions on modal split: An ex-post analysis for Sweden. Statens väg-och transportforskningsinstitut.

Villalobos, J., and Wilmsmeier, G. (2016). Freight transport by road: Tools and strategies for energy efficiency and sustainability. Boletín FAL No. 349, ECLAC, Santiago, Chile.

Vrouwenvelder, A.C.W.M. (2008), “Comparison of Truck-Semitrailer Combinations and LHVs with Regard to their Effect on Bridges”, TNO report 2008-D-R0102/B, TNO, April 7th.

Wee, B.V., Annema, J.A. & Banister, D. (red.) (2013). The transport system and transport policy: an introduction. Cheltenham, UK: Edward Elgar.

Ye, Y., Shen, J., & Bergqvist, R. (2014). High-capacity transport associated with pre-and post-haulage in intermodal road-rail transport. Journal of Transportation Technologies, 4(03), 289.

Yin, R. K. (2017). Case study research and applications: Design and methods. Sage publications.

Appendix 1- Literature Review

Aspects -	Costs		Environment			Infrastructure		Safety				
Reference	Operational	External	Emissions	Congestion	Noise	Bridges	Road wear	Capabilities	Risks	Road Freight	Modal shift	Other
Adell et al., (2013)	X		X				X		X	X		
Adell et al., (2016)	X		X							X	X	
af Wåhlberg (2008)								X	X	X		
Arnäs et al., (2013)						X				X		
Asmoarp et al., (2015)	X									X		
Asp et al., (2018)						X	X		X			X
Bálint et al., (2014)								X	X	X		
Ben Jebli & Hadhri (2018)			X									X
Bergqvist & Behrends (2011)	X		X	X			X		X	X	X	X
Bergqvist & Monios (2016)	X										X	X
Berndtsson & Åsman (2014)			X			X					X	
Castillo-Manzano et al., (2016)	X	X						X				
Christidis & Leduc (2009)	X	X	X	X	X				X	X	X	
Cider & Ranäng (2013)									X	X		X
Danish Ministry of Transport (2011)			X		X				X	X		
Debauche (2008)			X		X	X	X		X	X	X	
Ericson et al., (2010)	X	X	X	X	X		X		X	X	X	
Flodén (2007)	X	X	X							X	X	
Fröjd et al., (2017)					X			X		X		
Granlund & Lang (2016)							X					X
Hellung-Larsen (2012)		X	X		X		X		X			X
Johansson & von Hofsten (2017)	X									X		
Kharrazi et al., (2014)			X		X	X	X	X				X
Kharrazi et al., (2017)					X			X				X
Knight et al., (2008)	X	X	X	X	X	X	X	X	X	X	X	X
Koniditsiotis & Sjögren (2012)										X		X
Koskinen & Sauna-aho (2002)	X		X				X	X		X		
Kryster-Hansen & Sjögren (2013)	X		X			X	X		X	X		
Kulcsar (2017)								X	X			
Leach & Savage (2012)	X		X	X			X	X	X	X	X	
Leduc (2009)						X	X	X		X		
Liddle & Lung (2013)												X
Liimatainen & Nykänen (2017)		X	X							X		
McKinnon & Piecyk (2009)			X									
McKinnon (2005)	X		X	X		X	X		X	X	X	
McKinnon (2007)	X									X		
McKinnon (2009)												X
McKinnon (2012a)		X	X							X	X	
McKinnon (2012b)			X							X	X	
McKinnon (2016a)			X							X	X	X
McKinnon (2016b)			X							X	X	
Meers et al., (2018)	X	X									X	X
Monios & Bergqvist (2017)										X	X	X
Natanaelsson & Brandt (2019)			X		X			X	X	X	X	
Naturvårdsverket (2017)			X									
Netherlands Ministry of Transport (2010)			X		X	X	X		X	X	X	
OECD (2011)	X	X	X	X	X	X	X	X	X	X	X	X
Ortega et al., (2014)	X	X	X			X		X		X	X	
Pålsson et al., (2017)	X		X			X	X			X	X	
Rodrigues et al., (2015)	X		X			X	X		X	X	X	
Sandberg et al., (2018)					X							
Sharpe & Rodriguez (2018)								X		X		X
Steer et al., (2013)			X	X		X	X		X	X	X	
Tapio (2005)												X
Traffic administration (2018)	X	X	X	X	X		X		X		X	X
Vierth et al., (2008)	X	X	X		X			X	X		X	
Vierth et al., (2018)		X	X							X	X	
Ye et al., (2014)	X	X	X			X			X		X	X
Åkerman & Jonsson (2007)		X	X	X			X	X		X	X	
Åsman & Asp (2018)						X						

Appendix 2- Inter-relationships in heavy-truck accidents

Following table describes the number of accidents in Sweden between 2015 and 2017. The total number of accidents has decreased during the period, the different in each accident between a heavy vehicle and any other actor in traffic is specified below. (Trafa, 2019)

	Fatal Accidents			Severe Accidents		
Relationship:	2015	2016	2017	2015	2016	2017
Truck – Bus	0	0	1	4	2	6
Truck – Bicycle	5	4	4	16	18	16
Truck – Animal	1	0	0	1	2	3
Truck – Pedestrian	5	7	6	24	28	23
Truck – Truck	3	5	2	23	20	21
Truck – Moped	0	0	0	5	6	7
Truck – Motorcycle	6	4	5	9	7	5
Truck – Tractor/Harvester	0	1	0	0	4	6
Truck – Other	0	0	0	5	3	6
Truck (Single)	9	4	5	45	53	45
Truck – Passenger Car	25	26	20	128	114	116
Total Traffic Accidents	**240**	**243**	**233**	**2012**	**1947**	**1866**
Heavy Vehicles Involved	23 %	21 %	18 %	13 %	13 %	14 %

Appendix 3- Terminals of DHL Freight

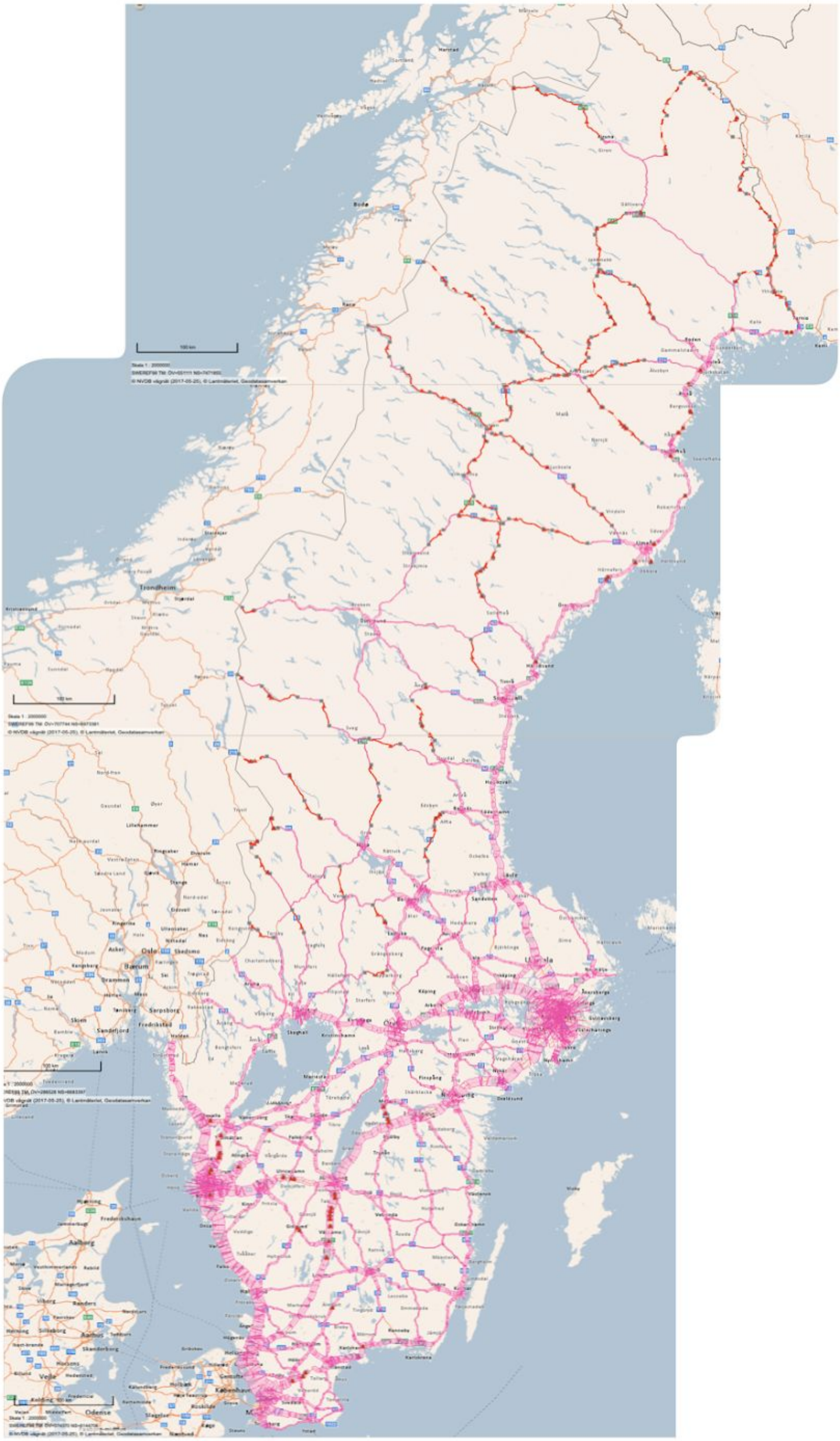
Number	City
1	Borlänge
2	Gävle
3	Gothenburg*
4	Helsingborg*
5	Karlstad
6	Luleå
7	Oskarshamn
8	Rosersberg*
9	Sundsvall
10	Visby
11	Växjö
12	Örebro
13	Östersund
14	Borås
15	Eskilstuna
16	Halmstad
17	Jönköping*
18	Malmö*
19	Norrköping
20	Skellefteå
21	Tibro
22	Umeå
23	Uppsala
24	Värnamo
25	Västberga

*Terminals with an international connection (DHL Freight, 2019).

Appendix 4- Distance Matrix of the Terminal Network (km)

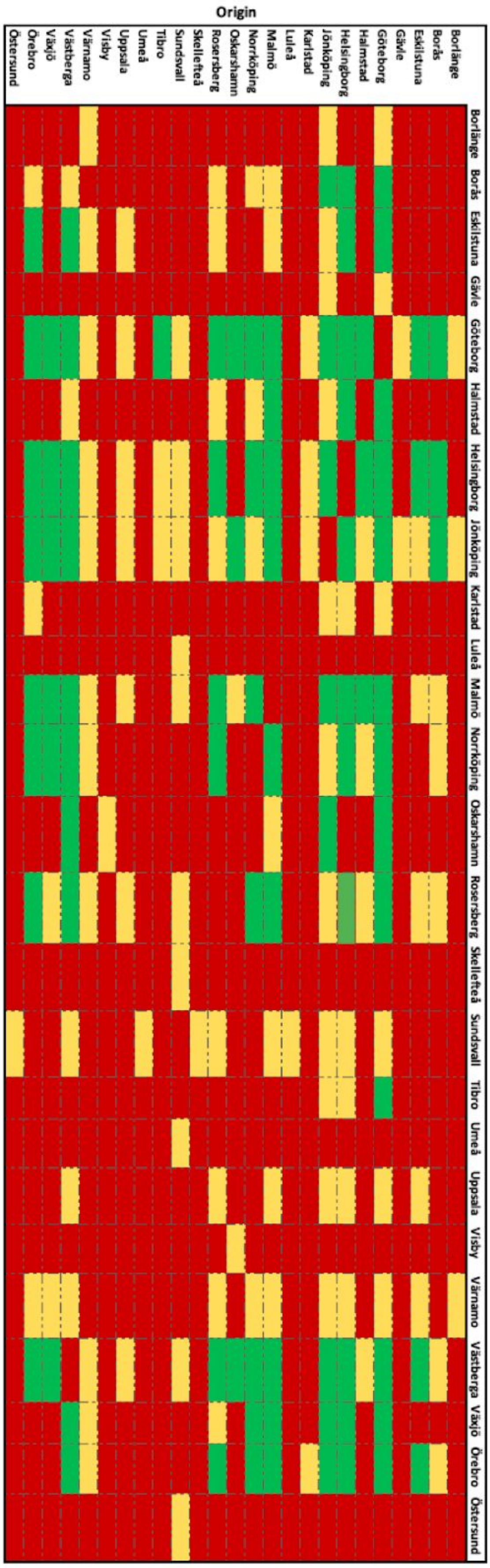
Distance (km)	Borlänge	Borås	Eskilstuna	Gävle	Göteborg	Halmstad	Helsingborg	Jönköping	Karlstad	Luleå	Malmö	Norrköping	Oskarshamn	Rosersberg	Skellefteå	Sundsvall	Tibro	Umeå	Uppsala	Visby	Värnamo	Västberga	Växjö	Örebro	Östersund
Borlänge		423	175	110	446	553	607	373	206	836	664	264	441	204	707	315	290	572	159	424	442	221	468	160	389
Borås	423		357	575	67	154	228	84	269	1301	285	250	255	438	1171	780	128	1037	473	385	108	399	172	262	758
Eskilstuna	175	357		188	374	438	505	273	198	914	563	112	289	143	784	392	219	649	111	281	341	104	368	91	572
Gävle	110	575	188		519	671	724	492	345	731	782	331	508	142	601	210	365	467	111	383	562	179	587	236	390
Göteborg	446	67	374	519		140	215	147	249	1244	272	312	319	499	1114	725	174	980	453	443	164	463	229	285	779
Halmstad	553	154	438	671	140		81	182	386	1397	139	346	256	519	1267	875	239	1118	555	384	116	495	131	393	869
Helsingborg	607	228	505	724	215	81		236	461	1450	65	398	309	586	928	928	316	1187	622	437	167	548	185	445	945
Jönköping	373	84	273	492	147	182	236		237	1218	293	167	174	354	1088	696	82	953	390	299	72	316	132	213	729
Karlstad	206	269	198	345	249	386	461	237		1071	518	220	377	298	940	549	160	806	279	475	313	297	385	109	541
Luleå	836	1301	914	731	1244	1397	1450	1218	1071		1508	1056	1234	868	131	525	1091	266	832	1108	1287	905	1312	962	577
Malmö	664	285	563	782	272	139	65	293	518	1508		457	326	643	1378	985	374	1243	680	453	224	605	204	504	1002
Norrköping	264	250	112	331	312	346	398	167	220	1056	457		172	193	926	535	194	792	228	299	236	154	262	118	715
Oskarshamn	441	255	289	508	319	256	309	174	377	1234	326	172		370	1104	712	259	966	406	128	171	329	127	285	890
Rosersberg	204	438	143	142	499	519	586	354	298	868	643	193	370		741	346	319	603	40	244	422	40	448	189	527
Skellefteå	707	1171	784	601	1114	1267	1321	1088	940	131	1378	926	1104	741		395	965	137	702	977	1156	774	1204	832	462
Sundsvall	315	780	392	210	725	875	928	696	549	525	985	535	712	346	395		570	261	310	586	764	383	791	440	188
Tibro	290	128	219	365	174	239	316	82	160	1091	374	194	259	319	965	570		827	300	384	152	318	204	130	648
Umeå	572	1037	649	467	980	1118	1187	953	806	266	1243	792	966	603	137	261	827		568	843	1021	640	1048	697	363
Uppsala	159	473	111	111	453	555	622	390	279	832	680	228	406	40	702	310	300	568		280	458	76	506	158	491
Visby	424	385	281	383	443	384	437	299	475	1108	453	299	128	244	977	586	384	843	280		299	211	254	367	766
Värnamo	442	108	341	562	164	116	167	72	313	1287	224	236	171	422	1156	764	152	1021	458	299		384	67	281	808
Västberga	221	399	104	179	463	495	548	316	297	905	605	154	329	40	774	383	318	640	76	211	384		411	190	562
Växjö	468	172	368	587	229	131	185	132	385	1312	204	262	127	448	1204	791	204	1048	506	254	67	411		308	859
Örebro	160	262	91	236	285	393	445	213	109	962	504	118	285	189	832	440	130	697	158	367	281	190	308		545
Östersund	389	758	572	390	779	869	945	729	541	577	1002	715	890	527	462	188	648	363	491	766	808	562	859	545	

Appendix 5- Traffic work in Sweden 2017

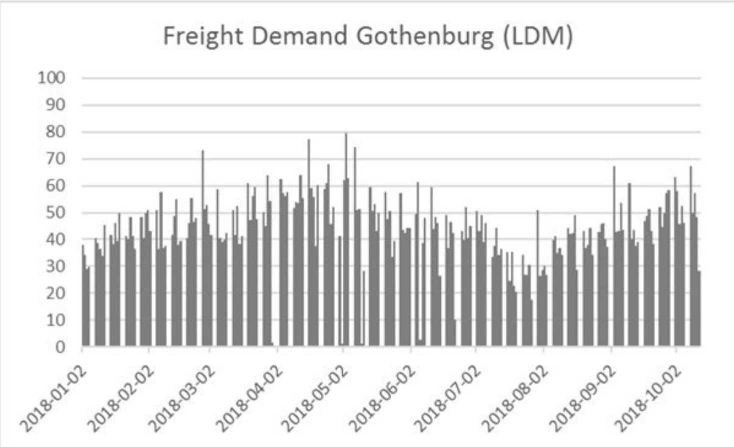


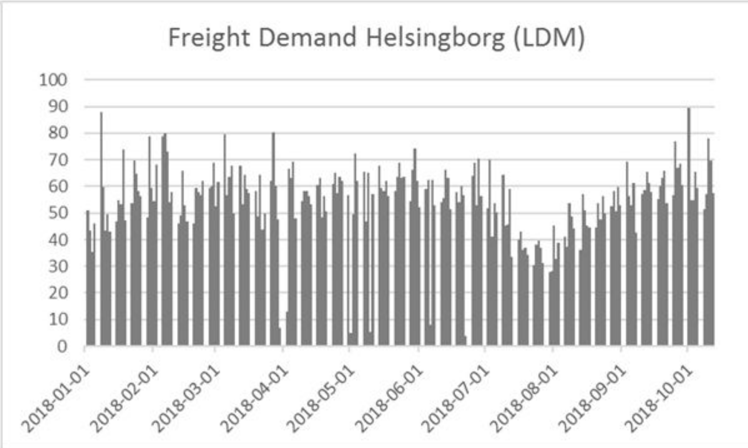
Swedish Transport Administration (2019a)

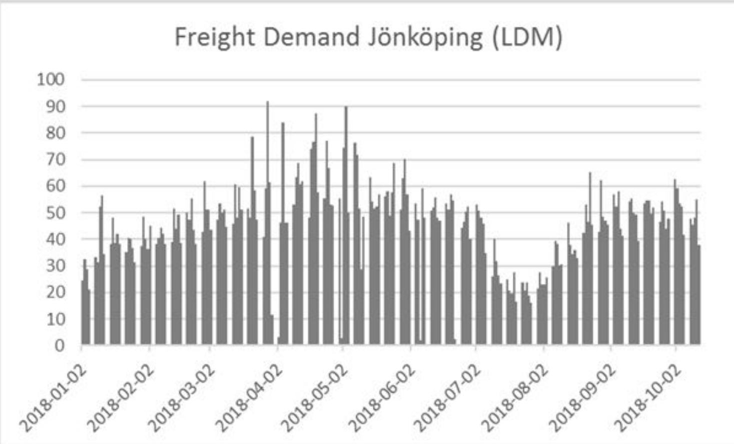
Appendix 6- Imbalances between two-way relationships

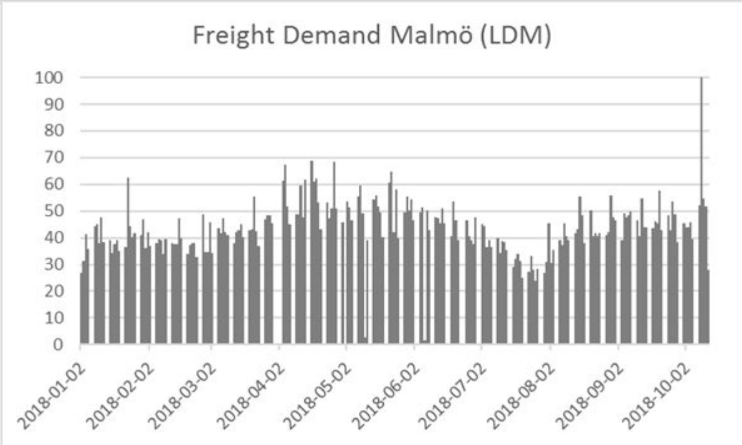


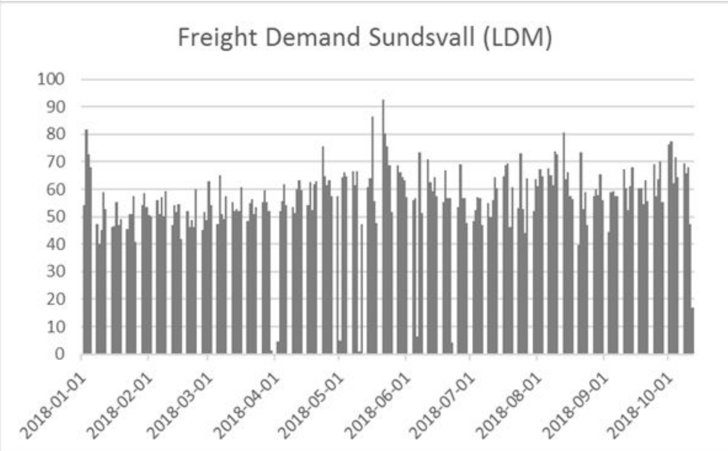
Appendix 7- Freight demand of highlighted terminals

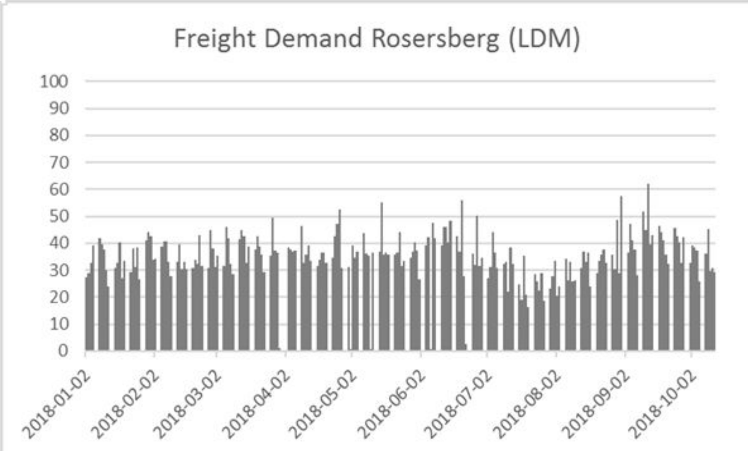


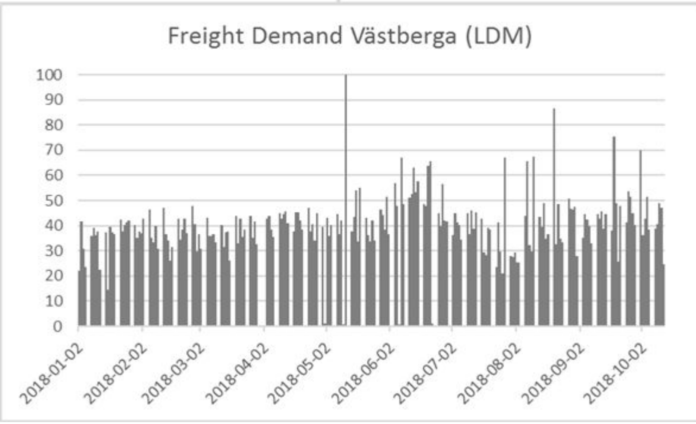




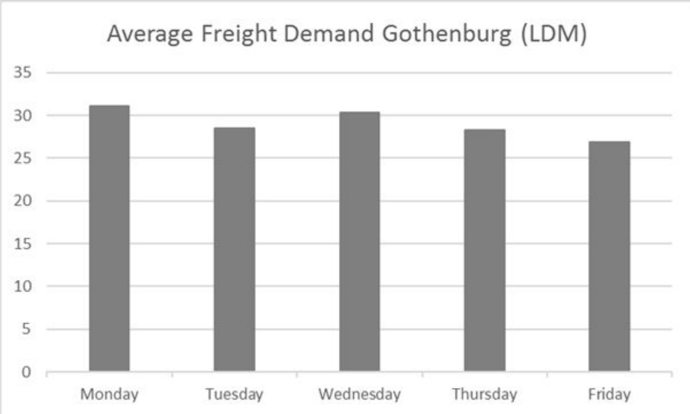


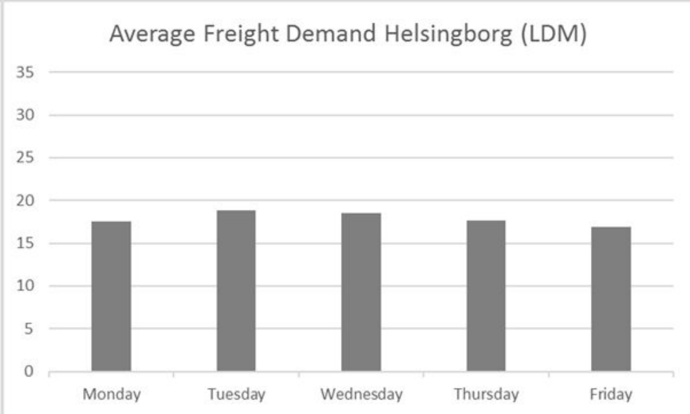


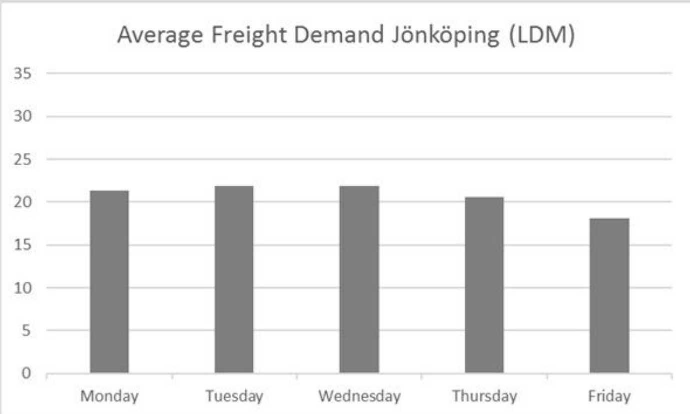


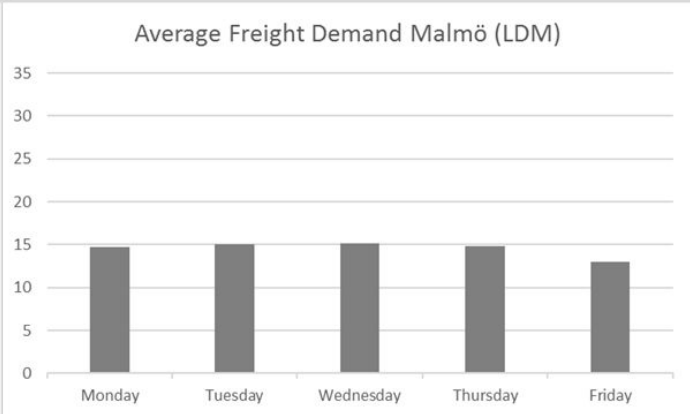


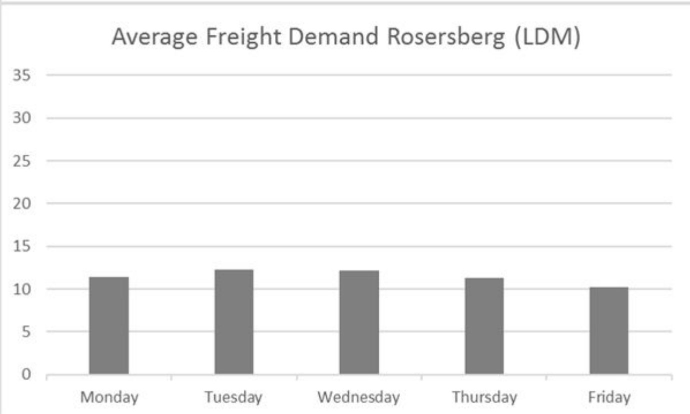
Appendix 8- Average freight demand allocation weekdays

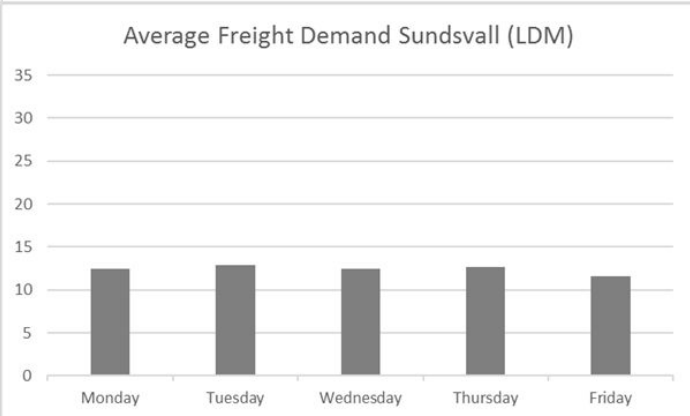


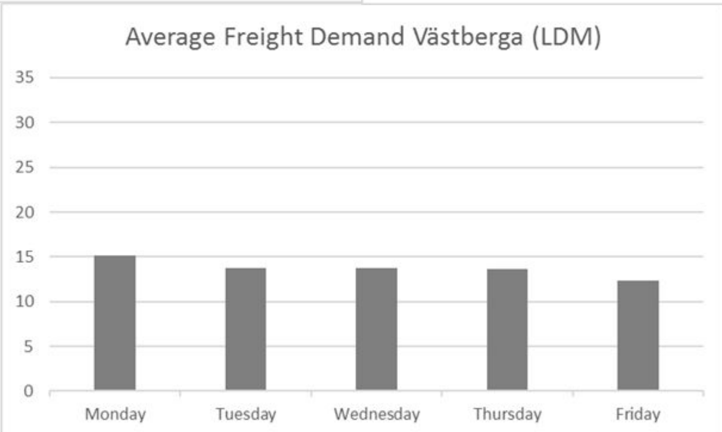












Appendix 9- Available roads for an introduction of HCT

Roads that can carry HCTs (Natanaelsson and Brandt, 2019, p.50).

Appendix 10- Intersections closeby the terminals

9.1 Gothenburg

Street view of the roundabout from the departing view of Gothenburg's terminal (correlate to figure 4.3).

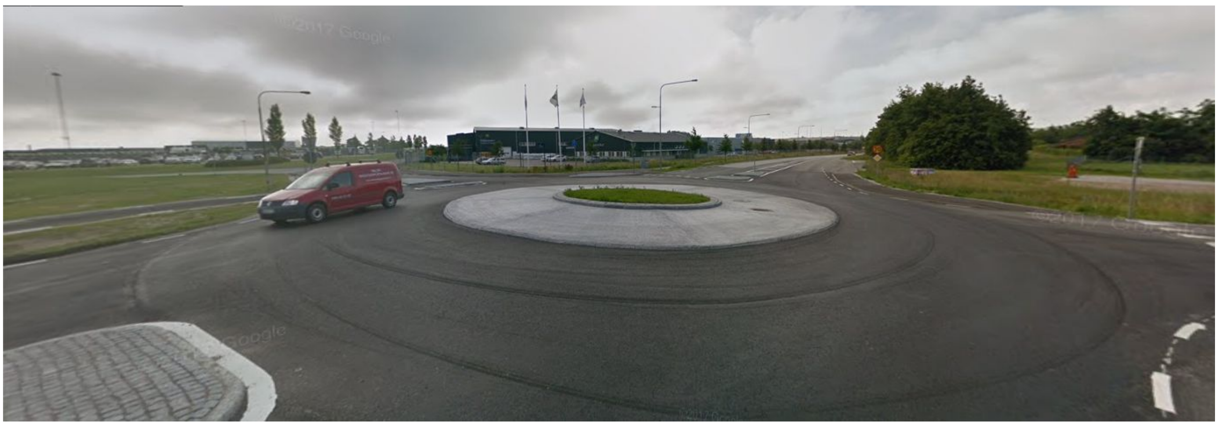
9.2 Helsingborg

Street view of the T-junction from the departing view of Helsingborg's terminal (correlate to figure 4.4).

Street view of the first roundabout when departing from Helsingborg (correlate to figure 4.4).

Street view of the second roundabout when departing from Helsingborg (correlate to figure 4.4).

9.3 Malmö



The first roundabout (not visible in figure 4.5 as it has recently been constructed) from the departing view from Malmö (correlate to figure 4.5).

A photo of the right turn to enter Road 11 from the departing view from Malmö (correlate to figure 4.5).

The right turn (exit ramp) to reach the terminal of Malmö from the view of an arriving vehicle (correlate to figure 4.5).

9.4 Jönköping

The smaller roundabout near the terminal (correlate to figure 4.6).

The T-junction on Sagaholmsvägen from the view of an arriving vehicle (correlate to figure 4.6 and 4.7).

The larger T-junction on Sagaholmsvägen/Barnarpsvägen in the view of a departing vehicle (correlate to figure 4.7).

A newly constructed roundabout in the view of a departing vehicle (correlate to figure 4.7).

The first T-junction after exiting E4 in the view of vehicles arriving from Helsingborg and Malmö (correlate figure 4.7).

The larger roundabout entered after exiting Road 40 in the view of arriving vehicles from Stockholm (correlate to figure 4.8).

9.5 Sundsvall

The T-junction on Klökanvägen could be an issue due to the width of the road. View from an arriving vehicle (correlate to figure 4.9).

The first roundabout in the view from a departing vehicle (correlate to figure 4.9).

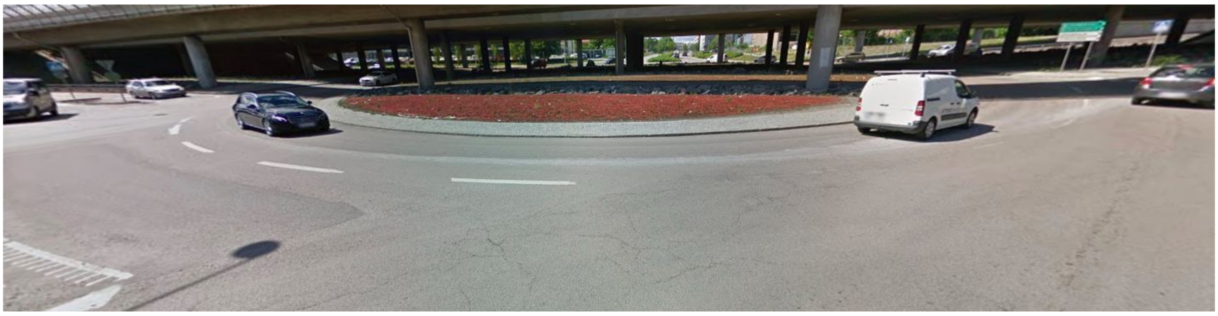
The first roundabout with a separated lane in the view from an arriving vehicle (correlate to figure 4.9).

9.6 Västberga

The first T-junction from the view of a departing vehicle (correlate to figure 4.10).

The first crossroad in the view of an arriving vehicle from the southern terminals, Gothenburg, Helsingborg, Jönköping or Malmö (correlate to figure 4.11).

The smaller roundabout in the view of an arriving vehicle (correlate to figure 4.11).



The larger roundabout in the view from a departing vehicle (correlate to figure 4.11).

9.7 Rosersberg

The roundabout in the view of a departing vehicle (correlate to figure 4.13).

Appendix 11- Costs and Sensitivity Analysis

The Total Cost When Each Parameter is Adjusted

Cost Parameter	Scenario A	-30%	-10%	0%	10%	30%
		Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent				
	Tires	1 007 826 555 kr	1 013 595 144 kr	1 016 479 439 kr	1 019 363 733 kr	1 025 132 323 kr
	Ratio	99,1%	99,7%	100,0%	100,3%	100,9%
	Repair	995 182 983 kr	1 009 380 620 kr	1 016 479 439 kr	1 023 578 257 kr	1 037 775 894 kr
	Ratio	97,9%	99,3%	100,0%	100,7%	102,1%
	Fuel	913 134 071 kr	982 030 983 kr	1 016 479 439 kr	1 050 927 895 kr	1 119 824 806 kr
	Ratio	89,8%	96,6%	100,0%	103,4%	110,2%
	Depreciation	980 018 052 kr	1 004 325 643 kr	1 016 479 439 kr	1 028 633 234 kr	1 052 940 825 kr
	Ratio	96,4%	98,8%	100,0%	101,2%	103,6%
	Salary	915 938 364 kr	982 965 747 kr	1 016 479 439 kr	1 049 993 130 kr	1 117 020 513 kr
	Ratio	90,1%	96,7%	100,0%	103,3%	109,9%
	Other	1 005 510 968 kr	1 012 823 282 kr	1 016 479 439 kr	1 020 135 595 kr	1 027 447 909 kr
	Ratio	98,9%	99,6%	100,0%	100,4%	101,1%

The Total Cost When Each Parameter is Adjusted

Cost Parameter	Scenario B	-30%	-10%	0%	10%	30%
		Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent				
	Tires	1 076 702 067 kr	1 086 455 628 kr	1 091 332 408 kr	1 096 209 188 kr	1 105 962 748 kr
	Ratio	98,7%	99,6%	100,0%	100,4%	101,3%
	Repair	1 060 109 121 kr	1 080 924 645 kr	1 091 332 408 kr	1 101 740 170 kr	1 122 555 695 kr
	Ratio	97,1%	99,0%	100,0%	101,0%	102,9%
	Fuel	991 382 919 kr	1 058 015 911 kr	1 091 332 408 kr	1 124 648 904 kr	1 191 281 897 kr
	Ratio	90,8%	96,9%	100,0%	103,1%	109,2%
	Depreciation	1 049 582 412 kr	1 077 415 743 kr	1 091 332 408 kr	1 105 249 073 kr	1 133 082 403 kr
	Ratio	96,2%	98,7%	100,0%	101,3%	103,8%
	Salary	997 834 962 kr	1 060 166 592 kr	1 091 332 408 kr	1 122 498 223 kr	1 184 829 854 kr
	Ratio	91,4%	97,1%	100,0%	102,9%	108,6%
	Other	1 078 569 517 kr	1 087 078 111 kr	1 091 332 408 kr	1 095 586 705 kr	1 104 095 298 kr
	Ratio	98,8%	99,6%	100,0%	100,4%	101,2%

The Total Cost When Each Parameter is Adjusted

Cost Parameter	Scenario C	-30%	-10%	0%	10%	30%
		Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent				
	Tires	951 857 945 kr	957 682 988 kr	960 595 510 kr	963 508 032 kr	969 333 075 kr
	Ratio	99,1%	99,7%	100,0%	100,3%	100,9%
	Repair	939 592 754 kr	953 594 591 kr	960 595 510 kr	967 596 429 kr	981 598 266 kr
	Ratio	97,8%	99,3%	100,0%	100,7%	102,2%
	Fuel	864 086 827 kr	928 425 949 kr	960 595 510 kr	992 765 071 kr	1 057 104 194 kr
	Ratio	90,0%	96,7%	100,0%	103,3%	110,0%
	Depreciation	925 865 476 kr	949 018 832 kr	960 595 510 kr	972 172 188 kr	995 325 544 kr
	Ratio	96,4%	98,8%	100,0%	101,2%	103,6%
	Salary	867 098 064 kr	929 429 695 kr	960 595 510 kr	991 761 325 kr	1 054 092 956 kr
	Ratio	90,3%	96,8%	100,0%	103,2%	109,7%
	Other	950 126 520 kr	957 105 847 kr	960 595 510 kr	964 085 174 kr	971 064 500 kr
	Ratio	98,9%	99,6%	100,0%	100,4%	101,1%

The Total Cost When Each Parameter is Adjusted

	Scenario A	**Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent**				
		-30%	-10%	0%	10%	30%
Distance Factor	Averge Speed	1 209 604 778 kr	1 066 548 971 kr	1 016 479 439 kr	975 513 458 kr	912 488 871 kr
	Ratio	119,0%	104,9%	100,0%	96,0%	89,8%
	Utalized Hour	1 050 305 429 kr	1 025 249 140 kr	1 016 479 439 kr	1 009 304 229 kr	998 265 444 kr
	Ratio	103,3%	100,9%	100,0%	99,3%	98,2%

The Total Cost When Each Parameter is Adjusted

	Scenario B	**Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent**				
		-30%	-10%	0%	10%	30%
Distance Factor	Averge Speed	1 209 604 778 kr	1 066 548 971 kr	1 016 479 439 kr	975 513 458 kr	912 488 871 kr
	Ratio	119,0%	104,9%	100,0%	96,0%	89,8%
	Utalized Hour	1 050 305 429 kr	1 025 249 140 kr	1 016 479 439 kr	1 009 304 229 kr	998 265 444 kr
	Ratio	103,3%	100,9%	100,0%	99,3%	98,2%

The Total Cost When Each Parameter is Adjusted

	Scenario C	**Change in the Total Costs, when each parameter is adjusted with 30 or 10 percent**				
		-30%	-10%	0%	10%	30%
Distance Factor	Averge Speed	1 209 604 778 kr	1 066 548 971 kr	1 016 479 439 kr	975 513 458 kr	912 488 871 kr
	Ratio	119,0%	104,9%	100,0%	96,0%	89,8%
	Utalized Hour	1 050 305 429 kr	1 025 249 140 kr	1 016 479 439 kr	1 009 304 229 kr	998 265 444 kr
	Ratio	103,3%	100,9%	100,0%	99,3%	98,2%