UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Intermodal High-Capacity Transport for Pre- and Post-Haulage

A multiple-case study of the potential for high-capacity rail-road transport in the Swedish freight transport market

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Abstract

The concept of intermodal freight transport has been acknowledged as a policy tool to achieve an improved utilization of the transport system. Particularly intermodal rail-road transport (IRT) has recently gained in importance due to the benefits associated with its operational and environmental efficiency. In this regard, the employment of longer or heavier vehicles (LHVs) for the road freight pre- and post-haulage (PPH) activities is a crucial factor to exhaust the potential of an IRT system. Based on previous studies and practices with LHVs in Sweden, this thesis develops a holistic perspective of the potential that intermodal high-capacity transport (IHCT) has in the Swedish market. Contributions of several national terminal providers and logistics service providers are utilized to identify the current barriers for IHCT and draw a picture of the improvements of the operational and environmental costs that can be achieved when LHVs are employed on distances to and from the nearest IRT terminal. The objective is to provide an enhanced understanding of the prospects that IHCT has as a national strategy to foster aspects such as competition and sustainability. Results show, that the allowance for LHVs in Sweden can contribute to operational costs reductions of up to 13.7%.

Key words: high-capacity transport, pre- and post-haulage, intermodal rail-road transport, LHVs, operational cost, external cost

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Abbreviations and Terminology

EMS - European Modular System

HCT - High-Capacity Transport

HCV - High-Capacity Vehicle

IAC – Intelligent Access Control

IHCT - Intermodal High-Capacity Transport

In this study used for the employment of LHVs in an IRT chain.

ILU - Intermodal Loading Unit

IRT - Intermodal Rail-Road Transport

ISO - International Organisation for Standardisation

LHV - Longer Heavier Vehicle

In this study defined as a road freight vehicle that is exceeding the currently in Sweden permitted dimensions of a length of 25.25m and/or a weight of than 64t. Specifically defined as a vehicle of a length of up to 34.5m and a weight of up to 74t.

LSP – Logistics Service Provider

PBS – Performance Based Standards

PPH - Pre- and Post-Haulage

SIAP – Smart Infrastructure Access Policy

STA – Swedish Transport Administration (Trafikverket)

TEU - Twenty-foot Equivalent Unit

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1. INTRODUCTION

This chapter serves to introduce the background on whose basis the research problem has been identified and formulated. Besides, the specific research project from which this study originates will be presented. Based on this project, the purpose of the study as well as the research questions that are sought to be answered are outlined. To classify the scope of the study, this chapter moreover presents the delimitations of the investigation, as well as the expected results.

1.1 Background

The European Union's competitiveness in the global economy relies strongly on the ability to promote efficiency in terms of their transport system. Therefore, it has been highlighted as a necessity to exploit the transport systems capacity as efficiently as possible, and thus foster aspects such as sustainability, reliability, and flexibility. In the late 1990s, the European Commission already raised the growth in freight traffic as a major concern with regards to the occurring environmental and social issues. The infrastructure was seen as being inefficiently used, and the employment of different modes of transport was strongly imbalanced. Particularly the market share of road transport in Europe has been steadily increasing together with the freight industry (European Commission, 1997). This fact poses a considerable problem, as road transports are accompanied by many externalities such as noise, urban congestion, and air pollution. Besides, the transport sector is a main contributor to CO2 emissions, accounting for approximately a quarter of the overall greenhouse gas emissions in Europe. With 71% in 2018, the highest proportion of these transport emissions can be attributed to road transports. While emissions in other sectors are declining clearly, projections indicate that by 2030 transport emission levels will still remain higher than in 1990. Therefore, it will be unlikely to achieve the EU's emission reduction targets for 2030, and moreover comply with the Paris agreement's overall target of being climate neutral by 2050 (European Commission, 2021a; EEA, 2021). These issues are becoming more significant given the fact that road transport is growing continuously and is projected to increase by about 40% more by 2030. This has been acknowledged by the EU within their White Paper on Transport which has been published in 2011. The White Paper has set targets to reduce the impact of freight transport, which includes the exhaustion of the potential of intermodal freight transport. The targets prescribe to achieve a modal shift of 30% of the road freight over 300 km by 2030, and a shift of at least 50% by 2050 respectively, with respect to business-as-usual developments (European Commission, 2011). Besides urging a modal shift from road to more environmentally friendly modes of transport such as inland waterways or rail, intermodal transport can also contribute to a more efficient infrastructure usage as well as operational improvements (Islam et. al., 2016). The European Commission therefore highlighted intermodality as a policy tool to enable a systems approach to transport, and thus strengthen the competition between transport operators through seamless, customer-oriented services (European Commission, 1997).

In alignment with the climate goals and transport strategies adopted by the EU, Sweden introduced its own national climate policy framework in 2017 with the long-term target of achieving net zero greenhouse gas emissions by 2045. The strategy integrates different action areas and instruments with the objective to incentivise a reduction of emissions in all sectors of society. One of the main action areas to reduce national emission levels is the domestic transport sector, for which an additional milestone has been established. It prescribes an achievement of emission reductions for domestic transports (excluding aviation) of at least 70% by 2030, compared to 2010 (Ministry of the Environment, 2020). Recent statistics for the year 2019 *(figure 1.1)* indicate that total greenhouse gas emissions in Sweden comprised around 50.9 million tonnes, whereof 16.4 million tonnes can be attributed to domestic transports. Roughly 15 million tonnes of these domestic transport emissions are in turn caused by road transport. Compared with previous years, the numbers show that national greenhouse gas emissions have already been declining persistently, also with regards to domestic road transports (SCB, 2021a; SCB, 2021b). However, previous reductions in road traffic emissions were mainly possible through the usage of alternative fuels, electrified vehicles, and a more energy efficient vehicle fleet. Together with continuously growing traffic volumes, these measures and instruments will however not be sufficient to comply with the Swedish long-term climate targets (Trafikverket, 2020). Moreover, it can be observed that electrification and the shift to alternative fuels are measures that can primarily be applied to passenger vehicles. For heavy duty vehicles on the other hand, electrification is still developing rather slowly, and they are often still propelled with diesel (Nordic Council of Ministers, 2018). With reference to the numbers of 2019, as exemplified in *figure 1.1*, heavy duty vehicles accounted for around 3.2 million emitted tonnes of the overall domestic transport emissions in Sweden, which constitutes a share of roughly 21% (SCB, 2021b).

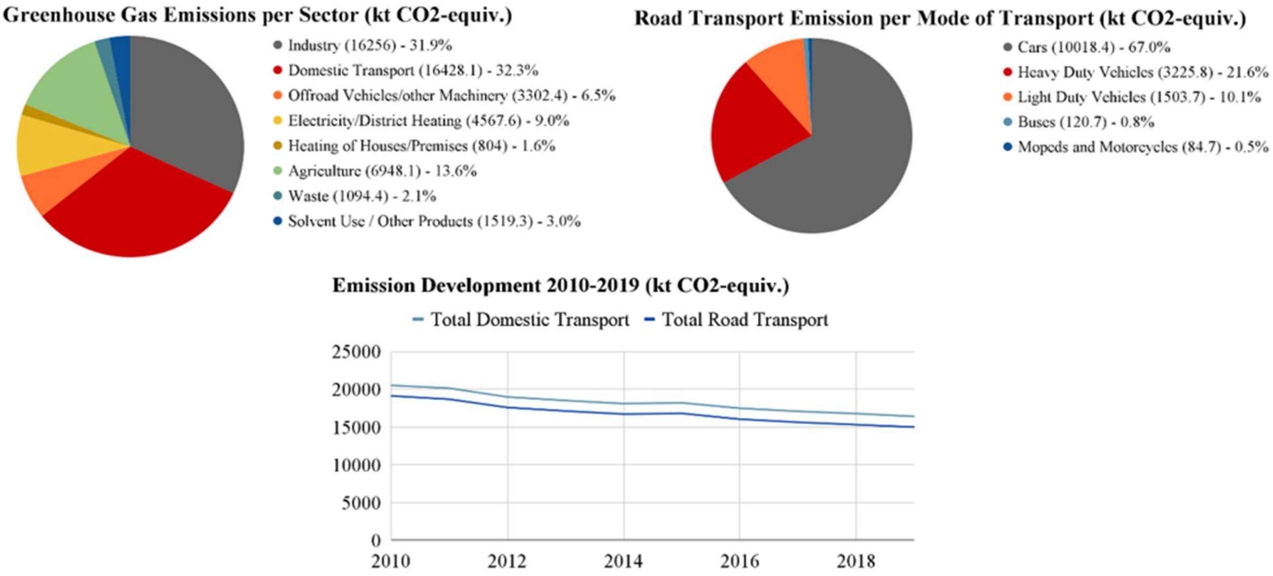

Figure 1.1: Swedish Domestic Transport Emission Levels 2019 and Development 2010-2019 (Data taken from SCB, 2021a; SCB, 2021b; SCB 2021c).

In the long-term, the International Road Transport Union (IRU) predicts a great potential for electrified long haul road transport in Europe. Accordingly, 40-45% of the long-haul road transport should be electrified by 2050, and at least 30% of the utilized fuel for road freight vehicles should be advanced biofuels (Transport & Mobility Leuven, 2017). However, to reduce road traffic emissions in the short term, and thereby achieve the 2030 and 2045 targets respectively, additional more indirect measures to increase the environmental and energy efficiency of the freight distribution system must be taken. These measures can comprise an increased usage of existing environmentally friendly vehicles such as railways and ships, an improved utilization of the transport mode's load capacity, or a better coordination and control of freight flows (Bergqvist et. al., 2017).

Besides the shift to more sustainable propulsion systems, Sweden's strategy for reducing greenhouse gas emissions therefore also contains the aspect of creating a transport-efficient society. For the coordination of freight transport, this can amongst others be achieved through "[...] higher use of vehicle capacity, greater opportunities for longer and heavier trains, [and] greater opportunities for longer and heavier trucks where switching to rail and sea is not a realistic option [...]" (Ministry of the Environment, 2020). These measures are aimed at nudging a process of restructuring in both the rail and the road transport sector, by integrating the exploitation of high-capacity transport (HCT). The suggestion of allowing for longer and heavier trains calls, similar to the EU aims, for a gradual modal shift of freight volumes from road to rail. In cases where this modal shift is not possible, the employment of longer and heavier trucks can contribute to an increased competitiveness of intermodal transport chains (Ye et. al., 2014).

1.2 Research Problem

The concept of intermodal freight transport has been acknowledged by national and international governments and institutions (European Union, 2010; Regeringskansliet, 2018; Trafikverket, 2020), as well as several researchers (Macharis & Bontekoning, 2004; Flodén, 2007; Bergqvist et. al., 2017) as a means of enabling a more efficient utilization of the transport system and promoting sustainability. The main goal of intermodal freight transport is to get different modes of transport joined together to promote cost savings and to maximize the operational efficiency of the transport system (Bergqvist & Behrends, 2011). In domestic freight transport, the predominant form of intermodal transport is performed as intermodal rail-road transport (IRT), where combined terminals are used to trans-ship the goods from rail to road for the Pre- and Post-Haulage (PPH) activities (UIC, 2020). IRT chains commonly stand in strong competition with road-only freight transport, mainly due to the costs associated with terminal handling and PPH. The main challenge for increasing the competitiveness of IRT is thus to become more cost-efficient in every stage of the transport network, in order to reduce the break-even point between road-only freight transport and IRT (Ye et. al., 2014).

One strategy to reduce the PPH costs of an IRT chain is to employ longer and heavier vehicles (LHVs) for road freight transports. LHVs allow for the transportation of more goods per trip and can thus reduce the cost per transported unit. Besides that, LHVs can contribute to reduced domestic transport emissions, as their usage will result in the circulation of fewer road freight vehicles in the transport network (Bergqvist & Monios, 2016). When LHVs are employed for the PPH operations within an IRT chain, one can refer to the concept of intermodal high-capacity transport (IHCT). The cost implications of IHCT have previously been investigated in several studies that yielded consistently positive results with regards to the operational costs, socio-economic impacts, and environmental performance (Ye et. al., 2014; Lindqvist et. al., 2020). At the current state, IHCT operations are however only being performed in very few instances, mainly due to the prevailing restrictions on the permitted length and weight of PPH vehicles, which hinder the competitiveness of IRT. Within Sweden, a number of practical investigations with LHVs have however been conducted in recent years (Löfroth & Svenson, 2012; Cider & Ranäng, 2014; Bergqvist & Monios, 2016). The vehicles employed in these pilot projects were exceeding the current freight vehicle dimensions as prescribed by the EU, as well as the already expanded Swedish regulations. The trials demonstrated that using trucks of up to 32 meters in length can promote increased gains in fuel efficiency and volume flows. Despite these positive outcomes, the general regulatory frameworks for road freight vehicle dimensions and weights in the EU as well as Sweden have still not been adjusted in favor of LHVs. This is mainly reasoned by the still persistent knowledge gap of researchers and practitioners with regards to the overall potential of HCT. Accordingly, the operation of LHVs raises major concerns with regards to safety, road wear and tear, and the maintenance of competition between hauliers (Leduc, 2009).

1.3 Case Presentation

Based on the above-illuminated aspects, the Gothenburg based platform for transport efficiency CLOSER published a "Roadmap HCT Road" in 2019, to provide the basis for a continuous implementation of HCT in Sweden. CLOSER is a neutral platform that fosters collaboration, innovation and knowledge exchange within the transport sector, by integrating the business community, industries, research institutions, the public sector, and governmental agencies. The aim of the platform is to contribute to efficient logistics and freight transport solutions and thus build a sustainable society. Therefore, the "Roadmap HCT Road" has been developed through contributions from representatives of the business sector, industry associations, and research as well as legal institutions. It outlines measures and sub-targets for 2020 and 2025 respectively with regards to HCT on the road, that are desired to be achieved by 2030. The main target that has been developed by the different participating actors asks for 80% of the road freight transport to be executed by HCT vehicles by 2030 (targets for 2020 and 2025 are 5 % and 45 % respectively), and a reduction of 10% of the energy consumption per tonne-kilometre compared to 2018. For the employment of LHVs, this means that the transport system has to facilitate the usage of different vehicle combinations and loading units for HCT. In particular, it is aimed at attaining permissions for vehicles of up to 74 tonnes, i.e. bearing capacity four standard, on current bearing capacity class one roads that have been appointed by the industry as important for the first and last-mile delivery. Moreover, vehicles with a length of up to 34.5 metres should be allowed to and from ports and terminals with dense goods traffic (Asp et. al., 2019).

This objective as well as selective goals prescribed within the "Roadmap HCT Road" are part of a current research project 'HCT Intermodal' initiated by CLOSER, which will be carried out through this thesis. The idea of the project is to improve the efficiency of intermodal transport chains by allowing HCT to and from the nearest combined rail-road terminal. In particular, the focus is on the employment of longer trucks for PPH, i.e. carrying two 40ft. containers. The aim of the study is to assess the feasibility of IHCT for local distribution in the Swedish market. Within the framework of this project, the possible barriers and difficulties of an implementation, as well as the possibilities in terms of costs, freight volumes, emissions, and quality will be investigated. Several industry actors such as terminal providers and logistics service providers (LSP) were selected by CLOSER as participants of this study. Their insights about IHCT will be determined through interviews and utilized to draw an overall picture of the market needs for IHCT.

1.4 Purpose

The purpose and research questions of this thesis are aligned with the objectives of the 'HCT Intermodal' research project of CLOSER and the corresponding "Roadmap HCT Road" as described above. Accordingly, the study aims to give an account of the potential that HCT for PPH has in intermodal transport chains connected to major rail-road transhipment nodes in Sweden. For the current theoretical foundation on IHCT, the study will provide an expansion to the existing body of knowledge and research, by presenting HCT as a concept for an overall transport system. Besides, the knowledge about the potential that HCT has at a national level can be increased among decision and policy-makers, which in practice can decrease the reluctance towards IHCT solutions. The practical implications of the study will in turn be the reinforcement of the efficiency and competitiveness of HCT on the road in combination with rail. It will contribute to the transfer of goods from road to rail and thus a reduction of the environmental and infrastructural impacts of the freight transport sector. These outcomes can be used as a basis for future pilot projects related to IHCT, as well as for the development of policies and regulations which incentivise actors such as transport buyers and IRT terminal operators to exhaust the potential of IHCT.

Within this thesis, the following research question will be answered through a set of different sub-questions:

What is the market potential for IHCT in Sweden until 2030?

Q1: What are the barriers for a broad implementation of IHCT and the main obstacles associated with IHCT in Sweden?

Q2: What are the main freight traffic flows/corridors and the corresponding required capacities that would benefit from exemptions for IHCT in Sweden?

Q3: How can the authorization of IHCT for these flows/corridors contribute to a reduction of the economic and environmental costs of freight transport?

Q4: How can IHCT be implemented on a large scale in the Swedish market?

The first sub-question is answered with information derived from the literature review and complemented by viewpoints gained from interviews with players from the industry. The second sub-question is solely based on the insights that can be obtained from the terminal providers and LSPs based on their current freight flows and capacities. Sub-question three will be answered through a quantification of the interview data as identified in question two, by integrating the occurring economic and environmental costs of the PPH distances. Lastly, sub-question four will make use of the data obtained from the interviews, and the regulative and infrastructural prerequisites as described in the theoretical framework. At the same time, examples from projects and regulation exemptions for HCT will be considered.

1.5 Delimitations

The study will be executed on Swedish national level and thus demonstrate the potential for IHCT in the Swedish freight transport market. The resulting implementation proposal therefore might not be applicable for other European countries. Particularly, results related to capacities and permits for specific roads, as well as cost estimations, will be adapted to the Swedish network. The analytical part of the study moreover merely includes a selective part of the Swedish business community, which will lead to assumptions and approximate estimations when evaluating the overall market potential. Moreover, it has been decided to solely evaluate the prospects of longer, instead of longer and heavier vehicles, that are concerned with the transport of containerized consumer and industrial goods. The opportunities for trailers for forest products are thus neglected in this study. Besides, the determined freight flows are subject to fluctuations and the long-term expected demand is difficult to assess, which complicates a precise valuation of the development until 2030. As the interviewed IRT terminals stretch from south to north Sweden and the operational area of the LSPs likewise cover large parts of the country, the results should however be generalisable. Another aspect that can provide guidance for potential adjustments of regulations in other national contexts are the demonstrated international projects and previous experiences with IHCT. The study will therefore result in strategic indications on how to implement IHCT in a national context and how to determine a designated network that is suitable for the employment of LHVs.

1.6 Disposition

The research will be outlined as exemplified in *figure 1.2*.

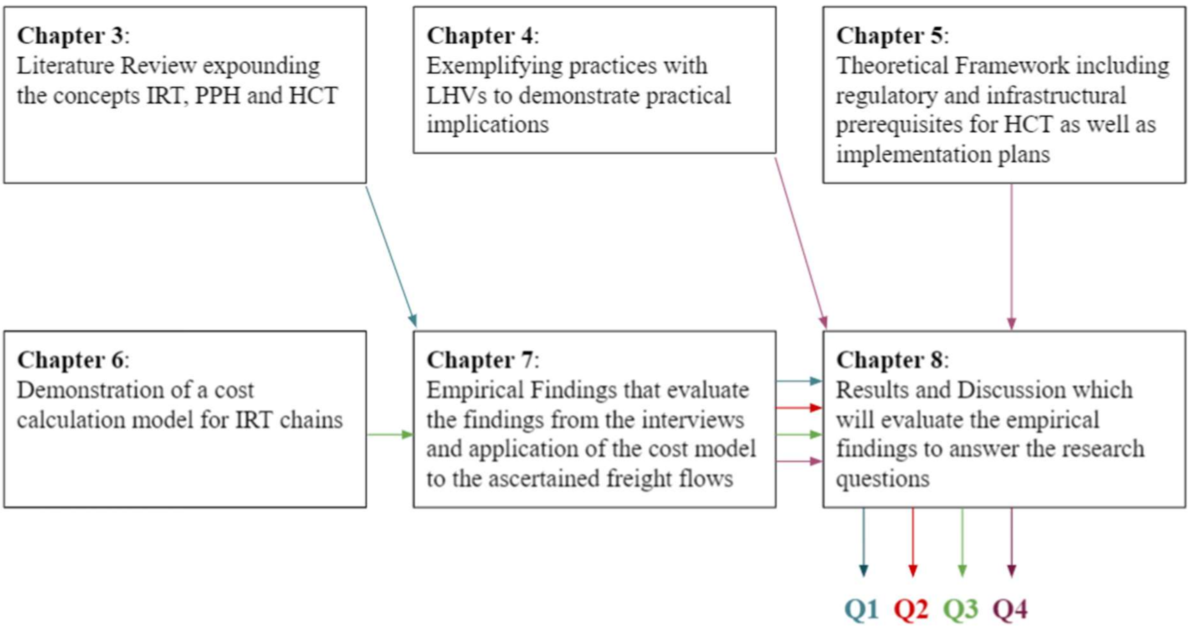

Figure 1.2: Thesis Outline.

2. METHODOLOGY

This chapter gives an outline of the research process and approach, and moreover discloses the chosen case study methodology. The data collection process for both the secondary and primary data will be elucidated, whereas a particular focus is placed on the representation of the interviewing procedure. This is followed by an explanation of the data analysis process for the qualitative data, and an illustration of the components and method applied for the quantitative data assessment. Lastly, the research process is evaluated according to its reliability and validity.

2.1 Research Approach

The study starts with a literature review of previous research related to IHCT with a particular focus on the PPH activities. Subsequent to the theoretical framework, which provides an overview of the legal and infrastructural basis for road freight haulage, a multiple-case study is executed to determine the needs for IHCT of some major players in the Swedish freight transport industry. According to Collis & Hussey (2014) an investigation can be classified according to the *purpose, process, logic* or *outcome* of the research. As the *purpose* of this research is to identify the possibilities and feasibility of IHCT to and from the nearest IRT terminal, the study can be classified as being exploratory. When conducting case studies, exploratory research is commonly used, as it is a technique to recognize patterns and ideas and thus gain insights and familiarity with an under investigated topic (Collis & Hussey, 2014). Even though possibilities for IHCT in Sweden have been investigated before, there has not yet been any exploration from a macro-perspective. Therefore, this study contributes to the existing body of knowledge, by exploring the overall potential that an implementation of IHCT has on a national level and by providing concrete action plans for its enforcement.

For the execution and evaluation *process* of the study, a mixed approach that uses qualitative and quantitative methodologies is applied. In contrast to a quantitative research perspective, qualitative research emphasizes on words rather than quantified numbers when collecting and analysing data (Bryman & Bell, 2011). As current logistics research is dominated by quantitative approaches, several researchers identified the integration of more qualitative methodologies as vital to develop and advance logistics research and avoid potential limitations (Näslund, 2002; Mangan et. al., 2004; Collis & Hussey, 2014). However, a methodological triangulation where both types of data are used seems to be the optimal form of logistics research. Triangulation establishes a great empirical support for the theory and facilitates the attainment of a more-dimensional view within the investigation process. Using both quantitative and qualitative techniques in one study can thus contribute to reducing potential biases and the sterility caused by single method approaches (Mangan et. al., 2004).

In this specific study the qualitative data are obtained through interviews with several industry players and are analysed subsequently. One issue when evaluating qualitative data, as stated by Collis & Hussey (2014), is the interpretivist paradigm adopted by social scientists. The main assumption of the interpretivist belief is that the observed social reality is highly subjective as it cannot be clearly separated from the researcher's mind. In the process of the research, the researcher is interacting with the examined phenomenon which leads to a procedure of personal investigation and inference. By focusing on the ascertainment of the complexity of social phenomena, the researcher thus employs a variety of methods to describe, translate and identify the meaning of the phenomenon under investigation (Collis & Hussey, 2014). To still guarantee plausibility of the results, the study is of deductive *logic*. Deductive research is applied in those studies, where one is moving from general recognitions to particular instances that seek to confirm the theory. Accordingly, the empirical observations derived from the interviews are underpinned by the concepts and theories developed within the literature review and theoretical framework. Moreover, the methodological triangulation, which at a later stage of this study incorporates a quantitative assessment of selected interview data, enables a more fact-based determination of the market needs for IHCT.

When it comes to the *outcome* of the research, Collis & Hussey (2014) distinguish between either applied or basic research, whereas the latter refers to research problems that are less specific and thus aim to understand general issues to generate new knowledge or theories. Applied research on the other hand applies existing knowledge to an immediate problem with the purpose of enhancing current management practices or policies (Collis & Hussey, 2014). As the primary aim of this study is to propose solutions and concepts for integrating IHCT in the operations of IRT terminals and PPH providers, it can be classified as applied research. Moreover, the objective is to provide suggestions for new demo projects with LHVs and to present the results to business practitioners such as decision and policy makers for actual application.

2.2 Case Studies

The research comprises case studies on a number of transhipment nodes in Sweden. A case study is a methodology to explore a single phenomenon in its natural setting by using a variety of methods to obtain thorough knowledge about it. The exploration can be made for one or several cases, whereas a case represents a particular business, process, person, or other phenomenon (Collis & Hussey, 2014). For this particular research project, the case study methodology was chosen, as the conditions for its applicability as stated by Yin (2009) were identified to be fulfilled. Accordingly, case studies are appropriate if the researcher has little control over the events under investigation, the focus lies on a contemporary phenomenon within a real-life context, and the formulated research questions are of a "how" or "why" type. These characteristics are crucial, as a case study aims not only to explore but also to understand a particular phenomenon in its context (Yin, 2009).

The researched phenomena of this study are several terminal providers as well as LSPs in the context of the Swedish freight transport infrastructure and regulations. Therefore, a multiple-case study is applied. This approach enables comparability and can in similar cases help to generalize the established theory or in dissimilar cases modify and extend the theory (Collis & Hussey, 2014). One advantage of the multiple-case study methodology is that the evidence is more convincing which makes the overall study more solid (Yin, 2009). Particularly for the purpose of this study - that is to investigate the potential for an implementation of IHCT in the Swedish market - the contemplation of multiple cases facilitates to assess the capability for a broad implementation of IHCT, as all actors are first considered from a micro-level before their individual circumstances are lifted to a macro perspective.

2.3 Data Collection

2.3.1 Secondary Data

For the first part of the study a literature review is conducted to establish a theoretical background based on prior research. Bryman & Bell (2011) describe a literature review as a process of identifying and listing pertinent information on a specific subject, by looking at several different sources of literature. The aim is to critically engage with the ideas of other authors and at a later stage make use of them to affirm the credibility of the findings obtained in one's own research. Another purpose of a literature review, as indicated by Collis & Hussey (2014), is to demonstrate how the research question and propositions of the research project can be placed within the current body of knowledge. It is thus a useful method to identify gaps in existing research and determine the aspects that should be elaborated in more detail.

The literature review comprises secondary data from a range of different sources. Denscombe (2010) emphasises the importance to critically examine and evaluate the gathered documents along the four criteria: *authenticity*, *credibility*, *meaning* and *representativeness*. The authenticity is decisive to ensure that the material used is genuine and thereby affirm the credibility of the extracted information (Denscombe, 2010). For this purpose, all scientific articles used within the literature review were taken from peer-reviewed journals and evaluated according to the publisher as well as the number of citations. Moreover, material was retrieved from websites and reports published by governmental institutions such as the OECD, the European Union or the Swedish transport agency, that were judged as credible, clear and unambiguous. To ensure representativeness a broad scope of material related to IHCT and PPH was researched, and different recognitions were acknowledged.

To obtain appropriate material, several databases have been consulted. The journal articles were retrieved from the database of the university library of Gothenburg, Business Source Premier, Google Scholar, or Scopus, which enables highly differentiated searches that are beneficial for a literature review. The main search terms included “intermodal high-capacity transport”, “pre- and post-haulage”, “combined terminals” and “intermodal freight”. By reviewing the journals, the ancestry approach has been applied, which involves the tracking of the citations from one study to another. This enables retrieving earlier related research on the investigated problem (Cooper, 1982). The reviewed literature covers the period from the late 1990s onwards, when research on intermodal freight transport started to advance. Prior transport research was therefore neglected, as it was not perceived pertinent for the purpose of this study. For the sections about HCT and PPH even more contemporary literature was consulted, as these subject areas have been brought into focus only recently. Referred governmental documents and reports are either published by the national authorities or on behalf of supranational organisations such as the OECD, European Union, or the European Commission. These documents as well as material from international federations such as the UIC (International Union of Railways) or ITF (International Transport Forum) were examined to stipulate the definitions of the prevailing concepts of this study.

Besides the literature review, a theoretical framework has been established. It serves the purpose of depicting the prevailing legal regulations for IHCT and expounding the Swedish prerequisites based on its road network and IRT terminal infrastructure. These fundamentals are based on current sources of the EU, ITF, International Union for Road-Rail Combined

Transport (UIRR), the Swedish Transport Agency (STA), or the Port of Gothenburg. Furthermore, the theoretical framework presents the actions that are required for a broad implementation of IHCT on a national level. For this purpose, strategies presented within Closer's "Roadmap HCT Road" as well as previous successful implementation cases have been consulted. The theoretical framework will be used as a foundation for the evaluation of the empirical observations.

2.3.2 Interviews

To collect primary data that reveal direct insights from the Swedish freight transport industry and its operations, several interviews were conducted for this study. The interviewees represent both terminal providers and LSPs, which facilitates the development of a systems perspective as several relevant stakeholders are included in the observations. The overall aim of the interviews was to identify current freight volumes and flows, PPH distances and routes, and the infrastructure and equipment that is currently being used by the transport providers. These points of data will allow for drawing conclusions on the respective research sub-questions.

The interview procedure was semi-structured. A semi-structured interview enables the researcher to pose prepared questions as well as to develop additional relevant questions during the interview. It is an appropriate technique when one wants to investigate confident and commercially sensitive matters and develop an understanding of the respondent's personal constructs and beliefs. Moreover, the high degree of flexibility that is usually given in semi-structured interviews encourages the interviewees to talk about the main topics of interest from their perspective (Collis & Hussey, 2014). The participants were on request provided with the precasted questions, which allowed an enhanced accuracy of their answers during the conversation. In most cases, occasional follow-up questions were nonetheless posed for the purpose of clarification or accentuation. As the completion of the individual interviews revealed the interviewee's major aspects of knowledge or concern, the questionnaire has been adapted continuously within the weeks of the interviewing procedure. Generally, the prepared set of questions, as to be found in *Appendix I*, varied slightly for the terminals and LSPs, respectively.

All interviews were conducted digitally via a video call of approximately 30-45 minutes through either the application Microsoft Teams, or Zoom. This method was chosen due to the restrictions on personal encounters during the period of research that the ongoing Covid-19 pandemic entailed. According to Collis & Hussey (2014) web-based interviewing methods can limit the choice of the sample, as the interviewees require an internet access, and must be willing to use a specific software. This potential limitation was however not perceived as applicable throughout the research process, as all interviewees were equipped appropriately. It was decided to not record the interviews, to document the initial reception of the transmitted information, and thus eliminate a later interpretation bias. Instead, both researchers of this study took individual notes of the respondent's answers for each question during the interviews, which were compiled directly afterwards. Subsequent to the interviews, there has been further communication with the interviewees via email, where additionally relevant internal or quantitative data were transmitted. In some cases, follow-up interviews were carried out for the purpose of clarification, or to determine missing data. The received information was complemented by desk research which consisted of company website articles and reports as well as recently observed developments in the business sector.

The interviewees that participated in this study all communicated their interest of being part of the 'HCT Intermodal' project to Closer. Accordingly, no personal sample selection of interview participants had to be carried out. Due to the stated interest of involvement, the assumption that all interviewees carry a fundamental interest in IHCT solutions, and that the introduction of IHCT would have an impact on their operations, can be established. Before the start of the interview procedure all participating organizations were researched and classified into the groups of either terminal providers or LSPs. This procedure facilitated the assessment of the interviewee sample as appropriate for this study, since all participants could be identified to be influential players in the Swedish freight transport market. The first interviews were decided to be carried out with the terminal providers as they are concerned with the arrival and thus inbound logistics of the goods, which precede the PPH activities. After the terminals, the LSPs that are directly involved in the PPH activities, by carrying out the outbound logistics that are originating from the terminal, were interviewed. In the process of this study, the interviews have been conducted as illustrated in *table 2.1*.

Respondent	Position	Group	Place of Employment	Date & Duration
Tomas Arvidsson	Senior Advisor	Terminal	Kombiterminal Vaggeryd, PFG Båramo	24.02.2021, 35 min.
Claes Sörman Pär Svensson	Technical Manager Logistics Development Manager	Terminal	Eskilstuna Logistik	10.03.2021, 40 min.
Tomas Widenfalk	Project Engineer	Terminal	Sundsvall Logistikpark	18.03.2021, 45 min. 05.05.2021, 15 min.
Victor Sunnliden Dino Keljalic	Inward Investment Manager Transport Strategist	Terminal (+ regional infrastructure)	Business Region Örebro Region Örebro Län	23.03.2021, 35 min. 05.05.2021, 30 min.
Rickard Bergqvist	Professor	LSP (+ Terminal)	University of Gothenburg, representative for Jula Logistics	29.03.2021, 15 min.
Johnny Holmgren	Terminalchef	Terminal	NLC Storumanterminalen	Written answers transmitted by email 09.04.2021
Markus Ekwall	Department Manager for Intermodality	LSP	GDL	09.04.2021, 25 min.
Johan Jemdahl	CEO	LSP	GreenCarrier	13.04.2021, 40 min.
David Sandahl	CEO	LSP	RealRail	16.04.2021, 35 min.
Daniel Rönnberg	Market Strategist	Terminal	INAB Umeå AB	19.04.2021, 20 min.

Table 2.1: Interview Outline.

2.4 Data Evaluation

2.4.1 Qualitative Data

The analysis of the qualitative parts of the data obtained through the interviews follows the general analytical procedure by Miles & Huberman (1994), as presented by Collis & Hussey (2014). Accordingly, a systematic data analysis typically follows the three simultaneous flows of: *data reduction*, *data displays*, and *conclusions* as well as data verification. In interpretivist studies, especially those including exploratory interviews, the processes of data collection and data analysis are part of an iterative cycle, which is why the collected amount of data is usually enormous and must be reviewed and analysed accordingly (Collis & Hussey, 2014). By applying the process of continuous *data reduction*, irrelevant data can be discarded through reflecting and restructuring the collected data. An efficient tool to do so is by systematically coding the data according to frequently occurring aspects or patterns mentioned by the respondents, and placing them into categories derived from the theory. Subsequently, the data can be portrayed in a *data display*, which summarizes the complex data in a visual format (Miles & Huberman, 1994). As the interviews of this study were decided not to be recorded, the main data source that was subject to this data analysis procedure were the written records that were made during the interviews. This material was however of such an extent that the main concerns extracted from the interviews could be reproduced within a matrix in the form of a checklist. The illustration of the data in such a display facilitates drawing valid *conclusions* and developing a set of generalizations that can be linked to the formalized body of knowledge and thereby be verified (Miles & Huberman, 1994). The analytical procedure and interpretation of the interview data is therefore closely connected to the theoretical foundation of the study. This approach of data analysis will be used to answer research questions one and two.

2.4.2 Calculation Method

The interview data that are determined in a quantitative format, will be evaluated through the application of a cost calculation model for IRT. According to Janic (2007), intermodal transport costs consist of internal or operational costs, and external costs which are also associated with the costs of emissions produced by the freight vehicles. Both types of costs will be calculated within this thesis. The components of the operational costs will be derived from previous research (Floden, 2007; Floden, 2011), and prices are adapted to inflation if necessary. For the determination of the external costs, that are predominantly CO2 emissions, the carbon calculator NTM Calc will be utilized.

The objective of the cost model is to compare the economic and environmental costs in an IRT chain that arise with currently authorized trucks opposed to LHVs. The calculations occur for each determined freight corridor individually before specifying the impacts for each terminal or logistics service provider, and eventually giving an account for the Swedish market as a whole. *Figure 2.1* demonstrates the holistic determination model of IRT costs in Sweden.

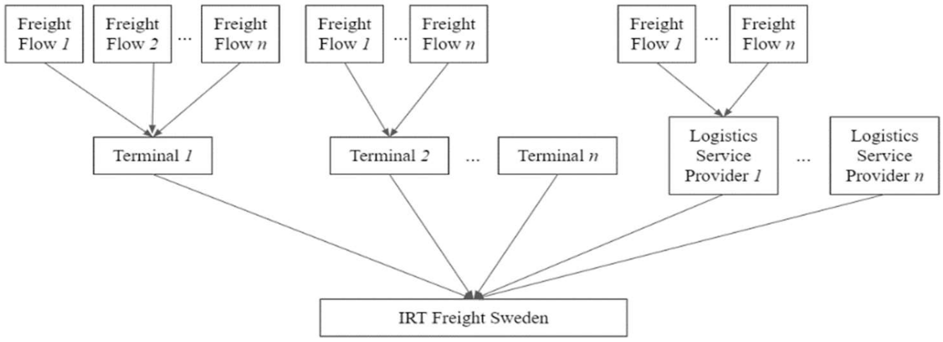

Figure 2.1: Calculation Approach for IRT Costs in Sweden.

This approach will enable to answer research question three. The accumulated results from the empirical findings and analysis eventually reveal results for research question four, and lead to an overall determination of the potential of IHCT in Sweden until 2030.

2.5. Research Evaluation

2.5.1 Reliability

A study can be defined as reliable, if all measurements have been accurate and precise, and the likelihood that differences in the results would occur if the research was repeated is merely marginal. Therefore, it is crucial to ensure that the research evidence and conclusions are able to withstand a stringent verification (Collis & Hussey, 2014). To guarantee the reliability of the study, the subjects under study have been observed persistently to gain an in depth understanding of the studied cases. Besides, the methodological triangulation incorporates different data sources and methods of data collection, which strengthens the evidence of the results. Besides, interview protocols and data are provided throughout the report, which enables other researchers to review the established evidence. The assumptions and variables applied in the cost calculation model incorporate multiple sources of data that can be recalled, and thus increases reliability.

2.5.2 Validity

The validity of a study can be established if the obtained results precisely reflect the phenomena under study, and if the investigation measures what the researcher wants it to measure (Collis & Hussey, 2014). The obtained results should thus be reasonable in order to answer the drawn-up research questions. In an interpretivist study, the validity is commonly high, since the researcher has a direct influence on the research. However, research errors might still occur in cases of poor samples, inaccurate measurements, or incorrect procedures (Collis & Hussey, 2014). To ensure a high degree of validity, the study involves interviewees from different settings. Moreover, the approach of a methodological triangulation helps to establish construct validity, by also involving less direct observable phenomena such as the respondents' attitudes towards HCT, and their anticipated impacts of an implementation.

3 LITERATURE REVIEW

The literature review will elucidate the terminologies of intermodal transport, HCT and PPH, and elaborate upon previous research with regards to these concepts. A particular emphasis will be on the evolution of intermodal transport as well as the prospects and challenges connected to PPH and HCT. Moreover, IHCT is contemplated from a systems perspective which considers the requirements of different actors within a logistics system.

3.1 Intermodal Rail-Road Transport

3.1.1 Definition

Intermodal transport as a means of freight transport has experienced a rapid rise in recent years. It fundamentally describes the combination of at least two or more modes of transport that are used successively within the same transport chain. While there are several appreciations of the term, the definition of the OECD can be identified as widely applicable. Accordingly, intermodal transport describes the "Movement of goods (in one and the same loading unit or a vehicle) by successive modes of transport without handling of the goods themselves when changing modes" (OECD, 2003). The various means of transport included in that definition represent trucks, freight trains, container ships as well as short sea vessels. Thus, it covers all road, rail and sea transport. A unit as addressed in this definition is often referred to as either an intermodal loading unit (ILU) or an intermodal transport unit (ITU). The European Union, United Nations, ITF and OECD (2019) define an ITU as a "container, swap body or semi-trailer/goods road motor vehicle suitable for intermodal transport". Lowe (2006) on the other hand defines an ILU as a consignment of freight or several small consignments bundled within one unit. He argues that goods are allocated into ILUs to enhance the transhipment operations as well as the repacking time and costs at each section of the journey. Moreover, ILUs facilitate the handling procedure of the goods within one transport chain (Lowe, 2006).

According to the above-mentioned characteristics, an intermodal rail-road transport chain can be illustrated as shown in *figure 3.1*. The railway as a large-scale transport mode incurs the greatest part of the shipment distance, which in this example is the terminal-to-terminal transport that is also referred to as long-haul. Road transport on the other hand is merely allocated to the short-haul activities like collection and distribution (Bergqvist & Behrends, 2011). This part of the transport chain can be summarised under the terms drayage, pick-up and delivery, or Pre- and Post-Haulage. The PPH activities moreover encompass the transhipment operations of providing an empty ILU to the shipper and subsequently transporting the full ILU to the intermodal terminal (Macharis & Bontekoning, 2004).

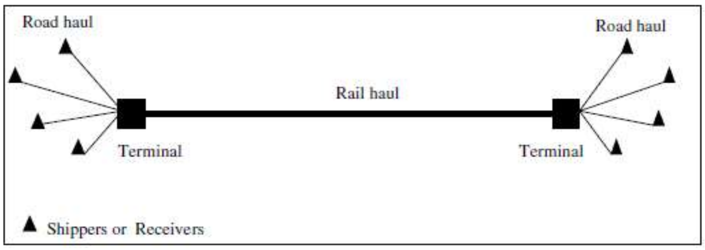

Figure 3.1: Rail-Road Intermodal Transport Chain (Macharis & Bontekoning, 2004).

In order to facilitate a broad applicability of intermodal transport, a range of different loading units as presented in *Chapter 5.1.1* have been standardized and internationally recognized throughout the years. A standard loading unit refers to either an ISO container, a semi-trailer or other swap-bodies. Beyond that, intermodal transport is also subject to several national and international policies, which highlight intermodal transport systems as a solution to offset increasing road freight transport volumes and the associated environmental as well as social impacts.

3.1.2 Historical Development and Legal Acknowledgements

In Europe transport policy has undergone a considerable evolution since the creation of the European Economic Community (EEC) with the Treaty of Rome in 1957, whereby intermodality only started to find recognition in the last decade of the 20th century. The early stages of the Common Transport Policy (CTP) were mostly aligned at national levels, and despite its commitment of facilitating competition and enabling free market access, it merely served the purpose of exchanging ideas between the countries. A first progress that liberalised the transport market could be observed in 1985 when the White Paper on the Completion of the Internal Market was published. The paper identified the restrictions on the provision of transport services as a main barrier to open the markets for trade. Consequently, a number of directives were published which focused on market access, infrastructure investments and the harmonisation of standards related to technical and social aspects (Giorgi & Schmidt, 2002). In 1992 the European Union eventually succeeded in almost entirely liberalising the transport market, with railway regulations being last on the agenda. In the same year, the conclusion of the Treaty of Maastricht gave a new impulse to transport policy and a further White Paper on the future development of the CTP was published (European Commission, 1992). Even though it still predominantly emphasised the opening and integration of the European transport market, environmental objectives, improved service offerings and intermodality were first acknowledged. This was mainly due to the increased traffic flows that occurred with the formation of the internal market.

European transport policy thus slowly experienced a shift from being centred on transport infrastructure and associated investments, to placing its emphasis on factors such as intermodality and strategic planning which facilitates an improved coordination between the modes (Giorgi & Schmidt, 2002). The White Paper “European Transport policy for 2010”, published by the European Commission in 2001, was correspondingly concerned with precisely these issues and represented a vital step forward towards a more sustainable transport sector that focuses on modal shift from road to rail and inland waterways (European Commission, 2001; Bergqvist & Behrends, 2011). A concrete goal regarding this modal shift was then expounded in the EU White Paper on Transport in 2011 which suggests that “thirty percent of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030” (European Commission, 2011). The fulfilment of this target will be reliant on an appropriate development of the traffic infrastructure, adjustments to the legislations on vehicle weights and dimensions, and the establishment of intermodal transitioning points for transport providers.

In Sweden, these aspects have been considered relatively early as drivers for an increased usage of intermodal transports. Based on its geographical and industrial prerequisites, the country recognized that intermodality can be used as a tool for strategic transport planning and network efficiency. Sweden is characterized by a wide elongation, many sparsely populated areas, and several export-oriented industries, which make both domestic and international trade flows very complex. Accordingly, the establishment of a national IRT terminal network already occurred in the late 1960s. Besides, the necessity for intelligently linked, small-scale terminals to enhance the competitiveness of IRT was early recognized (Bergqvist et. al., 2010). There have been many initiatives promoted by the Swedish State Railways to provide intermodal competitive solutions opposed to unimodal road transportation by large trucks. One of the most studied and elaborated initiatives was the Light-Combi project which was introduced in 1995. The initiative is characterized by small scale intermodal terminals that are distributed in a fine-meshed network and served by forklift trucks. These terminals were aimed to be a complement to the larger conventional terminals, in order to handle the many small-scale, dispersed goods flows in Sweden. The employable ILUs for the light-combi operations are limited to 20ft. ISO containers and swap bodies with a length of up to eight metres (Woxenius, 1998). Such applied initiatives as well as the targeted legal requirements for the market integration of intermodal transports show that intermodal transport remains a substantial area of research. Particularly the recently growing focus on the sustainable development of the transport sector can be identified as a main driver for intermodality.

3.1.3 Classification of IRT Research

The historical development of intermodal transport illustrates very well that the phenomenon is subject to constant advancements. Throughout the years, the emphasis of IRT research has accordingly been on a range of different aspects. Extensive literature on intermodal transport started to arise in the 1990s when the concept found intensified legal and strategic recognition (Bontekoning et. al., 2004). In early stages intermodal systems were predominantly acknowledged as competitive transport solutions due to their high degree of efficiency and flexibility (Muller, 1999). Generally, early research on intermodal transport was mostly concerned with operational issues of intermodal systems, such as network configuration or terminal design. A detailed review on operational research in intermodal transport was carried out by Macharis & Bontekoning (2004) where they categorised previous studies on intermodal transport according to the type of operator they were concerned with, and the time-horizon in which the observed operational problem could be embedded. The contemplated operators were classified in the four categories *(1) drayage, (2) terminal, (3) network and (4) intermodal operators*, whereas the operational problems that these actors face can be situated on either *a strategic, a tactical or an operational level*, where each covers a different time horizon. The authors concluded that intermodal systems have a much higher degree of complexity than unimodal systems. This can be justified by the involvement of various transport modes with different characteristics, the division of organizational tasks between several actors, and finally the complexity of assignment problems that result from the extent of available transport equipment (Macharis & Bontekoning, 2004). A similar distinction regarding the operators and research classifications has been made by Bontekoning et. al. (2004) who differentiate between *(1) drayage, (2) rail haul, (3) transhipment, (4) standardisation, and (5) multi-actor chain management and control* as the main characteristics of intermodal freight transport. Standardization therein refers to the usage of standardised load units which can increase the efficiency of the transport chain as they can easily be switched from one mode to another. The multi-actor chain management and control describes the issue of decentralised control which is prevalent in complex intermodal systems. Thus, strategic coordination between the actors is decisive for a well-working system but can be critical in cases of contradicting demands that might occur with regards to the transhipment activities (Bontekoning et. al., 2004).

More recent literature on intermodal transport planning has been reviewed in a paper by Steadieseifi et. al. (2014), where the classification of intermodal transport research is based on the decision horizon of planning problems. Similar to Macharis & Bontekoning (2004), the authors differentiate between *strategic, tactical and operational problems*. Strategic tasks are mainly concerned with infrastructure and network investment decisions; tactical tasks refer to the optimal utilization of the infrastructure, which includes decisions regarding the utilized modes and services as well as the offered capacities and frequencies; and lastly operational tasks are dedicated to real-time planning and adjustments in case of disturbances (Steadieseifi et. al., 2014). In contemporary literature, the classification of intermodal transport research according to the decision level can be observed frequently. The focus of intermodal transport research shifted from being centred around the basic principles and definitions of intermodal transport, to assessing the aspects that can improve both logistics performance and economic efficiency. An even more recent approach to intermodal transport are the emerging practices of modelling systems for freight distribution. The main objectives of system modelling are to allocate loading units, integrate supply chain members, and to configure the system in a way that CO_2 emissions can be steered (Agamez-Aris & Moyano-Fuentes, 2017).

3.2 Pre- and Post-Haulage

In the context of IRT, the stages of the transport chain are the rail haulage and the Pre- and Post-Haulage, which is referred to as PPH. This stage of the transport chain is conducted by tractor trucks carrying containers, swap bodies, semi-trailers or other units. The combination of the strategic and costly advantages in each stage of the transport chain are the factors that differentiate IRT from other transport solutions. The longest distances are covered by large-scale transport vehicles, in the case of IRT, that is rail haulage. The PPH stage, although representing a small fraction of the total IRT transporting distances, comprises a higher share in the total IRT transport cost structure proportionally to its transport distance, between 25% to 40% (Macharis & Bontekoning, 2004). This makes PPH a driving factor to determine the competitiveness for IRT against direct road transport. As transportation distances increase, IRT becomes more competitive against direct road transport, eventually achieving the break-even point where IRT is more cost-efficient and therefore, more competitive (Bergqvist & Behrends, 2011). For this reason, optimizing PPH operations has been a topic of discussion in previous literature, emphasizing on the impact of PPH operations for strategic implementation of IRT, which has seen increasingly more pressure after liberalisation of transport business in Europe, which solidified the position of road transport as an attractive choice for logistics forwarders for medium and long distances (Kreutzberger, 2001). As stated by Kreutzberger et. al. (2006), there are crucial cost driving factors of PPH that determine the competitiveness of IRT, such as haulage distances between shippers and intermodal terminals, the resource productivity, the transport network productivity, which pertains to the number of round trips per units delivered and loading and unloading efficiency. Finally, fuel and labour costs are also crucial. There is also the aspect of volume flows transported per shipper or per area, which will determine the marginal costs of transporting higher freight flows and therefore decreasing costs per unit transported.

Morlok et. al. (1995) states that the fact that most terminals, shippers and forwarders are located in the vicinity of urban areas, adds up to more pressure on PPH performance, since increased urban traffic congestion in the vicinity of terminals ends up affecting the quality of service and reliability of IRT. There is also the problem of high operational fragmentation for serving terminals by a high number of hauliers and lack of coordination between hauliers, resulting in low resource productivity for PPH. Woxenius (2001) puts emphasis on optimizing PPH operations and distribution of terminals, with an emphasis on the fact that smaller vehicles are mostly used for the urban areas also for IRT, and there are more empty trips since the uneven distribution of freight volumes over the day and short distances generate this low resource productivity for PPH. The distribution of terminals should also be spread out in urban areas, having in mind the conciliation of urban society with the presence of terminals these areas, which brings many effects to the everyday life of urban citizens who are commuting on early morning and afternoon hours, causing disruptive effects such as higher noise and air pollution levels and traffic congestion due to an increasing flow of road vehicles to and from terminals.

Bergqvist & Behrends (2011) emphasise that the level of pressure exerted by regulations promoted by governments to reduce externalities have been the greatest obstacle to make PPH more cost-efficient and therefore, IRT more competitive against only road transport. This exerting pressure calls for a more flexible and innovative legal framework for PPH, through extending legal limits for usage of LHVs for intermodal transport in Sweden. This would represent an extension of current legal regulations to allow tractor trucks to carry two 40-foot containers or even two semi-trailers for IRT, increasing PPH capacity and promoting potential cost savings of up to 10% in reduction of total transport costs.

3.3 High-Capacity Transport with Longer and Heavier Vehicles

High-Capacity Transport is defined as the usage of longer and heavier vehicles to conduct freight transport (Bergqvist & Monios, 2016). The usage of LHVs for freight transport has been a frequent topic of discussion for the last decades in the European context. The definition of LHVs is characterised as vehicles exceeding the established limits of dimensions and weight by the European Union of vehicles that can freely circulate in Member States. These dimension limits are defined by the Directive 1996/53/EC and are respectively 18.75m for road trains and 44 tonnes for three-axle motor vehicles with two or three-axle semi-trailer carrying a 40-foot ISO container as a combined transport operation.

In the Scandinavian context, Sweden and Finland were traditionally allowed to adopt usage of vehicles of up to 24m and gross combined weight of 60 tonnes. In order to preserve the competitiveness of Scandinavian forestry industry, the EU adopted a modular framework for combined transport and allowed Sweden and Finland to use combinations of two long modules, while the rest of EU member states had to comply with using only combinations of one small and one large module at maximum (Åkerman & Jonsson, 2007). According to Åkerman & Jonsson (2007), a study investigating the prospects of using the European Modular System (EMS) with LHVs of 25.25m in Sweden and Finland showed positive results, with reduction of total transport costs, positive effects on the environment and no significant change in traffic congestion.

According to McKinnon (2008), there is a wide range of positive and negative effects that come with increasing vehicle capacity. The main benefit consists of a central point of consolidating volumes into fewer vehicles, bringing downstream benefits such as reduction in internalised operating costs by shippers and forwarders, and also reduction in truck traffic which promotes lower congestion and alleviates environmental impacts. Each of these two main downstream effects has their own possible benefits and costs as *figure 3.2* shows, where the black lines represent positive effects generated and broken lines represent negative effects.

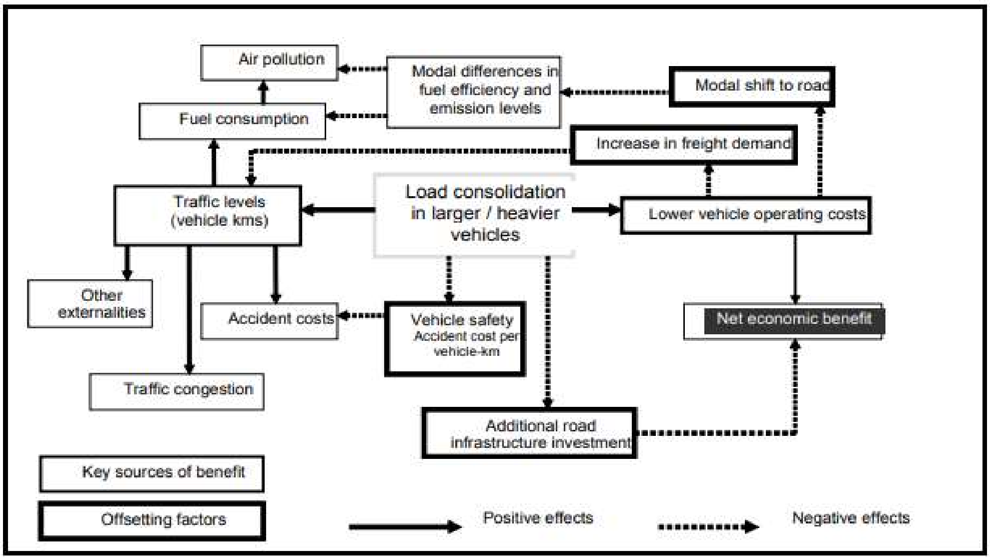

Figure 3.2: Costs and benefits of increasing vehicle capacity (McKinnon, 2008).

McKinnon (2008) also states that the load consolidation is not so easily translated into reality with the legalization of LHVs, since in some countries these vehicles have access restricted to specific roads, such as in Sweden and in Finland, where they are denied access to many urban areas. There is enough case to justify restricted road access of LHVs since there is reduced ability to negotiate curves in these vehicles, overtaking is quite harder for drivers and occasional opposition from urban citizens. For this reason, the main benefit of load consolidation is not as easily achievable when the routes that LHVs can access are limited, therefore reducing the shift from smaller vehicles to LHVs. The consolidation is further challenged by the fact that not always the volumes are high enough in some routes to justify demand for LHVs, making consolidation less viable. This demands that trials and governments must take into account where the freight flows are being capacity-constrained in trucks that are in the maximum current legal length and weight limits in order to obtain consolidation results that will justify usage of LHVs (McKinnon, 2008).

One of the most recognized negative effects of the introduction of LHVs is the modal shift from rail to road haulage. Many rail freight companies strongly oppose the introduction of LHVs in Europe. There is a perceptive threat that LHVs pose to the rail freight market in terms of replacing their demand with road freight. The English, Welsh & Scottish Railway (EWS) has argued that if LHVs were introduced in the UK, about 50% of all freight from rail would be shifted to road. However, countries like Sweden have shown that even with LHVs being used for many years, the rail freight industry is still growing in market share, with 29% of transport share, well above the average of 14% in the EU-25. The experience of LHVs in Sweden and

Finland have shown promising results in terms of load consolidation. Data analysis has shown that with LHVs, the number of vehicle trips was reduced by 32% and road transport costs reduced by 23%. Another study that analysed the consequence of a potential reduction of vehicle limits to EU standards of 18.75m and 40 tonnes in these two countries found that if that happened, the number of vehicles would have to increase 37% and freight costs would increase 24%. Dutch trials also indicated that LHVs have overall positive impacts, reducing traffic congestion by 0.7% to 1.4% and saving 1.8% to 3.4% of transport costs (McKinnon, 2008).

Bergqvist & Behrends (2011) stated that the adoption of exemptions for HCT in Sweden, with combinations of two 40-foot containers for IRT, is a potential contributor to competitiveness of IRT, providing reductions of 5% to 10% of intermodal transport costs for large scale shippers. There is, however, a highlighting of the cautions of conceding exemptions for HCT, as there are possible negative effects in urban areas, which are those areas where most IRT terminals and shippers are located. Therefore, it is essential for these policies to consider possible negative effects in urban areas before conceding exemptions for HCT. This requires analysing future freight flows, transport demands, times of the day, which routes/roads would be more used by these vehicles and requiring accompanying cars for LHVs traffic on roads (Bergqvist & Behrends, 2011).

4 PRACTICES WITH LHVs

The possible benefits and risks of introducing LHVs have previously been assessed internationally as well as in selected European countries. Accordingly, several HCT pilot case studies were conducted where governmental institutions granted exemptions for LHVs to certain operators or on certain routes. Therefore, this chapter gives an outline of situations in which LHVs have been permitted on the roads. It covers countries with general extended regulations as well as exemptions that were granted for specific trials on certain routes nationally in Sweden. The objective is to demonstrate how regulations for LHVs could look like in individual circumstances and to display the positive results that can be achieved with shifting policies.

4.1 International

Australia

To support the introduction and implementation of HCVs, several countries previously initiated research programmes to set up new regulations and policies. Among them are Sweden and Australia who established a close collaboration since 2011 to enforce pilot projects and new legislations as well as regulatory and technical frameworks for HCVs (ITF, 2019). Australia has long been recognised for their longer and heavier trucks which they also refer to as High Productivity Vehicles (HPV). The implementation started in the mid-1980s when a variation of the Canadian B-train, the B-Double, was adapted. In the 1990s the combination, which could achieve improved payloads of 30-40% compared to the conventional tractor-trailer combinations, was well established across the country (Hassall, 2005). The B-Double consists of a tractor that is towing two B-coupled semi-trailers with a length of 26m and a gross combination mass (GCM) of 68,5 tonnes (OECD, 2011). All B-Double configurations operate on long distance routes as well as within the major urban areas that are densely populated. The double and triple road train combinations, which have a length of 36,5m or 53,5m and a maximum gross vehicle mass (GVM) of 85.7 tonnes and 125.2 tonnes respectively, are on the other hand restricted to transports in remote areas and country highway regions (Hassall, 2005).

In 2007, Australia furthermore integrated the Performance Based Standards (PBS) framework as a new freight productivity initiative. Based on the PBS scheme, each truck is assessed against the key performance of the vehicle's safety. It includes 16 stringent safety standards and four infrastructure standards, which ensure a higher productivity and safety level through innovative truck and bus design (OECD, 2011; Koniditsiotis & Sjögren, 2019). The PBS are a significant contribution to facilitate the usage of HCVs within a wider network, as they match the vehicle to the roads by differentiating the road network into different classes according to the mass and length of vehicle combinations (ITF, 2019).

Canada and the United States

In Canada the normal regulations allow tractor doubles or semi-trailers with maximum dimensions of 23-25m and 63.5 tonnes. The provinces can however set their regulations considerably freely, and therefore allow Long Combination Vehicles (LCV) which are defined as vehicles that are longer than 25m and accordingly require a special permit. Three types of LCVs are currently allowed on the roads. However, their usage might be dependent on time and speed limitations and is usually merely permitted on roads with at least two lanes in each direction. The different types of LCVs include the Rocky Mountain Double with maximum dimensions of 32m and 63.5 tonnes, the Turnpike Double limited to 41m and 63.5 tonnes, and Triples which can be up to 35m with a maximum weight of 53.5 tonnes. The length specifications of these vehicles are subject to variations according to the provinces. In order to set special requirements for vehicles, PBS are also applied in Canada where they in fact originated (Kyster-Hansen & Sjögren, 2013). The approaches of their application do however differ to those in Australia.

In the US HCVs are constructed similar to those in Canada and regulations as well as possible combinations likewise differ between the individual states. LCVs accordingly include Rocky Mountain Doubles, Turnpike Doubles and Triples. In contrast to the Canadian regulations, the combinations of the US vehicles however also permit higher gross combination weights for LCVs and are not merely focused on length (Kyster-Hansen & Sjögren, 2013). LCVs are currently allowed in 23 states, where some only allow their operation on turnpike facilities. An expansion of the currently approved routes is however prohibited due to the directions set in the Intermodal Surface Transportation Efficiency Act of 1991 (ITF, 2019).

Finland

The most prevalent example of a nationwide introduction of LHVs within Europe is Finland. Since Finland's accession to the EU in 1995 they were granted an exemption to operate vehicle combinations with a length of up to 25.25m and a maximum weight of 60 tonnes, which have been in regular use ever since. In 2013 the Finish government extended these regulations by allowing HCVs with a weight limit of 76 tonnes and a height limit of 4.4m on Finish roads. The HCVs can operate freely, but their usage might be somewhat restricted on bridges or certain smaller roads (Liimatainen et. al., 2020). After the integration of this regulation trials for LHVs still continued and a new legislation to allow longer vehicles of up to 34.5m was initiated in 2018. This proposal was approved by the EU and is in force since January 2019 (ITF, 2019).

Other Examples from Europe

Besides Finland a few other European countries already carried out trials with LHVs. Experimental work for LHVs has particularly been underway in Denmark, the Netherlands, Belgium, the UK, and Germany, where compared to Sweden and Finland a higher concentration of trade flows can be observed. An increased usage of LHVs can thus counteract traffic and congestion levels. Germany has the largest national market in the EU and accounts for around 23% of its total road freight. First trials with LHVs in Germany started in 2012 on a comparably small scale (Steer et. al., 2013). The field trial with LHVs with a length of up to 25.25m continued until 2016 and were converted into continuous operation, after gains in efficiency and fuel savings of 15-25% could be recorded. The route network for the deployment of the LHVs is limited, but obtained a further extension in 2020, whereas restrictions on weight remain at 40 or 44 tonnes (BMVI, 2021). In the Netherlands and Denmark trials started even earlier in 2001 and 2008 respectively and have been upgraded several times ever since (Steer et. al., 2013). The most intense studies on LHVs in the Netherlands were made until 2010 when the LHV market consisted of around 153 companies and 397 vehicles. Results showed average fuel savings of 33% and cost savings of 20% (Rijkswaterstaat, 2011). Similar studies were executed in Denmark where four types of EMS vehicles were tested and a total of 408 EMS vehicles were registered by the end of 2010. The trials that were supposed to last until 2011 were extended until 2017 (The Danish Road Directorate, 2011). A study by Knight et. al. (2008) assessed the likely impacts of an introduction of LHVs in the UK and concluded savings with regards to emissions, vehicle kilometres, goods movements, and transport costs. In 2012 the UK government eventually introduced longer semi-trailers of 14.6m and 15.65m in length, and ongoing trials were extended until 2027 (Department of Transport, 2015).

4.2 Sweden

ETT Modular System for Timber Transport

One of the first projects for LHVs that has been realised within Sweden was the ETT (En Trave Till/One Stack More) modular system for timber transport. The project was initiated in 2006 by Skogsforsk (The Forestry Research Institute of Sweden) and dedicated to a more efficient transport of timber in the north of Sweden. Instead of using the conventional vehicles for timber transport that have a maximum length of 24m and a maximum gross weight of 60 tons, exemptions for vehicles with a length of up to 30m and a gross weight of 90 tons were granted by the Swedish Transport Administration. *Table 4.1* exemplifies the regulations for conventional timber transport vehicles as well as those vehicles permitted in the ETT project. As the new vehicles contained longer rigs with higher gross weights, four instead of three stacks could be transported. Moreover, the stacks on the new vehicles could be bigger, which enabled the replacement of three conventional vehicles by two ETT vehicles (Löfroth & Svenson, 2012).

Vehicle Type	Max. Length	Max. Gross Weight	Axles
Conventional	24m	60 tonnes	**7 axles** (3-axle truck, 4-axle trailer)
ETT	30m	90 tonnes	**11 axles** (truck, dolly, link, trailer)
ST *Kran Gen. 1* *Kran Gen. 2* *ST-drag*	25m	74 tonnes	**9 axles** (4-axle crane truck, 2-axle dolly, 3-axle trailer) (4-axle crane truck, 5-axle trailer) (3-axle crane truck, 3-axle link, 3-axle trailer)

Table 4.1: Dimensions of Conventional and ETT forestry vehicles.

Before the start of the operation in January 2009, the vehicles were designed and tested with regards to their stability, turning radius and anticipated road wear. The vehicles which carried 65 tons of timber eventually started running on a distance of around 170km between Överkalix and Piteå. In August 2009 the secondary project ST (Större Travar/Bigger Stacks) was initiated in Western Sweden with the aim of increasing the payload of vehicles by compiling different rigs. Within the project different modules such as dollys, links and trailers were used according to the EMS. The vehicles were tested both as part of a staging system in which the wood is transferred from a crane truck to a tractor at a dedicated staging area, and as separate vehicles which carry the timber directly from the forest or terminal to the mills (Löfroth & Svenson, 2012). The trial with different combinations was important to ensure that the foundation for the regulations and technical solutions are as favourable as possible (Closer, 2021). The new vehicle compositions were operated in the counties Dalsland, Bohuslän and Värmland as shown in *figure 4.1*.

Figure 4.1: Operational area of the forestry vehicles employed in the ST project (Löfroth & Svenson, 2012).

Both parts of the project yielded consistently positive results. The number of vehicles on the road diminished, fuel consumption could be reduced by around 20% for ETT vehicles and by 8% for ST vehicles whereas emissions decreased accordingly, and transport costs declined by 20% and up to 10% respectively. These benefits however did not compromise road safety or increased road wear since the weight was distributed over more axles, and the manoeuvrability and stability of the vehicles could further be guaranteed (Löfroth & Svenson, 2012).

The trucks for this project were built by Volvo trucks who also monitored the fuel consumption and environmental data along the project. Since the start of the operations of the ETT and the ST vehicles, Volvo thus continuously updated the vehicle combinations with new enhanced solutions to achieve further reductions in fuel consumption and greenhouse gas emissions as part of the VETT (Volvo Takes and Extra Pile) project. In turn, new vehicle generations were launched in 2014 and 2016 respectively. The target value for the 90-ton vehicles is to reduce the emissions by 25% and by 12-17% for the 74-ton vehicles (Larsson et. al., 2017). The updated vehicles were in operation until the end of 2018 when the test period discontinued, and further positive results could be recorded.

ECT

A range of projects similar to the ETT were the ECT (Ett Coil Till/One Coil More) projects that were carried out in Sölvesborg between 2012 and 2019. The projects were dedicated to transport either steel coils from the port of Sölvesborg to their processing destinations, or to carry round wood to the nearby mill of Stora Enso. The first trial was performed from October 2012 and is still proceeding between the port of Sölvesborg and Volvo in Olofström, where two 74 tonne carriages were employed. From December 2014 to February 2018 a similar test was carried out to transport steel coils to Volvo Torslanda in Gothenburg with one 74 tonne HCT carriage. The distance for this trip was significantly longer, however it also included return loads from Volvo which enabled an effective utilization of the vehicles. Lastly, a short distance HCT trial was implemented from August 2015 to September 2018 to transport round wood from the port of Sölvesborg to the Stora Enso mill in Nymölla with one HCT carriage (Englesson, 2019). The corresponding routes and distances that were covered in these trials are displayed in *figure 4.2.*

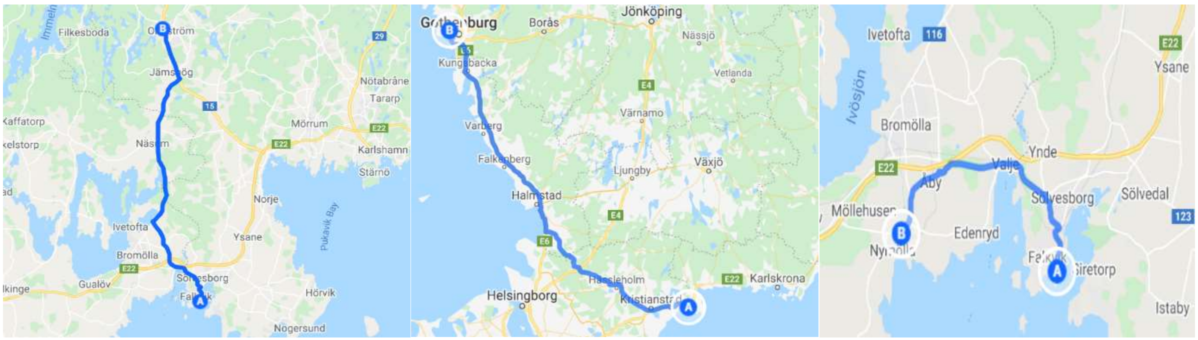

Figure 4.2: Routes covered in the ECT project. (Covering one-way distances of 40km, 360km, and 14km).

The results of the individual trials were partly divergent. All trials recorded savings in truck passages through Sölvesborg, reduced diesel consumption, and less carbon dioxide emissions. However, the route to Olofström was the only one that also demonstrated an economic feasibility where savings of 10-17% could be achieved through HCT. In the case of transporting to Gothenburg, savings of merely 4-7% could be attained and the trials were ceased due to difficulties of finding enough freight volumes and suitable logistics arrangements. The short distance transport to Nymölla was likewise discontinued as it even recorded 1% higher costs due to higher fixed costs and lower fuel savings that were induced by the small scale of the solution (Englesson, 2019). The ECT trials demonstrate the importance of the logistics arrangements, fill rates, frequencies and distances which are decisive for making IHCT solutions profitable.

Duo2

Another project for HCT vehicles that was concerned with general cargo is the DUO2 project which started its field tests in February 2012. The main objective was to reduce CO2 emissions from road freight by investigating combinations of vehicles of up to 32m and 80 tons. For this purpose, an 18 month exemption from the authorities was granted for a dedicated route between Gothenburg and Malmö. Within that test period, more than 500 one-way trips were carried out along the E6 (*figure 4.3*). A combination of vehicles with a tractor that was pulling two semi-trailers or 40ft. containers instead of one was used. The employed modular system enabled a high degree of flexibility, as each component could be used together or separately within the system and it was built on prior modules. For the trial alone, a special tractor, a dolly and four semi-trailers were built or upgraded (Cider & Ranäng, 2014). Similar as in the ETT project, aspects such as vehicle stability, fuel conditions, and accessibility needed to be considered before exemptions could be granted. A special concern was the stability of the vehicles due to their three joints which required a process of calculations, verifications and monitoring until they could start operating on the road with a speed of up to 80 km/h (Cider & Ranäng, 2014).

The results of the project showed CO2 reductions of 27% per amount of goods carried. Moreover, it did not reveal any adverse effects on road safety, while taking up less road surface and causing less congestion for the same amount of cargo carried. An optimization of vehicle and transport route utilization is however still desirable as the trucks in this project were merely allowed to operate at night times (Cider & Ranäng, 2014). The outcome of this project can be classified as highly relevant, as it was carried out on one of the main traffic axes in Sweden with relatively high traffic volumes for both passengers and freight. Therefore, the results show that potential negative effects that could occur when employing LHVs are uncritical.

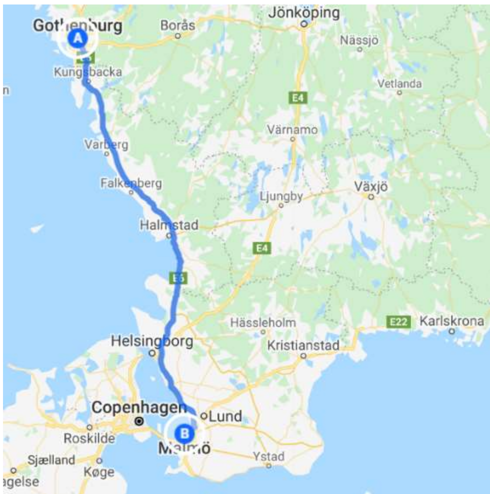

Figure 4.3: DUO2 project carried out on the E6 between Gothenburg and Malmö.

Autofreight

A project similar to the DUO2 project with two 40ft. containers being carried on a determined corridor, is the Autofreight project between Gothenburg and Borås. The project started running in 2020 with a test period of four years on the designated route along the road 40 between

Viareds Logistikpark in Borås and the Port of Gothenburg. The aim was to reduce the number of trips by at the same time maximizing the transport capacity, through the employment of vehicles with maximum dimensions of 32m and 80 tons respectively. Two to three daily departures were scheduled from the Port of Gothenburg, by trying to keep the fill rate as high as possible. Initial results showed that with the LHVs emissions can be reduced by around 30% compared to the previous operations with standard vehicles. Besides emission reductions, the project also resulted in cost efficiencies (Ahlgren, 2020). What makes the project unique, is that it is based on horizontal cooperation between several stakeholders, which enables them to jointly make use of the transport capacity. The trucks which are operated by the transport provider GDL follow an open booking system instead of only being dedicated to an individual customer (Closer, 2020). Moreover, the set-up includes the expansion of the regional logistics infrastructure, and the collection of traffic data for a development towards more autonomous transports (Ahlgren, 2020).

Jula

The most recent HCT exemption that has been granted for a specific route to and from the nearest IRT terminal was for the operations of Jula in Sweden. The service which has been operating since 2013 was jointly developed by Jula and Schenker Air and Ocean and operates between the Port of Gothenburg and Jula's central distribution centre in Skara. The set-up includes the inland terminal in Falköping which is located 120km from the port and handles the transhipment of the goods to the distribution centre through the established HCT road haulage at a distance of 27km. In December 2014 the Swedish Transport Agency granted an exemption to the prevailing road haulage restrictions which enabled Jula to transport two 40ft. containers simultaneously on the assigned road. The new solution had a great impact on cost-efficiency and the advancement of a modal shift from road to rail (Bergqvist & Monios, 2016). A study by Ye et. al. (2014) concluded that an employment of LHVs in the case of Jula can save approximately 25,2% of economic costs and 24,1% of emission costs of the PPH activities. For the overall IRT chain, total cost savings of 7,53% can be achieved which moreover helps to increase the competitiveness of IRT compared to unimodal transport (Ye et. al., 2014). The established service of Jula is still in operation today. Since Jula Logistics acquired the rail shuttle between Gothenburg and Falköping, the interest of other players to utilise this sustainable transport solution arose, and the company already extended their railway tracks to meet the expected increases in capacity (Jula Holding, 2021).

4.3 Implications from Practices

All of the outlined regulation extensions and pilot projects accentuate the prospects that IHCT solutions have internationally and above all in the Swedish market. The examples from Australia, Canada, or the US have been chosen as these countries have similar prerequisites as Sweden, by being elongated and sparsely populated. In such cases HCT for both road and railway transport is particularly feasible (Asp et. al., 2019). As the case of Finland likewise possesses vastly similar geographical conditions and commercial goods as Sweden, it can be qualified as a possible example of how Sweden could adapt their regulations for LHVs on dedicated roads within the national transport network. Although studies have shown that IRT is most competitive for large flows on long distances (Bärthel & Woxenius, 2004), the trials within Sweden point out that LHVs can in distinct cases also provide benefits on shorter distances. The individual economic and environmental cost savings that were recorded through the pilot projects are summarized in *table 4.2*.

	Types of Goods	**Vehicle dimensions**		**Distance travelled (km)**	**Economic Cost Savings**	**Emission Savings**
		Length (m)	**Weight (tons)**			
ETT	timber	30	90	170	20%	20%
ECT	industrial/wood	25.25	74	40/ 360/ 14	10-17%/ 4-7%/ +1%	14-19%/ 17-29%/ 12-13%
DUO2	commercial	32	80	285	*	27%
Autofreight	commercial	32	80	65	*	30%
Jula	commercial	32	60	27	25.2%	24.1%

Table 4.2: Cost and Emission Savings of HCT pilot projects in Sweden (no data available).*

The different trials present a good overview of the different effects that the employment of LHVs has depending on the transport distance, fill rate, or type of goods. Besides, the projects illustrate the importance of stakeholder collaboration when organizing PPH activities. The presented cases were feasible due to customers with predetermined volumes, a committed haulier, and the provision of appropriate equipment by vehicle manufacturers and terminals.

5 THEORETICAL FRAMEWORK

This chapter expounds the legal regulations for the maximum permitted weights and dimensions of road vehicles that are currently in place in the EU and specifically in Sweden. It moreover gives an overview of the road network in Sweden and its different bearing capacity classes. With regards to the Swedish IRT infrastructure, the concepts of combined rail-road transports are pointed out and exemplified on the present IRT terminals. Lastly, the relevant factors for a broad implementation of IHCT are presented.

5.1 Legal Framework

5.1.1 EU Regulations and ILUs

The maximum dimensions for freight trucks that are permitted for circulation between the member states in the EU have been prescribed in the directive 1996/53/EC. The aim of the directive is to facilitate international transport through the application of the European Modular System (EMS) which enables simple recoupling operations in intermodal transport. Moreover, it assures a fair level of competition between the member states by stipulating unified regulations (European Commission, 2021b). In 2015 this directive was amended by directive (EU) 2015/719 which was adopted after considerations regarding new limits for the vehicle weight, length or height were made. Even though the new directive did not modify the rules that are determined in directive 1996/53/EC, it represented an advancement to prior regulations, as the new directive grants derogations for longer or heavier vehicles in cases where the aerodynamic performance is improved or alternative fuels are being used (European Union, 2015). The currently applicable regulations according to directive 1996/53/EC are outlined in *table 5.1*.

Dimension	**Regulations according to Directive 1996/53/EC**
Length	18.75m/16.50m
Weight	40t (44t when carrying 40ft. containers)
Width	2.55m
Height	4.0m

Table 5.1: EU regulations of road freight vehicle dimensions.

The maximum length for articulated vehicles or road trains is thus restricted to 18.75m and to 16.50m for truck-trailer combinations. When it comes to the permitted gross weight, the directive indicates a maximum of 40 tonnes which can be extended to 44 tonnes if a 40-foot

ISO container is carried in a combined transport operation. The restrictions regarding width and height are steady at 2.55m and 4.0m respectively as they are limited by infrastructural conditions.

As previously mentioned, there are a number of different ILUs as standardized in the EMS that can be used in IRT chains. The most prevalent ones are ISO containers with a length of either 20-foot or 6.05m, 40-foot or 12.19m, or 45-foot which equals 13.72m. The width is identical for all ISO containers, while the height varies slightly between 20-foot or 40-foot containers and 40-foot-high cubes or 45-foot containers on the other hand (Discover Containers, 2020). *Table 5.2* exemplifies the dimensions of the different types of ISO containers. Besides the ISO containers, there are two types of swap-bodies which can be used depending on the employed vehicle. Swap-bodies “Class C” can have a length of 7.15m, 7.45m or 7.82m and are commonly carried on road trains. Articulated vehicles on the other hand make use of swap-bodies “Class A” that have a length of either 12.5m or 13.6m. 13.6m is also the maximum and typical length for semi-trailers which can be loaded onto wagons by means of gantries or mobile cranes (UIRR, 2021).

Dimension	**20-foot**	**40-foot**	**45-foot**
External Length	6.05m	12.19m	13.72m
External Height	2.59m	2.59m (2.89m high cube)	2.89m
External Width	2.44m	2.44m	2.44m

Table 5.2: Dimensions of ISO containers (numbers from Discover Containers, 2020).

According to the regulations set in directive 1996/53/EC different combinations of these existing load units are possible. A road train can carry two class C swap bodies or two 20-foot containers. Articulated vehicles are able to carry one class A swap body or a semi-trailer, one class C swap body, two 20-foot containers or one 40-foot container (Lowe, 2005; Bergqvist & Behrends, 2011). *Figure 5.1* gives an illustration of the possible configurations of ILUs according to directive 1996/53/EC. The different modules can be distinguished as “short carries” which include any type of swap body or a 20-foot container, or long modules with a length of 13.6m or one 40-foot container.

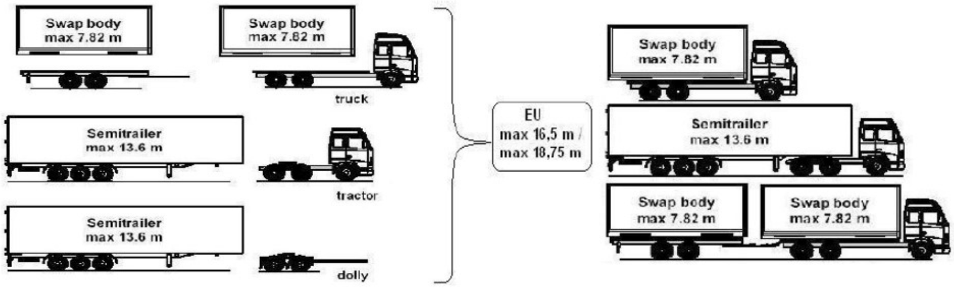

Figure 5.1: EMS configurations as allowed in the EU (adjusted from Åkerman & Jonsson, 2007).

5.1.2 Swedish Regulations and Bearing Capacity Clases

The directive 1996/53/EC sets the general maximum dimensions for road freight vehicles in the EU, however the ILUs according to the EMS can be combined flexibly. This was an important consideration when the EMS was introduced, as it was aimed to incorporate the requirements that had been in force in the individual member states prior to the introduction of the directive. As Sweden and Finland historically have been permitting LHVs, both countries were granted allowances to combine one long and one short module in order to keep transport costs stable and ensure the competitiveness of the forest industry (Åkerman & Jonsson, 2007). Before 1968, there was no limit on the length of vehicle combinations in Sweden and accordingly quite a few vehicles were 30m and longer. Most of the operating long-haul vehicles have however been 24m long, which also evolved as the maximum authorized total length in 1972 (Kharazzi et. al., 2015). When Sweden joined the EU in 1995, road freight vehicles with maximum dimensions of 25.25m and 60 tonnes were permitted. In 1998 the previously used vehicles with a length of 24m were eventually transitioned to the newly allowed specification of 25.25m (ITF, 2019). In 2015, the weight limitation was further increased to a total of 64 tonnes. The authorized height of the vehicles in Sweden likewise exceeds the general regulations prescribed by the EU, by being regulated to a maximum of 4.5m which has long been in place. *Table 5.3* exemplifies the current regulations for the maximum vehicle dimensions on Swedish roads.

Dimension	**Regulations according to directive 1996/53/EC and STA**
Length	25.25m
Weight	64t
Width	2.55m / 2.60m for temperature-controlled vehicles
Height	4.50m

Table 5.3: Swedish regulations of road freight vehicle dimensions.

These dimensions allow for the different trailer combinations as illustrated in *figure 5.2*. The HCVs thus can consist of a combination of one semi-trailer and one swap body or one 20-foot ISO container and one 40-foot ISO container. The combination of the different EMS modules enables the transition of the Swedish HCVs into common standard vehicles according to directive 1996/53/EU when cross-border trade is executed.

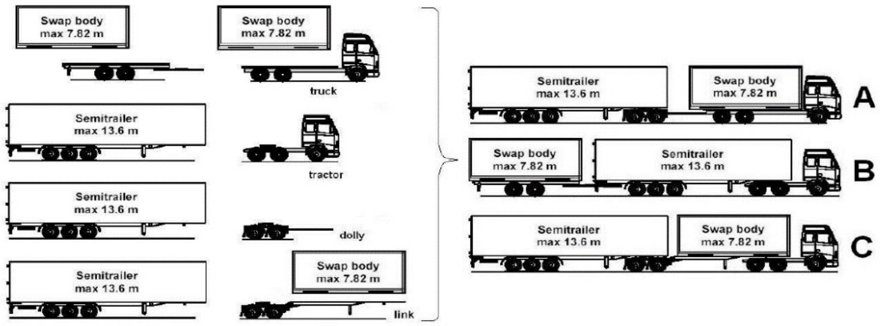

Figure 5.2: EMS configurations as allowed in Sweden (Åkerman & Jonsson, 2007).

All vehicles with the maximum dimensions as outlined in *table 5.3* are permitted to circulate on Swedish public roads, however the parts of the road network that are approved for HCVs is limited. The Swedish Transport Agency (STA) categorised the public road network into different bearing capacity classes that differ in terms of the permitted gross weight and axle as well as bogie load of the vehicles as shown in *table 5.4*. In July 2018 bearing capacity class four (BK4) was added to the existing road network. The roads that are currently classified as BK4 as well as those that should open as BK4 between 2020 and 2022 are illustrated in *Appendix II*. HCVs in accordance with the regulations of directive 1996/53/EC are currently approved on bearing capacity class one (BK1) and bearing capacity class four (BK4) roads, which account for approximately 95% of the overall public road network. The Swedish Transport Administration might however issue further conditions for vehicles and road trains that want to drive on BK4 roads (Swedish Transport Agency, 2018).

Bearing Capacity Class	**BK1**	**BK2**	**BK3**	**BK4**
Gross weight (tonnes)	64	51.4	37 (can be exceeded if axle distance ≥ 22m)	74
Axle load on driving axle (tonnes)	11.5	10	8	11.5
Axle load on non-driving axle (tonnes)	10	10	8	10

Table 5.4: Bearing capacity classes of the Swedish public road network.

According to the currently prevailing regulations, the maximum weight for road freight vehicles in Sweden is restricted to 64 tonnes, which makes them eligible on BK1 and BK4 roads. In case that LHVs would be allowed, they would even be capable of carrying 74 tonnes on BK4 roads. Within the past years there have been a number of trials with, or exemptions for, longer or heavier vehicles on a limited road network to and from the nearest IRT terminal, as it was elaborated on in *chapter 4*. An increased usage of LHVs also desires a greater network to be qualified for heavier vehicles. Therefore, the national plan for 2030 allocated ten billion SEK to strengthen the most important roads to a BK4 standard, and thus a bearing capacity of 74 tonnes (Asp et. al., 2019).

5.2 IRT Operations in Sweden

5.2.1 Dry Ports and Rail Shuttles

The need for connectivity between seaports and inland conurbations has been a focus of attention in the last decades given the growth in the container shipping industry, which is currently the backbone of global trade (Roso et. al., 2008). The container shipping industry has a high importance in freight transport cost competitiveness, given the fact that most companies outsource production to other continents and markets have spread across the whole world. In addition to that, the integration of international and domestic logistics has expanded through a globalised supply chain supported by reduced tariffs and trade barriers, which led to a decrease in sea-transport costs (Bergqvist et. al., 2017). These factors have played a key role in the expansion of the container shipping industry and in bringing adverse effects that came together with this expansion (Roso et. al., 2008). The growth of container shipping flows to seaports has overwhelmed their capacity, restraining the volume flows for hinterland areas. The hinterlands are known as the interior regions served by the transports from the port. In order to become more competitive, the main seaports attract as much volume flow as economically viable and develop vertical integration between actors to control the hinterland connections with railway operators and shipping lines. The seaport's terminals have become more crowded, urban traffic congestion around seaports have seen unprecedented levels, and containers have developed long dwell times (Woxenius et. al., 2004).

In this context, comes the concept of dry ports, which is defined by Leveque & Roso (2002) as "an inland intermodal terminal directly connected to seaport(s) with high-capacity transport mean(s), where customers can leave/pick up their standardised units as if directly to a seaport."

A dry port acts as a buffer that relieves freight congestion and stacking areas at seaports. The rail-road intermodal transport benefits that dry ports bring in their operations promote lower congestion at seaport gates and in the surrounding areas. The freight transportation by rail trains promotes advantages such as reducing externalities and the ability to replace as many as 35 lorries per train. Arguably, a dry port that is properly applied in its concept can shift freight volumes from road to more energy efficient transport modes that generate less carbon emissions, are able to reduce traffic congestion in seaport cities, and increase the handling efficiency in seaports themselves. Not only that, but the economic benefits of dry ports are related to providing shippers with more competitive costs and connections with wider areas around the hinterland, which facilitates to maintain a good quality of services and expand the reach of the forwarders' services. Well established dry ports have reliable schedules while operating high-capacity volumes to and from seaports, which improves the seaports situation with high influx of containers. Moreover, they make use of communication systems that promote safe and reliable exchange of information to maintain optimal interface between rail and road transport (Woxenius et. al., 2004).

In the Swedish context, the concept of a dry port is applied by the Port of Gothenburg which is the largest port in Scandinavia and is receiving constantly high influxes of volumes. Besides, it possesses a strategic location compared to other ports that would require a detour around southern Sweden, such as the Port of Stockholm. The port of Gothenburg is increasingly exploring its hinterlands through several intermodal rail-road transport connections to about 25 rail terminals throughout Sweden and Norway as illustrated in *figure 5.3*. The rail system is known as Railport Scandinavia and aims at replacing transport demand from road to rail. Currently, the annual container value handled by the port of Gothenburg comprises 753.000 TEU, whereof 60% of all containers to and from the port are transported by rail. The rail shuttles from the Port of Gothenburg save around 53,000 tonnes of carbon dioxide every year, which is equivalent to the annual emissions from 23,000 passenger cars (Port of Gothenburg, 2019).

Figure 5.3: Railport Scandinavia - Railport Intermodal Rail Shuttle System (Port of Gothenburg, 2019).

5.2.2 Transport Networks and IRT Terminals

Besides a strong connectivity of seaports and inland freight terminals, the coordination between the terminals and the LSPs that are performing the road haulage operations of the last-mile transport leg is crucial to round off an efficient transport network. In particular, the geographical location as well as the infrastructure of the combined rail-road terminals, herein referred to as IRT terminals, are decisive when seeking a modal shift from road to rail. The term combined transport (CT) can be identified as a sub-category of intermodal transport, where the road legs of the transport chain are kept to a minimum and a major part of the journey is carried out by rail, inland waterways, or sea (Bochynek et. al., 2020). Freight terminals as defined by the regulation (EU) 1315/2013 describe a "structure equipped for transhipment between at least two transport modes or between two different rail systems, and for temporary storage of freight" (European Union, 2013). An IRT terminal is therefore responsible for handling the arriving and departing rail haulages and transhipping the ILUs for the subsequent road transport or drayage activities. An inland freight terminal has a strategic role of being part of a network of other inland terminals around a main port to help establish the seaport in the inland region as a competitive port to serve the urban areas around it. Through an integration of services, which is shaped by the local geographical and economical attributions and a physical plant that serves the demands for an inland region, an inland terminal can develop its importance in a region (Woxenius et. al., 2004).

From a market perspective, the density and capacity of combined terminals represent decisive factors for the performance and thus the market share of the overall transport network. When contemplating the EU member states, one can observe considerable differences in their economic and spatial structures, which likewise has an effect on the formation of their terminal networks. For Sweden in specific, the CT terminal density can be classified above the EU average, even though the country does not function as a main transport hub within Europe. This can be explained by the fact that Sweden is located along one of the main intermodal transport trade routes in Europe (UIC, 2020). Via the ScanMed corridor, Sweden is well connected to the central parts of Western Europe where great parts of trade are handled by rail. Moreover, IHCT for road and railway has long been proven to be interesting for Sweden as a country, due to its industrial and geographical prerequisites which are very dependent on resource and cost-efficient transport systems (Asp et. al., 2019). According to the most recent report on combined transport in the EU as issued by the international union of railways (UIC, 2020), there are 92 CT terminals in Sweden at the current state. The most relevant ones for IRT are those terminals integrated in the Railport Scandinavia network, whereof a few will be investigated in detail in this study.

5.3 HCT Implementation

The infrastructure access for HCT road freight vehicles on a national level can be regulated in a variety of different ways. The "Roadmap HCT Road" outlined five potential forms of access, which have already been used internationally and represent potential prospects for an implementation of HCT in the Swedish market. The first form of access is the introduction of a specific road class for a limited part of the national road network that allows for HCVs. The introduction of BK4 in 2018 can in this regard be classified as a first effort to gradually strengthen the national HCT infrastructure. Another way to grant access for HCVs is to issue time limited permits to drive specific HCT vehicles on specific roads, particularly for research purposes. In Sweden this has previously been done through a range of HCT demonstration projects and trials that are partly still ongoing have been elaborated in *chapter 4*. Besides time limited permits, permits to drive specific HCT vehicles on specific roads can also be issued permanently. This form of access is appropriate for heavy duty or construction vehicles, as well as certified vehicles that fulfil certain predetermined safety standards. The permanent permits can also underlie situation adapted restrictions that can be adjusted dynamically according to changes in external conditions such as weather, frost, traffic, or types of goods to be transported. Lastly, exemptions to drive HCVs on a specific route can be granted for a specific purpose.

This includes for example transports of non-divisible loads, or exemptions for certain periods or a certain number of passages on a given route (Asp et. al., 2019). As Sweden already has different bearing capacity classes for its roads and various projects with time limited permits for HCVs have been carried out previously, the focus to strengthen the HCT market in Sweden should thus be on the attainment of permanent permits for HCVs on specific roads. If necessary, these permits can then be restricted to a certain situation or purpose.

In order to enable a more situation specific match of the permits to the load, vehicle and infrastructure, a smart infrastructure access policy (SIAP) is needed. The principle of a SIAP thus combines the frameworks of Performance Based Standards (PBS) and Intelligent Access Control (IAC), which can be seen as prerequisites to successfully grant road access for HCVs. The establishment of PBS aims to guarantee that the employed vehicles fulfil certain safety standards, by demanding certain functional requirements. This opposes the approval of LHVs according to precise vehicle dimensions and technical designs. The IAC on the other hand has the objective to eliminate disruptions for employment of a vehicle in time and space, by connecting the vehicles for steering and control. With an IAC in place, LHVs can more securely pass bridges or municipal roads that at the current state are classified as not suitable for an increased vehicle weight (Asp et. al., 2019).

6 COST CALCULATION MODEL

This chapter presents the cost calculation model that will be used to analyse the economic and environmental effects of the employment of LHVs in an IRT chain. It gives an account of the occurring railway, handling, and PPH costs of IRT by demonstrating all individual cost components. Lastly, the chapter introduces the different haulage scenarios including the underlying assumptions for which the cost performance will be compared.

6.1 Cost Structure

6.1.1 Operational Costs

According to Janic (2007) the cost of an intermodal transport network can be categorized into internal and external costs. The internal costs are the costs that occur when moving the units along the transport network from the point of production to the point of consumption. This includes the collection, distribution, haulage, and transhipment of the units. Daganzo (2005) classifies these cost components as either handling or transportation costs of a logistics operation, which can be summarized under the term "motion" costs. Opposed to the "motion" costs, a logistics operation commonly also includes "holding" costs, that comprise those costs associated with either rent or waiting time. These costs occur in relation to the warehousing activities and the capital tied up for storage (Daganzo, 2005). For this thesis, the focus is only on the "motion" costs, as these are the costs arising within an IRT chain. Furthermore, as suggested by Janic (2007), the costs for infrastructure investments are not taken into consideration, as the network infrastructure is assumed to be in place to handle the emerging demand. Similar to the "holding" costs, the infrastructure costs are not directly related to the contemplated actors which are concerned with the haulage activities. The internal costs as defined by Janic (2007) can thus essentially be translated into the operational costs occurring in an intermodal network.

The operational cost components of a transport operation can furthermore be divided into either fixed or variable costs. The division is completely dependent on the time period during which a system is studied. Thus, fixed costs fundamentally represent variable costs that are considered fixed over a predetermined period of time. Fixed costs mainly include overhead costs or general administration costs that are shared for each individual service or item (Floden, 2007). Therefore, fixed costs are often equated with so-called time-based variable costs. Besides, a road haulier commonly faces fixed costs in form of depreciation and cost of capital (Lindqvist et. al., 2020). These costs can however rather be classified as distance-based variable costs than time-based variable costs.

In this manner, variable costs of a transport operation can be divided into being either distance-based or time-based. Time-based variable costs are those costs that need to be accounted for in a fixed amount that occurs in a frequent temporal distance. Such costs include taxes, insurance, equipment costs, and salaries, and are therefore often treated in the same way as fixed costs. Distance-based variable costs on the other hand describe the costs that are dependent on the driven amount of kilometres, such as depreciation, repair and maintenance, or fuel costs. *Table 6.1* gives an overview of the different operational cost components.

Time-based variable costs (hour) / Fixed Costs	**Distance-based variable costs (km)**
Overhead Administration Salary Taxes, insurance, equipment, Cost of capital: depreciation of purchase price	Tires Repair, maintenance Depreciation Kilometre taxes Fuel costs/km Infrastructure fees Energy usage

Table 6.1: Operational Costs of Transport (self-made in alignment with Lindqvist et. al., 2020; Floden 2007; Folder, 2011).

According to Daganzo (2005), the total costs of transport, including fixed and variable costs, can be described as follows:

$$C\ total = cf + cv * v * d$$

cf = Fixed costs per shipment
cv = Variable costs per shipment
v = Freight volume
d = Distance from point of origin to destination

When applying the above formula to an IRT chain, the total costs must be further divided into the costs of rail-haulage, the handling costs that are associated with the transhipment activities, and the costs of road haulage. The costs of rail and road-haulage follow essentially the same structure as the total costs, as they are likewise dependent on transport volume and distance. Accordingly, the relationship can be reproduced as:

Road Haulage Costs	Rail Haulage Costs
*C road = cf-road + cv-road * v * d road*	*C rail = cf-rail + cv-rail * v * d rail*

Opposed to the haulage costs, the handling costs are only depending on the freight volume. Handling costs occur for each ILU that needs to be loaded or unloaded at the terminal. Thus, the total handling costs are:

$$C\ handling = cv\text{-}handling * v$$

When integrating all above-mentioned cost components of an IRT chain, the overall operational costs can be summarized as:

$$C\ total = C\ rail + C\ handling + C\ road$$

6.1.2 Environmental Costs

Next to the internal costs that are born by the transport operators, transport networks also place a burden on society. If the transport providers are not bearing these social damages themselves, the occurring costs are referred to as externalities. Externalities that are on the other hand monetized, can be summarized under the concept of external costs. These costs mainly include air pollution, climate change, congestion, noise, and traffic accidents (Macharis et. al., 2010; Janic, 2007). There has been much research about the internalisation of external costs which suggests to financially compensate for people affected by traffic accidents and take into consideration the time-based impact of noise and congestion in urban areas. However, the most prevalent external cost that harms people's health and the environment is air pollution which can be expressed in CO_2 emissions. Thus, the only external costs that are being considered in this thesis are the amount of CO_2 emissions that occur in the course of a transport operation. These emission costs are classified as distance-based variable costs, as they can be derived from the fuel consumption and distance travelled from the point of origin to the point of destination. Accordingly, the emission costs can be described as:

$$C\ road\text{-}emission = cvt \times N\ truck \times d\ road$$

$$N\ truck = Volume\ (TEU) / Truck\ Capacity\ (TEU)$$

cvt = variable emission costs per shipment

N truck = number of shipments related to a truck

d road = distance from point of origin to destination

Emission costs occur for both road and rail haulage, whereas railway transport is the much more environmentally friendly mode of transport. In an IRT chain, the majority of the emissions can therefore be allocated to the road haulage. As this study aims to compare the environmental impact of LHVs opposed to standard PPH vehicles, the emission costs will only be calculated for the road haulage operations.

6.2 IRT Costs

6.2.1 Rail Haulage Costs

For the evaluation of the rail haulage costs for each determined transport corridor of this study, all intermodal volumes are assumed to arrive at the Port of Gothenburg before being transported with the rail shuttle to the corresponding IRT terminal. The rail-haulage cost calculation will be based on Floden (2011) and can be divided into fixed and variable costs as described above. The fixed costs which amongst others include salaries and depreciation must however still be bound to the required working hours of an operation (*Ht*). Besides, the yearly freight volume for each corridor must be allocated to a number of trains (*N rail*) according to their maximum capacities, in order to calculate the distance-based variable costs. Therefore, the total rail-haulage costs can be summarized as:

$$C\ rail = C\ f\text{-}rail * Ht\ rail + C\ v\text{-}rail * N\ rail * d\ rail\ ;$$
$$Ht\ rail = N\ rail * (D\ rail/S\ rail)$$
$$N\ rail = Volume\ (TEU)\ /\ Train\ Capacity\ (TEU)$$

The majority of the costs concerned with the rail-haulage are fixed costs associated with the transport equipment and the employees salaries. The variable costs of the rail-haulage are mainly those costs that accumulate due to the usage of the public infrastructure. Besides, rail operators need to pay for the emerging electricity consumption (Floden, 2011). In Sweden, the railway infrastructure is publicly owned, which requires every operator to pay for the infrastructure equivalent to their usage. The fees for the infrastructure usage as well as for the electricity consumption are prescribed by the STA. Accordingly, the infrastructure charge can be divided into: the train path for a freight service, the track charge, and passage charges in certain metropolitan areas or the Öresund Link (Trafikverket, 2021). Some of these fees require the specification of a certain type of train to determine the level of the fee which can depend on the axle load. Similarly, the electricity fee is dependent on the train and vehicle type, which determines the loading weight and thus the overall costs.

In this calculation model, a typical intermodal train with a capacity of 60 TEUs, that on average includes 75% loaded wagons and 20% spare wagons, will be used as a standard train. Moreover, the train is specified as a medium cost electric line haul train equipped with a new TRAXX engine. According to Floden (2011), the time-dependent and distance-dependent variable costs occur separately for the engine, the empty wagon, and the utilized loaded wagon. When accumulating these costs, the time-dependent or fixed costs can be summarized as 1312.45 SEK per hour, and the distance-dependent costs result in 11.6 SEK per kilometre. The time-dependent costs include salaries, vehicle taxes and insurance, whereas the distance-dependent costs comprise costs for tires, fuel or energy consumption, maintenance, and infrastructure fees such as track charges (Floden, 2011). If adjusted to inflation, the default values for this model can be determined as shown in *table 6.2*. Furthermore, the table displays the default values for the train speed and capacity, which are set to an average of 70km/h and 45 TEU respectively as based on the above-described typical train (Floden, 2011).

Parameter	**Value**
C f-rail	1447.26 SEK/h
C v-rail	12.79 SEK/km
S rail	70km/h
Train Capacity	45 TEU

Table 6.2: Default values for rail haulage.

6.2.2 Handling Costs

The handling costs are the costs associated with the transhipment activities when loading and unloading the ILUs from rail to road and vice versa. As explained above, the handling costs are solely dependent on the transported volume, which in this model refers to the number of TEUs handled each year. Thus, the total costs of handling are:

$$C\ handling = c\ v\text{-}handling * N\ ILUs\ (TEU)$$

The number of ILUs handled will be determined for each terminal and LSP individually. The variable handling costs are then dependent on the size of the terminal, as the operating costs can differ according to the amount and type of train loaded. Based on Floden (2011) the different terminals including handling costs can be distinguished as shown in *table 6.3*.

Terminal Size	Small	Medium	Large
Average annual volume handled	25.000 TEU	50.000 TEU	100.000 TEU
Cost per load unit	256 SEK	182 SEK	166 SEK

Table 6.3: Variable handling costs per type of terminal.

6.2.3 Road Haulage Costs

As aforementioned, the road haulage costs are divided into fixed and variable costs. When classified as time-based variable costs, the fixed costs can be assumed to be dependent on the working hours (*Ht*) of the employed vehicles. Moreover, the fixed costs such as overhead costs, equipment costs, and salary, are assumed to increase proportionally with increasing freight volumes. The variable costs on the other hand are dependent on the number of shipments related to the truck haulage (*N*), and the corresponding distance travelled (*d*). The total costs of road haulage therefore can be calculated as follows:

$$C\ road = Cft * Ht + Cvt * N\ truck * d\ road$$
$$Ht\ truck = N\ truck * (d\ road / S\ road)$$
$$N\ truck = Volume\ (TEU) / Truck\ Capacity\ (TEU)$$

Both fixed and variable cost components for PPH will be derived from Flodén (2007). According to Flodén (2007) the hourly fixed costs of a 25.25m truck amount to 321 SEK. If this number from the study of 2007 is adjusted with inflation to 2021, we obtain fixed costs of 380.3 SEK per hour. For the variable costs, Flodén (2007) provides a value of 4.17 SEK per kilometre. These costs comprise fuel, tires, and repair and maintenance. As such costs are dependent on the distance, and thus the utilized fuel of the truck, the value from 2007 must be adjusted in alignment with the current diesel prices and fuel efficiency. The current diesel price in Sweden is considered as 15.65 SEK/l (Global Petrol Prices, 2021). Moreover, the fuel efficiency of HDVs has increased in recent years and comprises 23.6 litres/100km, which equals 0.236l/km, for a typical EU tractor-trailer according to a study from 2018 (Rodriguez et. al., 2018). Based on these adjustments, the variable costs for the truck end up at 5.15 SEK per kilometre. The default values for the parameters of the total costs of road haulage are presented in *table 6.4*.

Parameter	Value
Cft	380.3SEK/h
C vt	5.15SEK/km
S road	110km/h

Table 6.4: Default values for road haulage.

6.2.4 IRT Total Costs

The total transport costs of an IRT chain are represented by the sum of the rail-haulage, handling, and road haulage costs. Based on the above expounded formulas, the total costs of an IRT transport system can be constructed as presented in *table 6.5*.

Rail Haulage	Handling	Road Haulage
*C rail = C f-rail * Ht rail + C v-rail * N rail * d rail ;* *Ht rail = N rail * (D rail/S rail)* *N rail = Volume (TEU) / Train Capacity (TEU)*	*C handling =* *c v-handling * N ILUs (TEU)*	*C road = Cft * Ht + Cvt * N truck * d road ;* *Ht truck = N truck * (d road/S road)* *N truck = Volume (TEU) / Truck Capacity (TEU)*
IRT Total: *C total = C rail + C handling + C road*		

Table 6.5: IRT total costs of transport.

6.3 Scenario Presentation

To outline the environmental and economic cost implications that an introduction of IHCT compared to the usage of current standard vehicles has in the Swedish market, the costs will be calculated for two different scenarios as presented in *table 6.6*. Scenario A represents the present situation where all road freight volumes are carried by vehicles with the maximum permitted length of 25.25m. In Scenario B, LHVs with a maximum length of 34.5m will be employed. The differing length of the vehicles allows for different ILUs to be coupled in a single transport operation, as elaborated in *chapter 5*. The underlying regulations of scenario A allow the combination of one 40ft. and one 20ft. container, which equals 3 TEU. In the case of Scenario B, two 40ft. containers, which can be equated with 4 TEU, can be carried at a time. For both scenarios, the assumed gross weight is standardized to 64 tons which is the current maximum permitted weight of freight vehicles in Sweden. The standardization has been established as the transported goods of the examined cases vastly comprise grouped and mixed goods, which are rather limited by volume than by weight (Lindqvist et. al., 2020). Accordingly, the calculation scenarios will demonstrate the implications of only longer road freight vehicles.

	Scenario A	Scenario B
Maximum length	25.25m	34.5m
Maximum gross weight	64t	64t
Maximum TEU	3 TEU	4 TEU

Table 6.6: Road haulage calculation Scenarios for standard trucks and LHVs.

Based on the different dimensions of the road freight vehicles, there will be differences in the fuel consumption and the maximum speed of the trucks. According to previous investigations that compared the fuel efficiency of LHVs compared to standard PPH vehicles, LHVs carry a higher cost of approximately 20% per vehicle kilometre (Ye et. al., 2014). This increase will be considered for the distance based variable costs in Scenario B. Moreover, the LHVs are limited in the maximum speed they are permitted to drive. As the DUO2 project exemplified, previous exemptions for vehicles carrying two 40ft. containers were issued under the requirement of not exceeding a maximum speed of 80km/h (Cider & Ranäng, 2014). This number will be taken as a guide value for Scenario B as opposed to the maximum speed of 110km/h on Swedish highways that is assumed in Scenario A.

7 EMPIRICAL FINDIGNS

This chapter expounds the findings that could be derived from the interviews with a selection of Swedish terminal providers and LSPs. The interviewees were questioned with regards to the general impacts and challenges that they anticipate if LHVs are deregulated for operation. Besides, they were asked for more specific information regarding their current freight volumes, anticipated increases in demand through IHCT, and the main freight corridors that they are currently serving for customers with a potential for IHCT. These data are used to present an estimation of the economic and environmental costs that occur for the current operations without HCT, before being compared to the scenario where HCT is implemented.

7.1 Implications of HCT Operations

7.1.1 Terminals

The IRT terminals as illustrated in *figure 7.1* have been investigated within this study, and include: Båramo Kombiterminal in Vaggeryd, Eskilstuna Logistik, Hallsberg intermodal terminal in the region of Örebro, Sundsvall Logistikpark, NLC Umeå administered by INAB Umeå, and NLC Storumanterminalen. Besides, the terminal in Falköping has been marked in *figure 7.1*, as it belongs to the operations of the LSP Jula logistics, which is also part of this study. The terminals stretch from the south to the north of Sweden which makes them distinguishable in their geographic location and surrounding population density. Thus, the yearly volumes as well as the types of goods that the terminals are handling differ accordingly. While the terminals in Båramo, Eskilstuna and Hallsberg are mainly concerned with industrial/bulk and consumer goods, the terminals in Sundsvall and Umeå also handle timber and other forestry products. The terminal in Storuman is solely managing transports of forest raw materials.

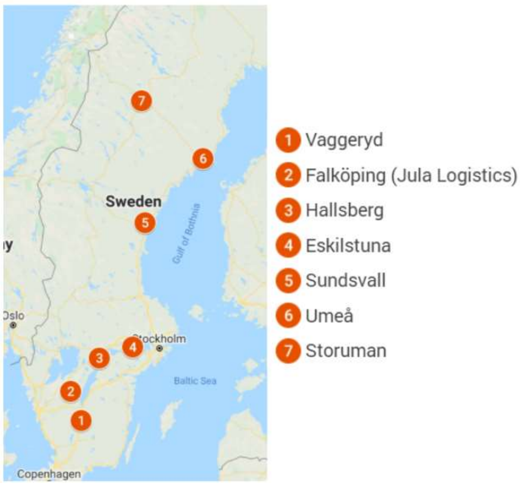

Figure 7.1: IRT Terminals investigated in this study.

As explained above, the role of an IRT terminal is to provide the necessary railway infrastructure as well as the equipment for the haulier to trans-ship the arriving goods from rail to road. If HCT road freight vehicles are being permitted, the terminal could be affected in a way that rail freight volumes or frequencies will potentially change, the overall demand on the terminal will scale up, and the handling and transhipment operations will alternate. Even though the terminal itself is not responsible for the execution of the PPH operations, it will still be concerned with the effects that LHVs will have on intermodal freight flows and capacities. To determine the effects that an implementation of LHVs could have on the IRT terminals, all terminals were consulted with regards to the challenges, negative effects, and operational improvements that they anticipate in case that LHVs would be permitted.

The results revealed that the main challenges that the terminal providers perceive with regards to an implementation of IHCT are bureaucratic issues, infrastructural conditions, and the road network. Most terminals criticized that it is difficult to get exemptions for LHVs approved by the STA, as the application procedures commonly take a long time and permits are merely issued for a limited period. Arvidsson therein emphasized that it would be of advantage if national regulations for the permitted weight and dimensions of road freight vehicles would be changed. In this way, the complicated procedures of granting individual exemptions could be eliminated. Sörman and Svensson expressed similar bureaucratic concerns for the development of the railway infrastructure at the terminal in Eskilstuna. As the trailer segment is growing in international trade, the terminal is currently extending its railway tracks. However, before the freight trains are allowed to operate on these tracks, they desire an approval from the STA, which commonly takes a long time and thus hinders quick adjustments to the market. Moreover, Sörman and Svensson highlighted that transportation is organised on a communal level, which complicates flows that are dependent on the infrastructure of a neighbouring municipality as separate regulations might apply. In terms of the road infrastructure the main concerns were that bridges might not be suitable for heavier trucks, and that the road network needs to be reinforced. Keljalic remarked that “large parts of the road network will have to allow for BK4" in the future to provide the conditions for heavier vehicles. Another aspect that was predominantly stressed by the more northerly terminals in Sundsvall and Storuman was that the standard of the municipal roads connected to the terminals is comparably low, with many hilly and curvy roads. These could represent a risk in case LHVs want to overtake other vehicles. In a similar regard Sunnliden mentioned that it is difficult to allow HCT vehicles on main roads that are also used by commuters and therefore serve a large traffic volume.

When it comes to the negative effects of an implementation of HCT road freight vehicles, the respondent's main concerns are the increasing competition between the different modes of transport, the market power of individual hauliers, and operational complications. The representatives of the terminals in Eskilstuna and Hallsberg stated that the implementation of LHVs could increase the competition between rail and road transport, and HCT road freight vehicles could become a main competitor to multimodal chains. Therefore, they stressed that permissions for LHVs should only be granted from the terminal to its corresponding customers and not on a far-reaching scale. Widenfalk was furthermore concerned that road haulage today is still relatively cheap and efficient compared to rail transport, which is why the break-even point at which rail transport becomes profitable compared to road transport is at a fairly long distance of 350-400km. If the overall transport distance of a consignment is thus not long enough, sole road transport will still be the prevailing transport solution. Arvidsson also raised the aspect of competition with regards to the pricing that will be executed by the forwarders. As the forwarders can determine the transport prices, they will do it to their own favour and the terminals can barely generate any additional profits. Keljalic moreover pointed out that new HCT solutions might desire high investment costs for smaller players in the road haulage sector. Therefore, these players need to be supported by methods that ensure competition in the transition to a sustainable transport system. From an operational perspective, negative concerns regarding IHCT were raised in that it might desire the acquisition of additional equipment, and additional operational efforts might arise as trailers have to be switched. The consolidation of cargo can also be complicated, which makes HCT very dependent on steady freight flows.

Besides these potential negative effects on the logistics operations, all terminal providers could likewise foresee major operational improvements that can emerge with the deployment of LHVs. These improvements include less congestion, smoother flows at the terminal, and benefits for large customers. Most of the terminal providers identified the circulation of fewer trucks around the terminal as a main operational advantage. It would decrease the congestion around the terminal and thus enable smoother transitions of the ILUs. Rönnberg moreover emphasized that less vehicles can also reduce risks of accidents around the terminal and in the city. Beyond that, he mentioned that the air quality in Umeå is currently suffering due to high traffic volumes in the city, which could be improved if less freight vehicles are being employed. Sunnliden and Keljalic from the region of Örebro predominantly stressed that the offer of IHCT solutions will create a positioning benefit for the region by maintaining the attractiveness of the logistics-dense area and providing a good infrastructure for their national and international customers. The provision of IHCT solutions could also urge the modal shift from road to rail and strengthen multimodal transport chains. Companies that do not yet drive goods by rail can be incentivised to transfer some of their operations to the railway. In turn, transport emissions can be reduced. From a cost perspective, all terminal providers held the view that IHCT will be most beneficial for large companies with steady volumes. If LHVs are employed, big companies can attain lower prices, as the road transport costs to and from the terminal will decrease with fewer vehicles in operation. Sörman and Svensson from Eskilstuna mentioned that HCT is presumably most suitable for companies with spatial products or products such as paper and steel. In order to make HCT a reasonable option, a company needs to have a certain volume to be transported. They accentuated the interplay between transport volumes and HCT offerings, which can potentially create a scale-up effect in the demand for HCT. If there is enough volume, HCT solutions will become profitable for a customer. Consequently, the terminal would increase its offering for HCT solutions and could thereby attract new customers to use this offering. At the current state the terminal in Eskilstuna handles the demand of a few big customers of consumer and industrial goods, for which the setup of HCT solutions would be possible and moreover improve the current operations. For the terminal in Vaggeryd, Arvidsson even estimated that 75% of the currently transported volumes would have the potential to be handled via HCT.

In order to assess potential future cost savings in case HCT road freight vehicles are employed, the IRT terminals were also consulted with regards to potential investments that could be required to handle the operations with LHVs. All of the examined terminals indicated that at the current state there are no major investments required. The current infrastructure at the terminals seems to be sufficient to deal with the anticipated flows of LHVs. It must however be remarked that most of the terminals are currently in a process of expansion which could have contributed to the fact that potential impediments have already been largely eliminated. Particularly the railway infrastructure is being extended on a broad scale, such as the rail tracks at the terminals in Vaggeryd, Eskilstuna and Sundsvall, or between Umeå and Luleå where the Norrbotniabanan is being constructed. With regards to further investments outside the terminal, some of the terminal providers commented that the regional infrastructure might have to be reviewed by the municipalities, and that it could be necessary for the hauliers to extend their vehicle fleet. For the terminals itself, the need for investments could merely be an important factor in the long term.

7.1.2 Logistics Service Providers

The LSPs that were investigated within this study include: GreenCarrier, RealRail, GDL, and Jula Logistics. All players were consulted in a similar regard as the terminals. The questions thus included aspects regarding the challenges, negative effects, operational improvements, and potential required investments that the forwarders anticipate in case that LHVs are being permitted. Besides, the road hauliers were questioned about previous experiences with HCT in their PPH operations, to place their attitudes in an appropriate context.

Due to the variability of the operational background of the LSPs, the answers must however be contemplated from different perspectives. GreenCarrier is operating on an international level, which mainly includes shipments between the Port of Gothenburg and Asia. Thus, the company does not execute sole domestic flows and instead merely performs pick-up and onboard services in Sweden. The attitude of Jemdahl towards the potential effects of an implementation of IHCT must therefore be distinguished as being formed without direct involvement in IRT processes. The transport operator RealRail is likewise not executing any road haulage operations. The insights of the interview are therefore mainly relevant with regards to a potential impact on future rail freight volumes and operations that a permission of LHVs for PPH could have. However, Sandahl has long-term experience in the company-group Sandahlsbolagen, which is also offering road haulage services. His perspective therefore reflects a rather integrative approach to IHCT. The responses of GDL and Jula Logistics can be interpreted as insights from players directly involved in PPH operations connected to an IRT terminal.

The main challenge that the road hauliers perceived with regards to an implementation of IHCT was the strict bureaucracy that makes it difficult to commence an operation with LHVs. Ekwall, who already has experiences with the approval of LHVs at GDL through the Autofreight project, mentioned that their company is ready to use combinations of two 40ft. containers, the application process for the approval of a test project is however complicated. Bergqvist moreover remarked, that one needs to prove technical innovation to be granted allowances for HCT. From the perspective of a rail haulage operator, Sandahl perceived it as a challenge to maintain the service quality of an IRT chain in case more freight is shifted to rail. He argued that the maintenance plan in the railway segment is too low and the trains tend to suffer with regards to their punctuality. Thus, increased IHCT operations could make it difficult to guarantee delivery on day one, which can be related to difficulties in synchronizing the trans-shipment operations between trains and trucks, and the overall flexibility of deliveries in an

IRT chain. From the perspective of GreenCarrier, Jemdahl argued that there could be a lack of demand for LHVs, as it is difficult to achieve an appropriate fill rate to make it cost efficient. Moreover, he emphasized that LHVs might be restricted to a speed level which merely enables slow driving that could lead to the drivers becoming impatient and thus increase risks. In a similar manner as Sandahl, Jemdahl also stressed concerns with regards to on- and offloading the consignments when transhipping from rail to road.

The perceived negative effects of LHVs in IRT coincide with those highlighted by the terminals. Ekwall mentioned that LHVs could be dangerous on the road, but at the same time remarked that the road traffic volume would also decrease with fewer vehicles. Besides, he was concerned that the employment of LHVs could lead to the railway sector losing freight to road transport. The perspective of RealRail however showed that this concern is mainly a threat in the short term. Indeed, Sandahl was optimistic that the railway sector could be strengthened through HCT if the politicians and lobbies invest more in the railway maintenance and corresponding regulations. Lastly, Jemdahl emphasized the negative effects that could occur with regards to the road wear, and argued that many roads must be adapted to be dual-laned in order to be suitable for LHVs.

When it comes to operational improvements through IHCT, the perspective of RealRail showed that the main benefits in the system would occur for the road freight forwarders. Besides the cost efficiencies that already have been proven by the current HCT service of Jula Logistics, GDL identified it as a main advantage to increase the volume on the same amount of drivers. This could counteract the currently prevailing lack of truck drivers. In this regard Ekwall indicated that the number of trucks in operations could be decreased by around 30% when shifting to IHCT operations.

Like the terminals, the LSPs were asked about the anticipated investments that they presume in case IHCT operations become the norm. From a forwarder's perspective, Ekwall mentioned that the company might need to invest in 40ft. container links for their vehicle fleet in case of a demand increase for LHVs. However, none of the other players anticipated any necessary investments in the near future. Sandahl merely noted that in case longer trains would be permitted, there might be investments needed in the tracks. This would then be a matter of concern for the public infrastructure providers.

7.2 Transport Operations

7.2.1 Capacities and Operational Area

To determine how the introduction of LHVs could affect the operational area and the transport volumes handled by the IRT terminals, the terminals were questioned about their currently handled capacities, including recent trends in demand development, as well as about their anticipated increases of the terminals' operational area in case IHCT is being permitted. The LSPs were likewise asked to specify their currently handled freight volumes and anticipated increases in demand in case of an employment of LHVs. All data that could be determined from the consultations are displayed in *table 7.1*.

	Currently handled capacities in TEU/year (as of 2020)	**Trends in demand increase**	**Operational Area of the terminal**	**Expected Increase of operational area after HCT**
Båramo	44.000	+ 20% annually	50-60km	
Eskilstuna	120.000			+10-20%
Hallsberg	30.000	+20-30%		
Sundsvall	22.000	Doubled capacity at new terminal	250km	+10-20%
Umeå	50.000	+10% annually		+10%
Storuman	280.000m³ forest raw material/year	+20-30% through HCT		
GreenCarrier	*	*	*	*
RealRail	50.000 trailer/year	+5-10% through HCT	*	*
GDL	150.000	+10% through HCT	*	*
Jula Logistics Falköping	40.000	+10% through HCT	* 50km	* +10-15%

Table 7.1: Transport Capacities and Operational Area of the IRT terminals, (: not applicable in this study).*

As the focus of this study is on high-capacity operations with road freight vehicles for containerized goods, the data of some of the interviewed players were considered as not applicable for the purpose of this study and will thus be disregarded in the analysis. The neglected players include GreenCarrier and RealRail as they do not carry out any road haulage operations. Moreover, the terminal in Storuman will not underlie a detailed consideration in this investigation, as it is solely transporting forest raw materials which is not measured in TEUs.

7.2.2 PPH Corridors for HCT

Besides the more general impacts that an introduction of LHVs would have on the capacities that need to be handled by the terminals and LSPs, the respondents were also asked about the specific transport corridors and corresponding transport volumes that they are currently serving, and that could be suitable for IHCT. The terminals and LSPs could identify both transport corridors that would be suitable for HCT through the demand of current customers, as well as road connections that are generally attracting large freight volumes and could become more valuable if HCT solutions are offered.

The terminal in Vaggeryd identified four different customers with large enough volumes that already stated their interest in using IHCT solutions. Moreover, the terminal could attract one more customer that is located at a distance that exceeds the current operational area of the terminal. For this flow, the employment of IHCT transports could start with a temporal retardation of twelve months, in case LHVs would be permitted. The terminal in Eskilstuna identified three main customers that are located in the Stockholm-Mälardalen region and are currently suitable for IHCT. Furthermore, the terminal will soon have customers at the Logistikpark, which is located approximately 19km away from the terminal. Besides that, the terminal representatives indicated that the region is very consumer intensive, with around four million people reachable by a one-hour drive from the terminal, and around 65% of the Swedish exports handled in the area. Thus, the transport corridors towards Stockholm, including Västerås, could become more valuable if LHVs would be allowed. A similar conclusion is made from the terminal in Hallsberg, as it is likewise closely connected to the Stockholm-Mälardalen region where most of the last mile transports commute to. At the current state, the terminal in Hallsberg identified one customer for which the employment of LHVs would be suitable based on their current freight volumes. Besides, the region of Örebro previously studied a range of cases that would be compatible for HCT solutions (Region Örebro Län et. al., 2021). However, not all of them are part of an IRT chain and thus not qualified to be included in this study. The terminal in Sundsvall, which covers a comparably large operational area, could name several coastal roads as well as road connections towards Norway that would benefit from the usage of LHVs today. The terminal in Umeå determined three big Swedish companies that would be suitable to use IHCT solutions to and from the terminal. All of them are located in a close proximity to the terminal which makes the PPH distance rather short. The terminal in Storuman qualified the road E12 between the terminal and parts of Norway as a transport corridor that would become more valuable if LHVs were permitted.

The LSPs that are directly concerned with road haulage operations likewise identified certain transport corridors connected to an intermodal transhipment facility that would be suitable for LHVs in the PPH operations. As described above, Jula Logistics has previous experiences with HCT and is already employing LHVs in their PPH operations for their main customer Jula. Besides, they identified one more customer that would be suitable to make use of LHVs. Just as Jula Logistics, GDL has previous experiences with HCT through the Autofreight project which is running on the route between Gothenburg and Borås. As several other customers are currently located in Jönköping, GDL identified the Gothenburg-Jönköping route as another valuable corridor for the employment of LHVs.

Table 7.2 gives an overview of the identified freight corridors that are suitable for HCT. It moreover indicates the customer at the destination of delivery and the corresponding PPH distance in kilometres, the railway distance to the port of Gothenburg, and the associated transport volume in TEU.

	Customer (Destination)	Railway Distance from Port of Gothenburg in km	PPH Distance in km per round trip	Transport Volume in TEU/Year
Vaggeryd	Waggeryd Cell AB	140	12	12.480
Vaggeryd	IKEA (Torsvik)		56	3.840
Vaggeryd	Elgiganten (Torsvik)		56	3.840
Vaggeryd	(Värnamo)		70	1.920
Vaggeryd	(Mjölby/Skänninge)		260	2.880
Eskilstuna	H&M (Svista)	328	24	x
Eskilstuna	Minelco (Strängnäs)		76	x
Eskilstuna	BSH (Nykvarn)		144	x
Hallsberg	ELON (Örebro)	241	50	1.560
Umeå	IKEA	822	14	1.300
Umeå	Volvo Lastvagnar AB		20	9.000
Umeå	Ålö AB		60	1.000
Jula Logistics (Falköping)	Jula (Skaraborg)	120	54	12.000
Jula Logistics (Falköping)	Mio (Tibro)		100	6.000
GDL (Gothenburg)	(Borås)	*	130	x
GDL (Gothenburg)	IKEA, Elgiganten (Jönköping)		320	x

Table 7.2: Identified Road Freight Corridors and respective volumes suitable for HCT, (: not applicable in this study, x: missing data).*

7.3 Cost Calculations

7.3.1 Operational Costs

The determined data of the currently handled capacities in TEU per year as displayed in *table 7.1*, as well as those for the freight volumes and corresponding rail and road haulage distances for each identified HCT corridor as listed in *table 7.2* are used for the calculation of the operational costs. The calculation procedure follows the approach as exemplified in *figure 2.1*, by considering each cost component of the total cost for IRT individually, as displayed in *table 6.5*. Accordingly, the road haulage costs are calculated separately for every corridor corresponding to its freight volume and transport distance. The rail haulage and handling costs are calculated as yearly total costs for each terminal, before being proportionally attributed to each corridor, to define the total IRT costs for each relationship. Based on the incomplete data set for the HCT corridors and volumes as to be seen in *table 7.2*, the results merely include the freight flows for the terminal in Vaggeryd, the terminal in Umeå, and the terminal in Falköping that is operated through Jula Logistics. In addition, one individual freight flow could be calculated for the terminal in Hallsberg. Besides, all calculations were made for both Scenario A and Scenario B, which enables to directly compare the total road haulage as well as total IRT costs for each corridor. The results of the expected cost decreases in case of an employment of LHVs as specified in Scenario B are displayed in *table 7.3*.

<table>
<tr><th></th><th>Customer (Destination)</th><th>Cost Savings PPH</th><th>Cost Savings IRT Chain</th></tr>
<tr><td rowspan="5">Vaggeryd</td><td>Waggeryd Cell AB</td><td rowspan="11">13.7%</td><td>1.47%</td></tr>
<tr><td>IKEA (Torsvik)</td><td>4.93%</td></tr>
<tr><td>Elgiganten (Torsvik)</td><td>4.93%</td></tr>
<tr><td>(Värnamo)</td><td>5.65%</td></tr>
<tr><td>(Mjölby/Skänninge)</td><td>9.9%</td></tr>
<tr><td>Hallsberg</td><td>ELON (Örebro)</td><td>3.4%</td></tr>
<tr><td rowspan="3">Umeå</td><td>IKEA</td><td>0.66%</td></tr>
<tr><td>Volvo Lastvagnar AB</td><td>0.92%</td></tr>
<tr><td>Ålö AB</td><td>2.44%</td></tr>
<tr><td rowspan="2">Jula Logistics (Falköping)</td><td>Jula (Skaraborg)</td><td>4.98%</td></tr>
<tr><td>Mio (Tibro)</td><td>7.04%</td></tr>
</table>

Table 7.3: Operational cost savings for PPH and IRT when employing LHVs.

Based on the above presented results for each transport corridor, the average total cost savings for IRT can be determined for each terminal if aggregating the results. The average IRT cost savings for each terminal with LHVs opposed to standard road freight vehicles are presented in *table 7.4*.

	Vaggeryd	**Hallsberg**	**Umeå**	**Jula Logistics (Falköping)**
Average reduction total IRT costs	**5.38%**	**3.4%**	**1.34%**	**6.01%**

Table 7.4: Average total IRT cost reduction per terminal.

8 DISCUSSION

The discussion will evaluate the empirical findings by connecting them to the main theoretical background established in the literature review. The qualitative findings will be discussed with regards to research question one and two, and the operational and environmental cost calculations will be grounded and validated through previous studies and literature to draw an overall conclusion on research question three.

8.1 Barriers and Chances

The results from the interviews clarify, that there are a few essential barriers that both the terminals and LSPs anticipate with regards to the usage of LHVs. These barriers mainly include factors such as bureaucracy, the current road network that does not allow for BK4 on a far-reaching scale yet, and the road infrastructure in some sparsely populated areas. Minor concern were costs, safety, or a lack of demand. However, several operational improvements could be identified by both the terminal providers and the LSPs. For the terminals it would mainly be beneficial to have fever vehicles in circulation around the terminal and to attract more customers. For the LSPs on the other hand the main improvements would be the decreasing costs and the smaller required vehicle fleet on the same amount of drivers. Overall, IHCT can be seen as a potential strategy to increase collaboration between different transport providers and thus strengthen the economic strength of a market.

8.2 Costs

The cost advantages can mainly be attributed to the LSPs, as rail haulage and handling costs remain relatively stable, even if higher volumes are recorded. The results show, that overall IRT cost savings are highest if the railway distance is shortest. This is due to the high amount of fixed costs of the rail haulage, which enabled better economies of scale if the proportion compared to the road haulage distance decreases. For terminals far in the north, such as Umeå the railway distance from the port of Gothneburg is relatively long, which is why the decrease in total IRT costs is merely marginal for the terminal. However, this can also be reasoned by the particular short PPH distances from the terminal in Umeå. Nevertheless, HCT trucks still have a positive effect on overall transport costs.

9 LIMITATIONS AND FUTURE RESERACH

This section presents the limitations that can be drawn to the calculations as well as the overall study which had to be based on a few generalized assumptions. Moreover, some general limitations to the research questions and process have been considered to classify the outcomes of the study in an adequate way.

The main limitation to this study is the small sample of quantitative data which merely enabled a rough presentation of the anticipated cost reductions for a small selection of terminals. The data limitation was mainly due to a slow response rate on the follow-up communication subsequent to the interviews and moreover justified by the unavailability of exact transport volumes on the part of the terminals. As the sample of LSPs in this study is very small, the obtainment of road haulage transport data was hampered. Thus, the small sample of calculated cost reductions might not be representative to determine the overall national impacts and therefore market potential for Sweden. As the long-term effects of permissions for IHCT are relatively unpredictable, it was moreover difficult to determine demand increases and actually attracted volumes. The anticipated changes in demand must thus be contemplated with caution, as there might be other factors contributing to increased transport volumes. These factors can include new companies establishing in an area, or the overall expansion of a terminal which could be observed in several cases and might attract new volumes.

The construction of the calculation model likewise bears some limitations. The chosen train was a standardized electric one, that is however not always the case in each transport relation. Depending on the specific type of truck and a varying fill rate, the specifications for the road transport costs also might differ. The limitation of the focus on solely longer vehicles thus neglects some alternations. For future studies this means that investigations should be made on an even broader scale, where the specific load and transport equipment used is considered.

10 CONCLUSION

This chapter will answer the four different research sub-questions and thus draw a final conclusion on the market potential for IHCT in Sweden. Moreover, it will outline a number of theoretical and practical implications that can be drawn from the research and make suggestions on future studies that are perceived as appropriate according to the limitations and conclusions.

Q 1: What are the barriers for a broad implementation of IHCT and the main obstacles associated with IHCT in Sweden?

The interviews with the different intermodal terminal providers and LSPs clearly demonstrated the challenges and perceived negative impacts that the transport business community faces with regards to LHVs for intermodal transport. The main barrier for the logistics providers to shift to high-capacity operations seems to be the persistent bureaucracy that is connected to the permissions of operating LHVs. Most terminal providers and LSPs are in fact prepared to operate on a high-capacity scale but perceive the current legal framework as a main barrier. Besides, the current road network, especially related to municipal roads, could pose a burden on a broader implementation of HCT. The concern that rail could face stronger competition from the road transport sector and thus loose market share if LHVs are allowed is moreover still anchored in most actor's minds. This concern can however be refuted for the studied case, as LHVs would merely be permitted on determined distances to and from the nearest IRT terminal.

Q2: What are the main freight traffic flows/corridors and the corresponding required capacities that would benefit from exemptions for IHCT in Sweden?

The study identified several freight corridors that were identified to become more valuable if HCT to and from an intermodal terminal is permitted. These corridors have been outlined in *chapter 7.2.2* and exemplified in *table 7.2* together with the corresponding transport volumes. The identified corridors that are suitable for HCT comprise different distances from merely 12km to up to 320km. Even though previous research suggests that the transport distance must be rather long for IRT to be competitive, the findings show that longer road freight vehicles can nevertheless be beneficial for certain volumes or in certain geographical areas.

Q3: How can the authorization of IHCT for these flows/corridors contribute to a reduction of the economic and environmental costs of freight transport?

The development of an IRT cost model enabled to calculate the operational costs for the transport corridors suitable for HCT. The results indicate that the PPH costs for each transport relation can be decreased by 13.7% if LHVs are in operation. The decrease in total IRT costs for each corridor depends on the freight volume and mainly the distance. Thus, the study concluded total IRT cost reduction in a range of 0.66% to 9.9%. These detected values are in line with earlier research as well as LHVs practices that have previously been conducted in Sweden.

Q4: How can IHCT be implemented on a large scale in the Swedish market?

The study presented several freight corridors including their current transport capacities that were appointed by the industry as particular suitable for operations with LHVs. Moreover, cost calculations for these corridors show, that both operational and emission costs would decrease if LHVs are employed for PPH opposed to the current standard road freight vehicles with an inferior load capacity. These results could be transferred into practice by permitting LHVs in this appointed network. As the main barrier for IHCT was identified to consist of a high degree of bureaucracy, a permanent change in regulations for LHVs would represent a step towards a more integrated transport system. Concerns such as decreasing safety or increased road wear could be counteracted by establishing a PBS system that regulates the quality of the road freight vehicles. Besides, IAC can be used to track the vehicles position and achieve an improved coordination of road freight flows. If plans are made to integrate LHVs as a significant component of the transport system, considerations regarding road infrastructure restorations and investment plans in the railway segment must however be made.

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APPENDIX

Appendix I: Interview Guide

Questions for Terminals:

- Please describe your daily operations at the terminal and tell us a bit about your work and position.
- What are the average capacities that you are currently handling per year?
- What are the main challenges you perceive with regards to the implementation of intermodal HCT?
- Do you see any negative effects that could occur with the implementation of intermodal HCT?
- Would the usage of HCT require any infrastructural changes/major investments at the terminal?
- How could the implementation of HCT improve current operations?
- Can you identify certain transport corridors that would become more valuable though HCT? / Do you think you have any routes/customers where HCT would be beneficial? Please indicate the name of the road, the distance in km, and the transport volume in TEU/year.
- How much would average volume change after HCT is implemented? Low to high estimates. / Do you think your average transported volume and catchment area would increase if intermodal HCT was implemented? Please indicate an approximate estimation (10%, 20%, more? less?).

If applicable:

- What are your experiences of applying for exemptions at the Swedish transport agency?
- What efficiency improvements can you expect if high-capacity vehicles for timber transport were to be allowed on the roads?
- How could the implementation of HCT provide benefits for the region?
- Have you carried out any pilot projects with LHVs yet and what were the results?

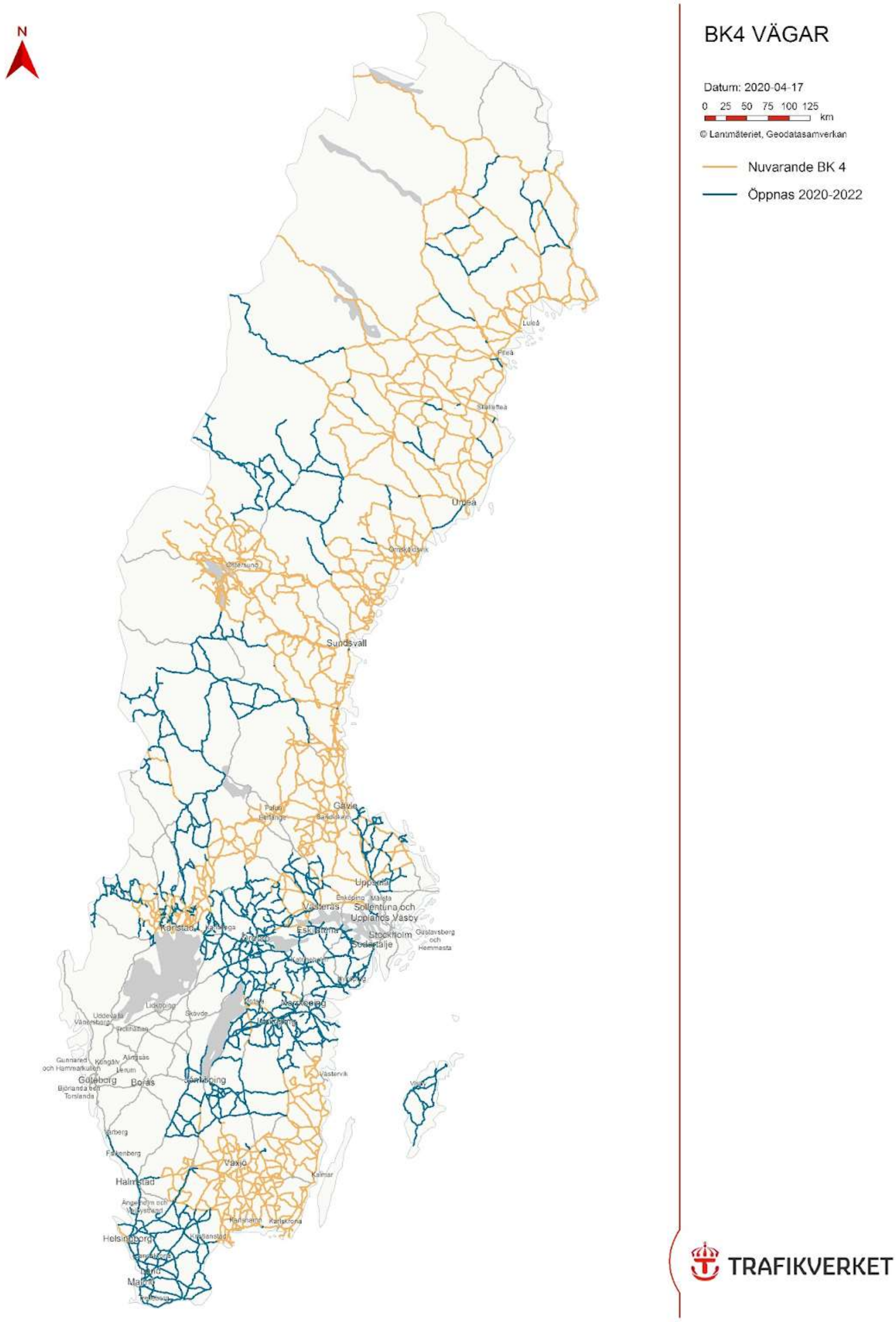
Questions for LSPs:

- Please describe your daily operations and tell us a bit about your work and position.
- What are the average capacities you are currently handling per year as road freight/intermodal freight?
- What are the main challenges you perceive with regards to the implementation of intermodal HCT?
- Do you see any negative effects that could occur with the implementation of intermodal HCT?
- If HCT for road freight vehicles would widely be permitted, would you be prepared for the consequent operations or would you require investments in additional transport equipment?
- How could the implementation of HCT improve current operations?
- Can you identify certain transport corridors that would become more valuable through intermodal HCT?
- Do you think your average volume and catchment area would change if intermodal HCT was implemented? Please indicate an approximate estimation (10% increase, more? less?).

If applicable:

- Is the demand for your service anticipated to increase within the next few years? / Do you expect any increases in demand for intermodal containers?
- Do you have any experiences with intermodal HCT on the road?
- Do you have customers that would benefit from using HCT associated with the rail haulage?
- If HCT would be implemented for pre and post rail haulage, would there be any effects on train frequencies or train lengths that would be transporting the increased flows of containers?
- What is your operating area for intermodal rail-road transport in Sweden? What are the main transport nodes for intermodal road-rail container flows?

Appendix II: Map with current and planned roads with bearing capacity class 4. (taken from: Natanaelsson & Eriksson, 2020)



Appendix III: Factors identified from interviews.

		T1	T2	T3	T4	T5	T6	LSP1	LSP2	LSP3	LSP4
Challenges	Bureaucracy										
	Bridges										
	Municipal Roads										
	Local Regulations										
	Road Network										
	Competition										
	Costs										
	Demand										
	Fill Rate										
	Speed										
	Service Quality										
	Track Maintenance/Investments										
Negative Effects	Restricted Road Network										
	Road Wear										
	Road-Rail Competition										
	Reverse Modal Shift										
	Safety										
	Consolidation										
	Investments in equipment										
	Forwarders Pricing										

	Operational Complications	green	red	red	red	red	red	green	red	red	red
Operational Improvements	Cost benefits for forwarders	green	red	red	green	red	red	grey	green	green	green
	Volume increase	green	green	green	green	green	green	grey	green	green	green
	Decrease in trucks	red	red	red	red	green	green	grey	red	green	red
	Beneficial for big customers	green	green	green	green	green	red	grey	red	red	red
	Positioning benefit	red	red	green	red	red	red	grey	red	red	red
	Less congestion	red	red	green	red	green	red	grey	red	red	red
	Decrease in emissions	red	red	green	red	green	red	grey	red	red	green
	Smooth terminal flows	red	red	green	red	green	green	grey	grey	grey	grey
	Reduced risks	red	red	red	red	green	red	grey	red	red	red
Investments		red	red	red	red	red	green	grey	grey	green	red

Where: red = not mentioned, green = agree, grey = not applicable.