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Improving Transportation Efficiency: Cost Comparison Between Single Trailer and High-Capacity Transport in Container Road Freight

Master's thesis in supply chain management

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Abstract

This thesis examines the use of High-Capacity Transport (HCT) vehicles in container logistics, as well as the use of dry ports and last mile efficiency. The study focuses on comparing single and double trailer configurations, examining their respective advantages in terms of cost-effectiveness, operational efficiency, and environmental sustainability. Meanwhile dry ports, as key hubs for relieving congestion in seaports and streamlining the distribution process, focus on specific situations suitable for implementation. The thesis assesses the economic viability of HCT vehicles and dry ports in transport scenarios through a combination of literature review, case studies, and data analysis.

The results of the study show that the combination of HCT vehicles and strategically located dry ports can significantly reduce transport costs, improve supply chain efficiency, and support more sustainable logistics operations. The study provides insights into optimizing container transport for long-haul and last-mile movements, contributing to the development of more efficient and environmentally friendly freight transport solutions.

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Keywords: High-capacity Transport, Dry port, Last mile, Container transport, Road transport, Transportation cost

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CONTENTS

1. Introduction

In the current landscape of increasing global logistics demands, transportation plays a crucial role in maintaining efficient supply chains. Container transport, in particular, has become an indispensable mode of freight transport due to its flexibility and ability to seamlessly integrate multiple transportation methods, such as ships, trains, and trucks (Crainic & Kim, 2007). As the volume of freight continues to expand and a growing emphasis on environmental sustainability, innovations, such as High-Capacity Transport (HCT) vehicles, have been introduced to meet these evolving needs. Longer and heavier vehicles (LHV) combinations as a form of HCT offer significant advantages in terms of efficiency and sustainability, but they also present unique challenges, i.e. requirement of intermodal terminal or dry port and last mile delivery (Fröjd et al., 2021).

This thesis will study the comparative advantages and disadvantages of traditional trucks (single trailers) versus LHVs in container transportation. By understanding the specific contexts in which each mode of transportation is best suited, we can better address key logistical challenges, such as transshipment operations and fleet planning. The insights gained from this study will contribute to the ongoing development of more efficient and sustainable logistics strategies.

2. Background

Road and rail are the two primary modes of land freight transportation; today, road transport accounts for roughly 60% of the global distribution, while rail accounts for about 40% (Kaack et al., 2018b). Road freight transportation has grown significantly over the last 50 years, mostly due to the consequences of globalization and increases in income and consumption. This growth has also been facilitated by improvements in vehicle load capacity and the modification of vehicles to suit particular freight market segments, such as containers, construction materials, fuel, and perishable commodities (Rodrigue, 2024). The significance of effective road transport networks, which are essential for regional economic growth and productivity, is highlighted by differences in rail development throughout the European Union (Alexandersson & Rigas, 2013; Eberts, 2000).

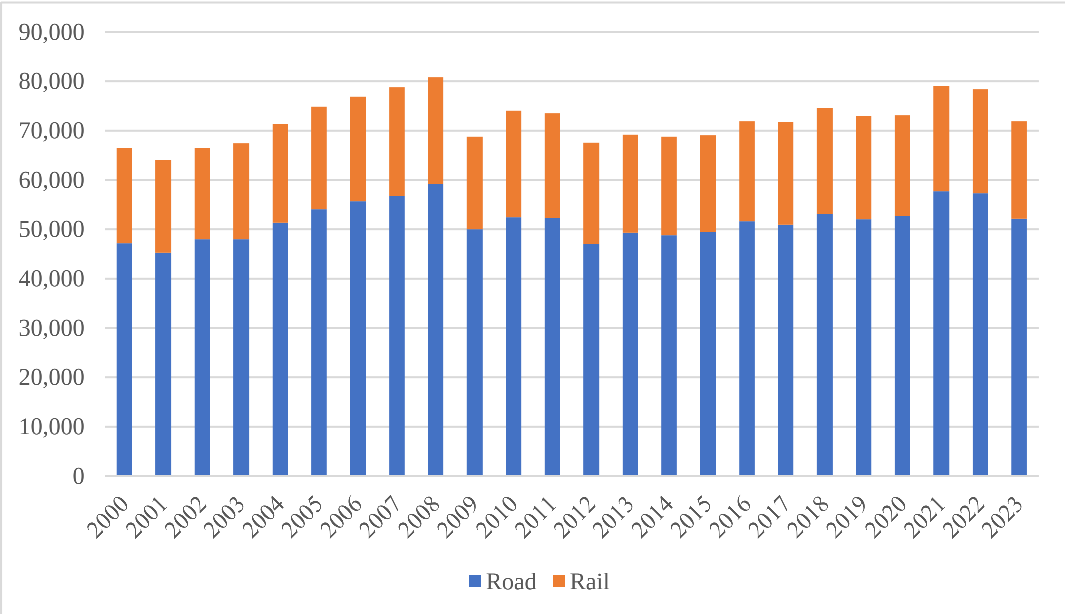

Figure 1. *Market shares of land freight transport modes in Sweden (Data from Transport Analysis (2021)).*

In Sweden, a significant portion of road freight transportation is dominated by heavy trucks (Vierth et al., 2020). Roughly 88% of domestic commodities were transported by heavy trucks in 2014 (Trafikanalys, 2016b). While consumption is concentrated in Southern Sweden's cities and residential regions, the main centers for commencing goods movement are found in Northern Sweden, Västra Götaland, and along the Norrland coast (Trafikanalys, 2016a). Greater emphasis on sustainability and escalating demand for freight transportation have led to the introduction of High-Capacity Transport (HCT) vehicles, which are heavier and longer combinations. These cars are a big step toward a more sustainable logistics future in addition to being an improvement over the present transportation systems (Fröjd et al., 2021). HCT vehicles have the potential to improve transportation efficiency by reducing CO2 emissions and lowering operating costs while addressing issues such as traffic congestion and fleet planning (Walter, 2023).

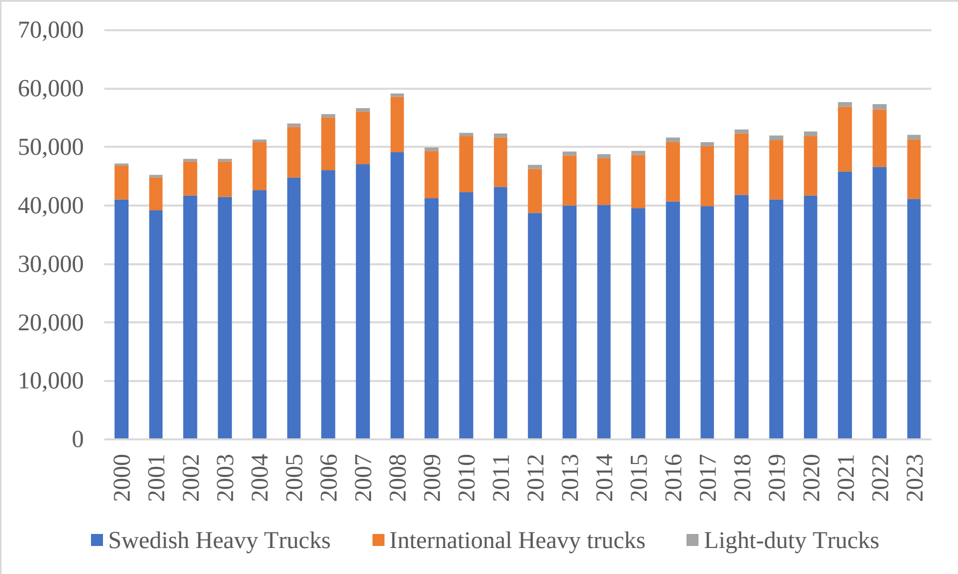

Figure 2. *Market share of transportation of different vehicles in Sweden (Data from Transport Analysis (2021)).*

A number of HCT projects initiatives have been started in Sweden in order to evaluate their efficacy. Launched by Skogsforsk in 2006, the ETT project brought longer and heavier vehicles that could transport up to 90 tons of timber instead of the traditional 60 tons. Without sacrificing road safety or causing more vehicles on the roads, the result of ETT showed a 20% reduction in fuel consumption and emissions in addition to a 20% decrease in transportation expenses (Löfroth & Svenson, 2012). Positive outcomes in lowering CO2 emissions were also shown by other projects, like ECT and DUO2, which reduced CO2 emissions by up to 27% for general freight between Gothenburg and Malmö. The Autofreight project, launched in 2020 between Gothenburg and Borås, achieved similar results, reducing emissions by an average of 20% by enhancing transport capacity (Larsson et al, 2022).

HCTs can hold an additional container per shipment compared to single trailers, doubling container capacity which increases capacity and leads to fewer trips, lower fuel consumption per container, and reduced labor costs. However, deploying HCTs comes with its own set of challenges. Compared to traditional single trailers, the usage of longer and heavier vehicle combinations may demand additional space for turning, parking, and loading which is something that not all customers can supply. They may face regulatory restrictions on certain roads, impacting their flexibility and accessibility (Fröjd et al., 2021).

Thus, the dry port presents a potential solution to this issue. By serving as transfer hubs for containers to be transported between various transport modes, these terminals assist customers overcome space constraints at their locations and guarantee the effectiveness of HCT operations. Building on this idea, "dry ports" could be a solution to the space requirements faced by HCT as well as last-mile transportation. Dry ports simplify the logistics chain by acting as an extension of the seaport and allowing customers to drop off or pick up goods at the dry port. Dry ports also promote intermodal transportation and simplify the movement of goods, thereby promoting regional economic development, reducing traffic around seaports, and improving logistics efficiency (Roso & Lumsden, 2009).

The increasing demand for freight transport is putting pressure on existing systems, requiring more innovative solutions to cope with the higher volume of goods being moved across various regions. There is often difficulty in selecting the most appropriate transport mode in different contexts. Factors such as cost, environmental impact, and operational efficiency must be carefully considered when choosing between HCTs (double trailer) or single trailer transport, making the decision-making process more complex. Thus, addressing these challenges is critical for optimizing container transport and ensuring a sustainable and efficient logistics network.

3. Purpose

Rail and road are the dominant modes of container transportation in the hinterland today, and each has its own advantages and disadvantages. Compared to road transportation, rails have a larger transport capacity and less fuel consumption/loading unit, which means that they are more environmentally friendly (Wolff et al., 2021). However, the use of rail to transport containers requires a substantial amount of rail infrastructure, this requirement can limit the feasibility of train transport. In Europe, the rail freight infrastructure is falling behind, and within the EU, rail freight's market share is declining (Kaack et al., 2018). Meanwhile, trucks are more flexible as a mode of land transport, especially in the last-mile process.

This thesis aims to analyze container transport from seaports to inland customers to compare single-trailer and double-trailer solutions, particularly cost-effectiveness. In addition to examining the transport options, this research will also consider the role of dry ports as an alternative solution to support the last-mile process. The research will explore the conditions under which a dry port becomes a viable option and investigate the following research questions:

Question 1: Compared with the single trailer, is it more cost-effective to use double trailers for transport?

Question 2: From an economic point of view, under what circumstances can dry ports be implemented?

Question 3: How can the vehicle use in last-mile transport services effectively when using HCT as well as dry ports?

4. Methodology

This chapter describes the research methodology used in this study. This provides the foundation for understanding how the research was conducted and sets the stage for the presentation of the findings. This thesis firstly provides a preliminary understanding of the theories of container transport, HCT, and dry ports through the literature review, and at the same time supports the basic theoretical framework in this paper by screening and summarizing the ideas in the literature. Secondly, some detailed case studies are conducted to collect actual situations and data from Gothenburg Port and Viared Borås to fill in the summarized theoretical framework. Finally, the data from the literature review and the case study were used to complete the data collection for the detailed data analysis.

4.1 Literature review

A clear frame of reference is essential to clearly delineate the scope of this thesis and to ensure that the research remains focused on a specific objective. It maintains coherence and logical links between the research methodology, data analysis, and results by outlining the key concepts, theories, and models relevant to the research to establish a foundation as well as demonstrating how knowledge is advanced during the research process (Rocco & Plakhotnik, 2009). However, there are limitations that may restrict the exploration of new or emerging concepts outside the intended scope. For instance, the choice of theoretical frameworks and models might be biased, and a too narrow or selective frame of reference could influence the findings and interpretations (Snyder, 2019). Therefore, integrating the theoretical framework with practical contexts can be challenging due to differences between theoretical models and actual operational environments.

After determining the purpose of this thesis, and the specific research question, begin the literature search. Google Scholar and Chalmers Library were mainly used to search for literature and journals, which were narrowed down after extensive keyword searches, e.g., container transport, road transport, high-capacity transport, etc., And then the abstracts were read first to initially screen out some of the text, and then the full-text article is read to determine if it is appropriate. The literature review was obtained by reading through the articles to identify useful information and extracting summaries to provide a solid theoretical foundation for further analyses.

In this thesis, the literature review began with the theories of Meisel (2009) and Rodrigue (2024), which are important for analyzing current practices and challenges in container logistics. It also examines the adaptability, efficiency, and environmental impact of truck container transport, as well as the coordination challenges in planning, collecting, and managing empty container logistics. Last-mile delivery issues in intermodal transport, as discussed by Zhang et al. (2013), provide theoretical support for the presentation of transport ideas. Furthermore, High-Capacity Transport (HCT) and dry port concepts were studied for their potential to mitigate the adverse impacts of road transport, such as accidents, congestion, and noise pollution (Kurtuluş, 2023; Larsson et al., 2022; Fröjd et al., 2022; Padilha & Ng, 2012).

4.2 Case study

According to Flyvbjerg (2011), case studies allow for a thorough and detailed examination of a specific topic, providing insight into the context and complexities involved. Case studies are flexible and can be adapted to new trends, phenomena, or unexpected findings that emerge during the course of the research. At the same time, the data provided in the case study can be used in subsequent qualitative and quantitative analyses for a richer and more nuanced understanding of the research topic. Theoretical concepts are also illustrated through examples of actual occurrences, making complex ideas easier to understand and relatable. At the same time, case studies have some limitations, for example, the results of a case study are usually specific to a particular case, and the results may change when the actual situation changes (Ridder, 2017). For example, the results of the Port of Gothenburg to Borås Viared case study mentioned in this thesis may not be useful to apply to other ports or transport routes with different conditions.

As this thesis focuses on the choice of land transport modes between seaports and end customers, so introduces case studies in order to obtain real data from actual situations, for example in the case of the Port of Gothenburg which describes the existing logistics of the port, detailing real-world data and practices, providing the conditions for the subsequent analyses to gain insights into the challenges associated with the different trailer options and the challenges and opportunities associated with the development of Viared. The case study also allows for an analysis of the existing logistics practices and infrastructure in the port as well as the terminal, providing insight into operational dynamics and constraints. This includes how trucking routes, vehicle loading capacity, and logistics workflows work under existing conditions and regulations. Meanwhile, the case study also provides data to support the subsequent assessment of single and double trailer usage, its impact on efficiency, and cost-effectiveness.

In addition, in order to explore the feasibility of dry port applications, this paper explores the potential of Viared as a dry port by using data from the case study to assess Viared's existing infrastructure, its geographical advantages, and the necessary improvements required to support the transition. Falköping Dry Port, Sweden, as a successful dry port case study in Sweden, provides data on the investment required for the construction of a dry port as well as the underlying conditions and provides data to support and analyze the subsequent analyses.

4.3 Data collection

The data in this thesis is secondary data, gathered from literature reviews and case studies. Secondary data offers several advantages, including being easily accessible and cost-effective, as it is typically pre-existing and published in reliable reports without the need for extensive primary data collection (Johnston, 2014). That allows for comparative analyses that provide a broader context by examining various studies and datasets. However, secondary data also presents limitations. One major concern is that it may not fully align with the study's specific objectives or the variables of interest, which could lead to a mismatch between the available data and the research requirements and there is the potential for the data to be outdated, failing to account for the latest technological advancements or regulatory changes (Smith, 2008).

Another inherent bias in secondary data is the possibility of sampling or methodological differences in the original data collection process, which may introduce inconsistencies or inaccuracies (Hox & Boeije, 2005). For example, the methods used in earlier studies may not align with current best practices, leading to biased results or limited generalizability to the current research context (Stewart & Kamins, 1993) which could affect the reliability of the conclusions drawn from such data.

To mitigate these issues, validation of results through multiple approaches is crucial. Cross-validation using multiple secondary data sources can enhance the accuracy of the findings and help identify inconsistencies or areas where data may be unreliable (Hox & Boeije, 2005). Contextual analysis of the secondary data is also essential to ensure its relevance to the current study, while the standardization of data formats can improve the comparability of datasets (Ritchie & Lewis, 2003)

Therefore, in order to reduce the limitations of secondary data and its impact on the results of the analyses, data from different cases were reviewed and compared in this thesis, for example, in the calculation of the fixed cost, the data from the case study was collected while the impact of inflation on the price was taken into account for the calculation to reduce the limitation. In addition to this, this thesis uses cross-validation to improve the accuracy of the data, in addition to obtaining the theoretical cost of building a dry port in Literature and comparing it with real data from the case of the dry port in Falköping to obtain more realistic conclusions and recommendations.

5. Frame of reference

The frame of reference chapter elucidates the terms container transport, HCT, and dry port, as well as illustrates the research on cost modeling of road transport in previous related studies. Introduction to the concept of multimodal transport from the point of view of container transport. Special emphasis is placed on the conditions for the implementation of HCT in road transport and its advantages and disadvantages. In addition, dry ports are introduced to explore the help provided by dry ports to HCT in the last mile problem.

5.1 Container transport

5.1.1 Container definition

A container is a large, standardized metal load unit used for packing and shipping cargo. Containers are widely used across various transport modes, including ships, rail, trucks, and barges; however, due to weight, air freight is excluded (Meisel, 2009). This is facilitated by the use of standardized handling equipment as well as reducing the labor required for cargo moves (Rodrigue, 2024).

Figure 3. A 40-ft standard container

Rodrigue (2024) also highlighted the container serves as the primary unit of cargo, streamlining the logistics process by standardizing the size and handling procedures. The most common size for these containers is designed according to ISO standards. The 20-foot unit, officially referred to as a Twenty-foot Equivalent Unit (TEU), which has dimensions of 20 feet in length, 8 feet in width, and 8’6” in height. While 40-foot containers, or Forty-foot Equivalent Units (FEU), which are twice the length of a single TEU, are also widely used in ocean, road, and rail transport. Additionally, “Hi cube” containers are offered in both 40ft and 45ft length sizes. At 9’6” tall, this type of container has an additional foot of height over standard containers and is commonly used to transport taller items, adding another layer of versatility to containerized shipping. (Meisel, 2009).

Table 1. Dimensions of ISO containers (International Organization for Standardization, 2020)

Container Type	External Length (m)	External Width (m)	External Height (m)
20 ft Standard	6.06	2.44	2.59
40 ft Standard	12.19	2.44	2.59
40 ft High Cube	12.19	2.44	2.90
45 ft High Cube	13.72	2.44	2.90

5.1.2 Intermodal transport

Intermodal transport represents the movement of goods from the point of origin to the point of destination by at least two modes of transport, with the changeover from one mode of transport to the next taking place at the intermodal terminal (Crainic & Kim, 2007) and it has seen a significant increase in popularity as an approach to freight transportation in recent years (Agamez-Arias & Moyano-Fuentes, 2017). In the definition of intermodal transport, the various modes of transportation include trucks, freight trains, container ships, and maritime vessels.

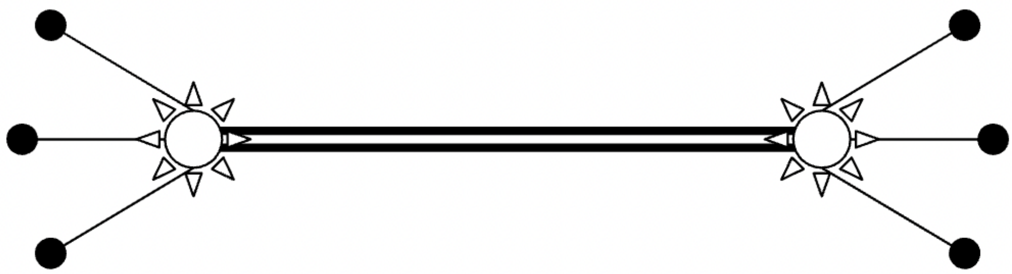

Figure 4. Schematic diagram of an intermodal transport system (Flodén, 2007)

The primary benefit of intermodal transport is its ability to optimize efficiency across long-haul by consolidating cargos into intermodal loading units and combining the strengths of different transportation modes, such as the flexibility of road transport for local deliveries and the capacity and cost-effectiveness of rail or vessel for long-haul shipments (Crainic & Bektas, 2007). Thus, container transport is widely used in intermodal transport, mainly because containers can be transported by almost any means of transport and are easy to handle.

Containerized freight transport by a combination of truck, rail, and sea transport, and dedicated rail services for the long-haul transport of large numbers of containers and trailers are the main modes of international freight transport (Sharypova, 2014). The main participants in an intermodal transport system are the shippers who generate the demand for transport services and the intermodal terminal operators who provide those services. The interactions, objectives, and requirements of these parties significantly affect the performance of the intermodal system, while the complexity of the transport system is further exacerbated by a variety of operations and services, including freight forwarding, vehicle synchronization, scheduling, routing, and load planning. In addition, it is unavoidable that the goods to be transported may come from multiple locations with different delivery destinations and different due dates, which also leads to the problem of last-mile services in intermodal transport (Sharypova, 2014).

5.1.3 Container transport by truck

Trucks provide highly adaptable road transportation, allowing them to access nearly any desired destination along roads, including the ability to facilitate cross-border transfer. According to Åkerfeldt and Knutsson (2019), trucks are the dominant mode of transportation in the short and medium haulage sector, offering both speed and cost-effectiveness. On the other hand, the railway offers the benefit of being able to transport substantial and weighty cargo over greater distances. However, it is important to note that the time required for transportation is comparatively longer. Therefore, the railway is unsuitable for moving perishable items like food, which is also the primary area of rivalry between road and rail transportation (Reis et al., 2013).

Truck-based container transportation is commonly employed for transporting goods over short-haul after they have been transported over long-haul by vessels or railroads (Bergqvist & Behrends, 2011). In other words, truck-based container transportation offers door-to-door service, a capability that ships and trains lack. Conversely, container shipping presents its own distinct challenges and concerns, particularly in relation to the collection and transportation of goods. It encompasses the transportation of commodities from pick-up to delivery places, as well as the coordination of empty container transit planning. This further complicates the process of planning and confirms that truck container transit has a significant role in causing road congestion, transportation delays, and the release of greenhouse gases. Truck container transport involves considering various factors, including container terminal operations and hinterland container transport networks. Nowadays extensive study has focused on container transshipment and terminal operations in order to optimize efficiency and logistics and most of the research conducted on the transportation of containers has focused on single-size containers and has not taken into account the transportation of double-trailer vehicles (Zhang et al., 2013).

5.2 Transportation cost

According to Janic (2007), the total cost of the transport system is mainly generated from internal and external costs. The internal costs primarily include the costs of moving goods between shippers and consignees, and more specifically the costs incurred in collecting, transporting, and distributing the goods. These costs usually depend on the state of the transport network, such as the location, distance, and number of transport demand points. Also, there are variable operating costs. Variable costs are, in a sense, costs incurred over a while due to changes in time and distance, for example, during the road transport process, the infrastructure or vehicles will incur a certain amount of wear and tear, and this part of the depreciation, repair, and maintenance costs can also be considered as a variable cost. In addition, variable costs include taxes, insurance, vehicle costs, and driver's wages incurred during the transport process. The external costs incurred in transport include air pollution, traffic accidents, climate change, etc. (Macharis et al., 2010).

Sahin et al., (2009) also defined the total transport cost which consists mainly of capital, vehicle fuel, lubricants, operating costs, and equipment maintenance costs, which also need to be taken into account, as well as wear and tear over time during the use of the vehicle. Daganzo (2005) proposed a transport cost model aimed at optimizing and analyzing transport systems, particularly freight transport. The framework simulates the costs associated with different modes of transport, such as road, rail, or intermodal. The model consists of long-haul transport costs, terminal costs, and handling costs, with long-haul transport costs being variable costs related to the distance traveled (Daganzo, 2005). Long-haul transport costs are mainly affected by factors such as fuel consumption, labor, vehicle depreciation, and maintenance. They usually increase linearly with distance in the model. Terminal costs are costs incurred at the beginning and end of a trip, including loading, unloading, and handling of goods at ports, terminals, or warehouses. These costs are usually fixed for each operation and are independent of the distance traveled but have a significant impact on overall transport costs. In addition to this, there are physical loading and unloading processes between different modes of transport which generate loading and unloading costs. Loading and unloading costs are usually related to the volume or weight of the goods and are more than an integral part of the intermodal system.

According to Daganzo (2005), the general transportation cost of each shipment has the following mathematical relationship:

$$shipment\ cost \approx c_f + c_v * v * d$$

Where c_f refers to the fixed cost, c_v refers to the variable cost (including fuel consumption), v refers to the shipment size and d refers to distance.

Daganzo (2005) has pointed out the effect of distance traveled and demand density. Higher demand densities can lead to economies of scale, as the average cost per unit of freight transport decreases as the volume or distance increases, especially in modes such as rail transport. This is one of the reasons why rail is usually more cost-effective than road transport for long distances. For long-distance transport, fixed costs such as terminal costs become less important, and mainline transport costs dominate. In dry port operations, the rate of increase in operating costs tends to gradually slow down as the size of the volume handled grows, also reflecting the impact of scale effects. It is mentioned in the article that as the scale of dry ports continues to grow, automated trucks (ATs) can be introduced, and their introduction will result in subsequent savings in transport costs, with the most significant savings coming from the elimination of driver wages, particularly in 1-tonne trucks, where the cost drops by 56.25%.

Meanwhile, Martínez-Zarzoso and Nowak-Lehmann (2007) examine the elements that influence transport costs in road transport, emphasizing that transport conditions, physical distance, and transport time are the main determinants. In addition, they highlight that the utilization of economies of scale can greatly diminish transportation expenses in road transport. For example, in the case of Spain cited in Martínez-Zarzoso and Nowak-Lehmann (2007), an increase in the volume of exports from Spain will have an impact on reducing some of the transport costs because an increase in the volume of exports generates economies of scale at the level of the exporter. The relationship between trade and transport costs is reciprocal, with an increase in trade also reducing transport costs. Another factor that can reflect the impact of economies of scale is the container throughput of the port, which, when it increases, requires better terminal equipment, larger carriers, and more loading and unloading shifts. Hence, it is evident that numerous aspects influence the expenses associated with road transportation. These factors encompass the specific demand for freight, transportation conditions, transportation rates, transportation duration, physical distance, transportation mode, economies of scale, and service quality. The complex nature of transport logistics requires a thorough investigation to determine the most economical and efficient transportation options.

5.3 High-capacity transport

5.3.1 Overview

In the transportation of containerized cargo by road, the single trailer is the common form which refers to the mounting of a container on a trailer drawn by truck. This approach offers the flexibility and convenience of transporting cargo directly from the point of origin to the destination without the need for additional handling at container terminals. However, given the global push to reduce greenhouse gas emissions and improve resource efficiency, road transport, the second largest global emitter of all categories (Figure 5, Rhodium Group, 2023) and the largest of all transport categories

(Figure 6, IEA., 2023), presents significant challenges. Apart from this, road transport contributes to other significant issues such as accidents, congestion, and noise pollution (Kurtuluş, 2023).

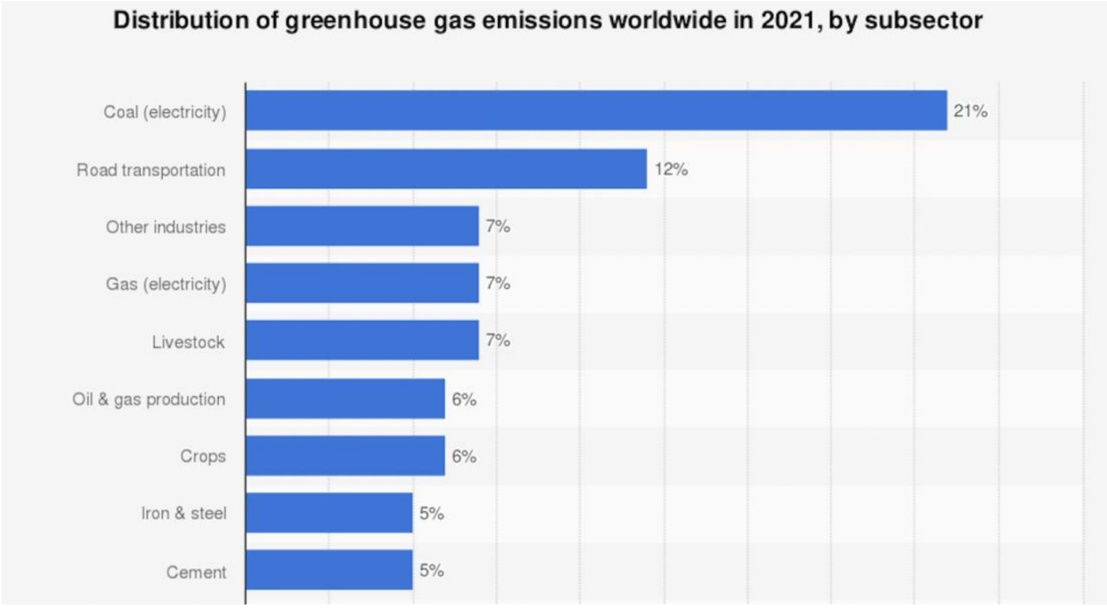

Figure 5. Share of global greenhouse gas emissions 2021 (Rhodium Group, 2023)

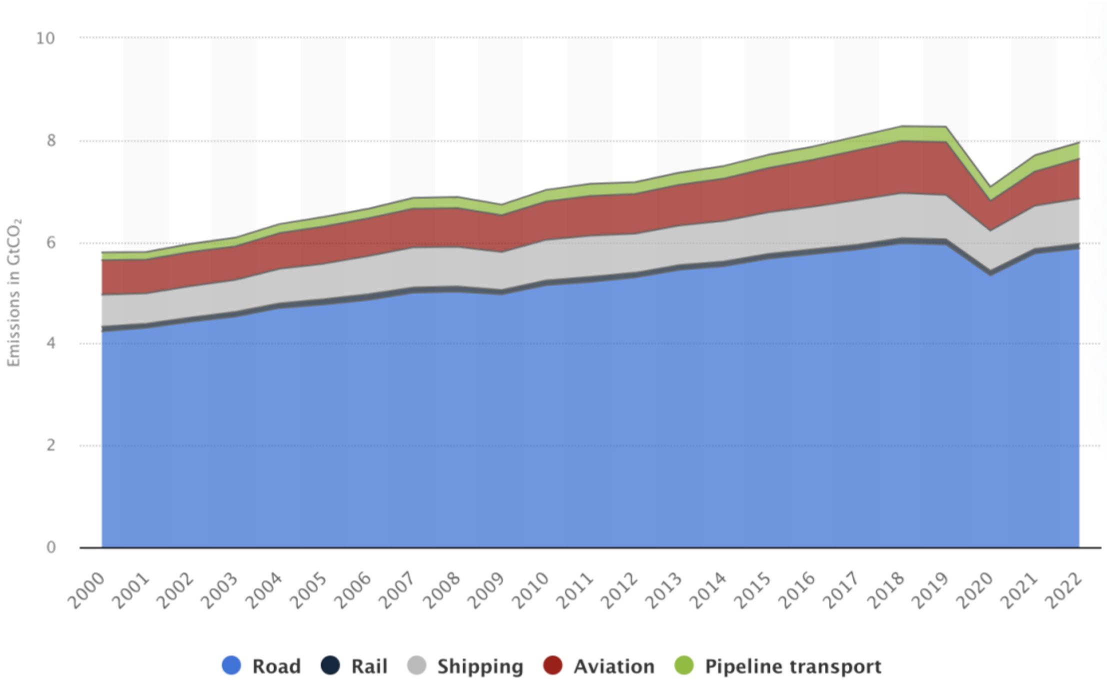

Figure 6. Carbon dioxide emissions from the transportation sector worldwide from 2000 to 2022, by sub sector (IEA., 2023)

As the demand for container transportation continues to rise, to cope with the increasing pressure of sustainable factors such as climate change and energy shortage, transport vehicles need to innovate and develop (Kaack et al., 2018b). One of these is High-

Capacity Transport (HCT) also as known as longer vehicle combinations (LVCs), which refers to connecting multiple freight vehicles into longer vehicle combinations, effectively reducing energy consumption per ton of cargo (Larsson et al, 2022). In addition, longer and heavier vehicle combinations can theoretically reduce the total number of vehicles on the road (Fröjd et al, 2021), e.g. containers that used to be transported by three vehicles can be transported by only two.

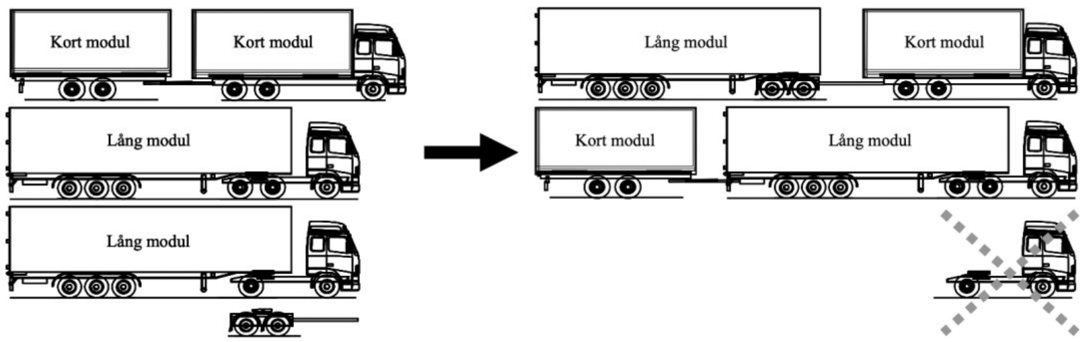

Figure 7. Imagined reduction in the total number of vehicles when the freight model shifts to HCTs.

In 1996, the EU adopted Directive 96/53 EC. The directive establishes a maximum vehicle length of 18,75 meters and a maximum width of 2,55 meters. Furthermore, the regulations of the 96/53 EC directive additionally clarify that member states may link modular units and permit the use of vehicle combinations in their territories exceeding the dimensions set out in the directive, as long as the individual modules of the vehicle combination comply with the dimensions set out in the 96/53/EC directive. Thus, a maximum length of 25.25 meters can be used for truck transportation in Sweden and Finland. This meant that the need for three vehicles to transport the same amount of goods was reduced to a two-vehicle combination, see Figure 7. This also led to a direct reduction in fuel consumption per unit of goods transported. Several European countries have now adopted the 25.25m standard (Larsson et al., 2022).

In 2013, Finland increased the allowable load capacity of full trailers to 76 tons after more than half of the trucks met the maximum load capacity, which saved overall costs and improved transportation efficiency. At the same time, the Swedish Transport Agency has also raised the maximum allowable load of trucks to 74 tons, although as the weight of vehicles increases, some bridges will be unable to bear the traffic. To optimize the efficiency of transportation and mitigate its environmental impact, the Swedish Transport Administration has enacted new regulations, which will come into force on 1 December 2023, allowing for combinations of vehicles up to a total length of 34.5 meters to be driven on national roads (Trafikverket, 2024). A detailed of the national road network is shown in Figure 8. The creation of the HCT fleet reduces the number of vehicles on the road while completing the transportation work (Korpinen et al., 2019) & (Asmoarp et al., 2018). However, an earlier study showed that the result of congestion reduction was rather not significant. (Åkerman & Jonsson, 2007)

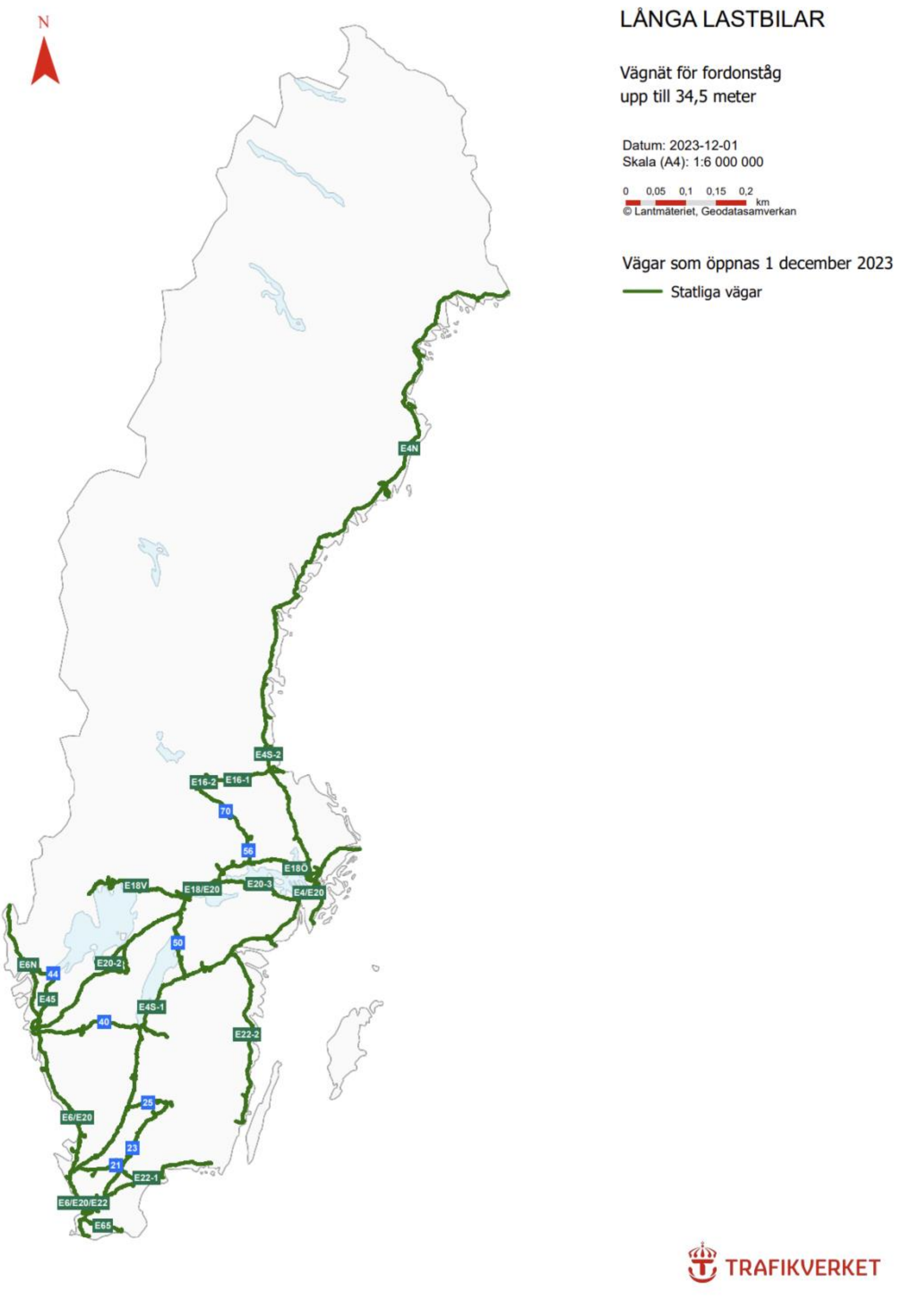

Figure 8. Road map for longer vehicle combinations (Trafikverket, 2024)

5.3.2 HCT

The use of HCT, particularly the use of double trailers, provides an advanced method of increasing freight efficiency and reducing environmental impacts. However, double trailer is not universally applicable to all types of roads. It is important to recognize that longer and heavier vehicle combinations are not suitable for urban environments, where roads may not be able to support long or heavy vehicles. Therefore, the deployment of double trailers is limited to environments where the infrastructure can fully support their operation without risk of damage or inefficiency (Aurell & Wadman, 2007). In urban areas, where roads are typically narrow and congested, such long vehicle combinations are impractical and potentially dangerous.

Various impacts of consolidating containers into HCTs on the transportation system and their interrelationships, according to McKinnon (2008). The use of HCT will bring multiple positive and negative effects. Positive effects include reductions in air pollution, reductions in traffic congestion and increases in net economic benefits. Reduced overall fuel consumption due to improved fuel efficiency results in lower air pollution; a reduction in the total number of vehicles contributes to the reduction of traffic congestion; and lower transportation costs and increased efficiency result in overall economic benefits. In addition, lower transportation costs may lead to increased demand for freight and result in more goods being shifted from other modes of transport to road transport. On the negative side, while the total number of vehicles decreases, the cost of single-vehicle accidents may increase, as larger/heavier vehicles cause more damage in accidents. At the same time, these vehicles may require additional infrastructure investment to support their operation, increasing road maintenance costs and pressure on existing traffic management systems.

A remarkable feature of the HCTs is its modular design, as they can be easily broken down into shorter standard combinations, introducing a high degree of flexibility for freight transportation (Aurell & Wadman, 2007). This adaptability is crucial because the containers can continue to move even on roads that are unsuitable for the transportation of extra-long or extra-heavy loads. By breaking down into two separate containers, these trailers can travel on roads with less capacity, ensuring that the last mile delivery process is able to be completed over a variety of infrastructures.

Additionally, the integration of rail, road, and waterways into the road classification system significantly increases the efficiency of the HCT system. This full integration supports a seamless transportation network and facilitates smooth intermodal movement. This coordination is critical to optimizing logistics operations, allowing containers to be easily moved from road to rail or waterways as needed (Aurell & Wadman, 2007).

5.4 Dry port

5.4.1 Dry port concept

In the context of globalization of international trade and rising trade, the number of container shipments has also been increasing gradually, container ports are under great pressure to store and handle containers (Cullinane et al., 2012). However, most of the traditional seaports are located near the cities or in the suburbs and it is difficult to increase the size of the facilities, thus the concept of dry ports has been proposed as a solution, and dry ports are facilities located in the hinterland areas that not only perform traditional port functions but also provide additional services to relieve the pressure on the seaports (Padilha & Ng, 2012).

As shown in Figure 9, the dry port can connect the port with the inland seamlessly, and at the same time, dry ports also fulfill other seaport functions, such as providing customs clearance which also the differences between hinterland terminals and dry ports. According to Rodrigue (2020), a hinterland terminal serves primarily as a regional hub for the consolidation and distribution of goods and is connected to the port by road, rail, or inland waterway. It facilitates the movement of goods within the port hinterland but lacks customs services and the full range of port-related activities. While hinterland terminals are more focused on redistributing goods regionally, dry ports are key logistics hubs that improve the overall efficiency of the transport system by decentralizing port services. Thus, dry ports alleviate congestion at seaports by offering aligned services, easing the burden on seaport operations. Meanwhile, hinterland terminals are primarily used for facilitating the efficient distribution of goods within regional areas.

In addition, dry ports can be seen as buffer zones for the provision of services (Bergqvist & Monios, 2016), providing a safe and secure long-term storage place for containers, as well as a wide range of services such as transshipment, storage, consolidation, yarding, tracking, container maintenance and customs clearance. The presence of a dry port provides a designated space for the safe storage of containers and within this space, the truck loading and unloading process can be optimized. (Bergqvist & Monios, 2016). Therefore, one of the functions of a dry port is its integration with intermodal transport. Intermodal transport refers to transporting containers to destinations using more than one mode of transport to make transportation more flexible, adaptable, reliable, and efficient. During the delivery process, the replacement of means of transport and the loading and unloading of containers can be operated in dry ports, this means that a dry port can be considered as an inland intermodal terminal with a direct connection to the seaport. Customers can unload and/or pick up goods in an intermodal loading unit as if they were traveling directly to the seaport (Roso, V. & Lumsden, K., 2009).

Similar to intermodal transport, the application of dry ports can also be combined with the use of HCT. In recent years, the utilization of HCTs has steadily risen, leading to the formation of operational challenges related to the locations where trailers are connected and disconnected, as well as the storage of containers for distribution in the last mile of transportation. Combining these factors and needs in the implementation of dry ports seems an effective option.

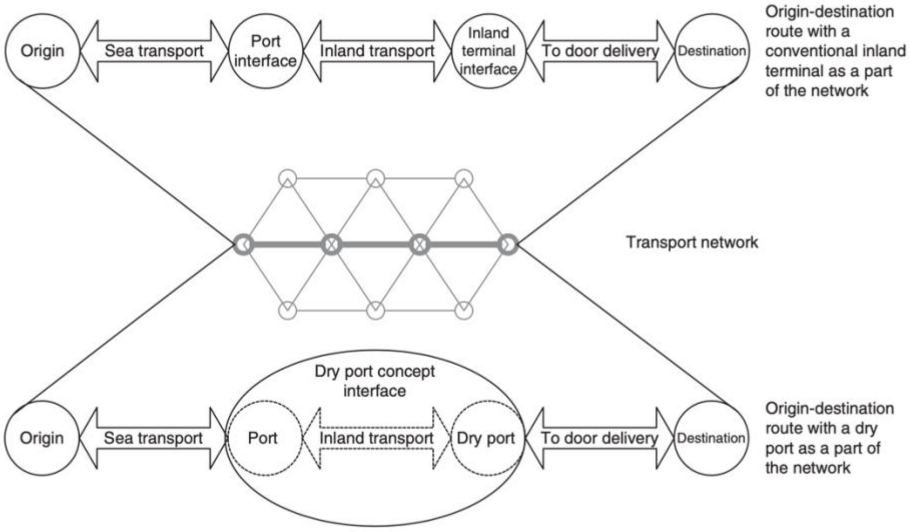

Figure 9. Dry port concept

Indeed, the corresponding maintenance of the dry port will increase the operating cost. A successful dry port needs to adapt to complex environmental changes and have a successful operational system to assist, which means that the dry port needs to be equipped with a mature infrastructure and regularly maintained (Padilha & Ng, 2012). The mode of operation of dry ports is also affected by regional policies and regional economic development, and hence there will be operational differences between dry ports in different regional contexts. The European Commission defines a dry port as an inland port directly connected geographically to a seaport. For example, in Germany, dry ports are seen as inland freight transfer stations to support and enable the development of multimodal transport to reduce cargo congestion in the port, relieve container storage pressure, and reduce operating time and operating costs (Oláh et al., 2018).

5.4.2 Dry port application

The Swedish dry port of Hallsberg is jointly owned by the municipality and the railway operators and is connected by rail to Gothenburg, Trelleborg, and Malmö respectively. Its main services include storage of containers, maintenance of containers, customs clearance, and transshipment, and in addition to this, its main advantage is the establishment of new businesses to attract more consumers. The emergence and increase in the number of dry ports has led to the development of railways and an increase in rail transport, which has improved the structure of inland transport corridors, as well as dry ports, which have increased the capacity of ports and improved congestion at port terminals, thus reducing the environmental impact. (Roso, V. & Lumsden, K., 2010)

Taking a look at Africa, the Isaka dry port in Tanzania was established in 1999. However, due to technical and managerial reasons, in the early days of its operation, Isaka functioned more like a railway station. However, as time went on and the demand for freight transportation increased, Isaka gradually transformed into a freight terminal and dry port. The fact that Isaka is a dry port means that it offers transshipment services and efficiently safeguards cargo. This means that the dry port effectively enhances port services and minimizes the amount of time it takes to deliver cargo as well as the expenses associated with transporting it (Roso, V. & Lumsden, K., 2009).

Therefore, the construction of dry ports needs to be adapted to local conditions. The study by Henttu et al. (2011) aimed to test the impact of a hypothetical Finnish dry port network on the transport network and to use a model of linear integer programming to be used to minimize transport costs. Among the results, it was shown that the implementation of a waterless harbor structure in the Finnish transport network improves cost efficiency, and that optimal cost savings can be achieved through four to six dry ports, but the addition of more than six dry ports leads to diminishing returns and investment costs exceeding the benefits. One of the key findings is that the use of multiple harbors along the Finnish coast significantly reduces the cost of unimodal road transport, i.e. due to the limited number of suitable cities and the concentration of the population around the capital city, the scientific selection of dry port locations can be effective in reducing the cost of transport in Finland, and the conclusions of this study are further studied to open the way for transport innovations. Meanwhile, Henttu and Hilmola (2011) highlighted an analytical model that supports the implementation of inland distribution dry ports, a strategy that can reduce emissions and total transport costs.

According to these examples of different dry ports in different countries, the specific characteristics of the national transport system need to be taken into account when designing the transport network. Finland, for example, differs from Sweden in that it needs more harbors to support its transport system, resulting in fewer inland dry ports. However, due to Finland's extensive coastline, more harbors improve the cost efficiency of the Finnish dry port network and overall inland transport. In other words, Sweden may be better suited to applying dry ports to save transport costs.

Therefore, in order to ensure an efficient inland transport system, the road transport of goods from the Port of Gothenburg to inland areas such as Viared requires a careful selection of truck sizes as well as the implementation of the last mile. At the same time, the increasing use of road transport, especially high-capacity transport, has led to discussions about the potential role of dry ports and the integration of sustainable transport solutions to reduce costs, emissions, and road congestion. Meanwhile, Mohan and Naseer (2022) highlighted the location of dry ports is influenced by five main factors: economic (e.g., land prices, construction, and operating costs), proximity (proximity to seaports, railways, roads, etc.), environmental (e.g., air and noise pollution, traffic congestion), site-specific conditions (e.g., scalability, infrastructure availability), and social factors (e.g. labor supply and population density). Therefore, analyses based on the physical location of the dry port site will also affect the feasibility of the dry port.

6. Data collection

6.1 Port of Göteborg to Borås Viared Logistics Park

6.1.1The port of Gothenburg

The Port of Gothenburg is located in Sweden's second-largest city, Gothenburg, and is recognized as the largest container port in Scandinavia, handles an impressive 914,000 containers annually, accounting for 57% of all container transport to Sweden. This significant throughput, evenly divided between imports and exports, underscores the port's critical role in the nation's international trade.

The port offers a wide range of services through numerous operators, including transshipment, container stuffing and stripping, and container servicing and repair. These facilities, located next to the main port area, feature transshipment terminals with weather protection and rail connections, ensuring efficient onward transport to and from global destinations.

In the first quarter of 2023, the Port of Gothenburg handled 225,000 TEUs, reflecting a 6% increase compared to the same period the previous year, despite a nearly 20% drop in import volumes. This rise in total container throughput underscores the strength of Sweden's exports, which have driven the overall growth. Over half of Sweden's container transport is handled at the port of Gothenburg, with the majority being handled at the APM Terminals container terminal.

The Port of Gothenburg has also gained market share from other Northern European vehicle hubs that continue to struggle with capacity problems and disruptions. This reflects the port's resilience and adaptability in the face of global and regional challenges. With its strategic initiatives and robust infrastructure, the Port of Gothenburg remains a pivotal player in Sweden's logistics and trade sectors, ensuring efficient movement of goods.

6.1.2 Viared, Borås

Viared is an important area for the future expansion and development of Borås and is already home to a number of companies. It is located along Highway 40, 25 minutes from Landvetter Airport and 50 minutes from the Port of Gothenburg. The map below (Figure 10) shows the approximate geographic access to Viared Logistic Park and indicates the approximate location of the main customers and dry port terminals within Viared Logistic Park.

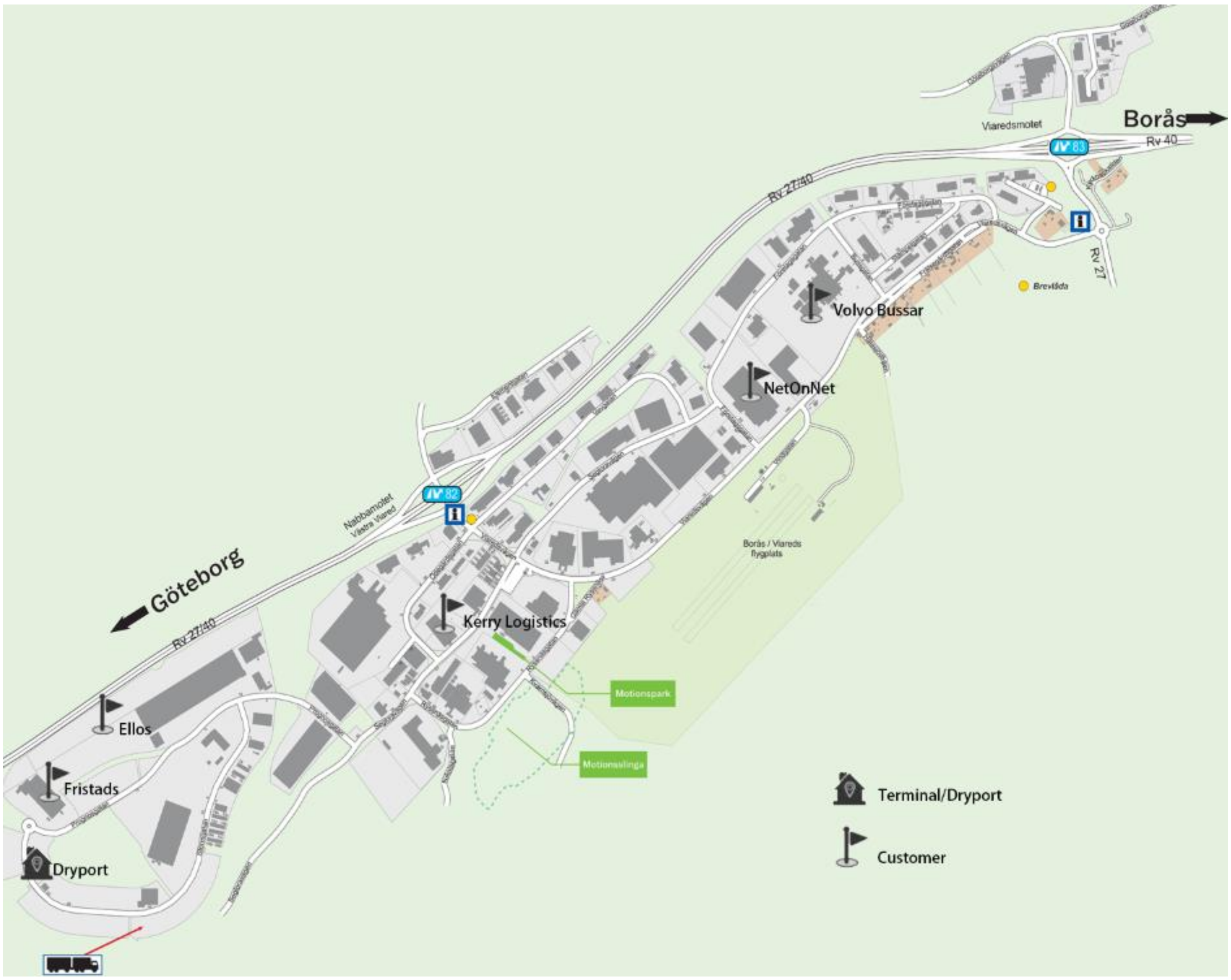

Figure 10. Map of Viared logistic center and the main stakeholders (Larsson et al., 2022).

6.1.3 Transportation between Gothenburg port and Viared

The distance between the Port of Gothenburg and Viared is approximately 70 kilometers, which translates to around a one-hour drive under normal traffic conditions (see Figure 11). The road infrastructure connecting Gothenburg and Viared is well-developed, featuring major highways that facilitate smooth and efficient travel for heavy freight vehicles. Unfortunately, there is no direct railway transport between the Port of Gothenburg and Viared. The transportation of containers between these two locations is primarily handled by road transport. Trucks, including single trailers and High-Capacity Transport (HCT) vehicles, are used to move containers from the port to Viared.

Figure 11. The route between APM terminal and Borås Viared (Google map, 2024)

6.2 Autofreight

6.2.1 The AutoFreight Project in Sweden

There is a project of HCT being used in Sweden, the logistics pathway connecting the Port of Göteborg with the Borås Viared Logistics Park, this route is critical for the seamless transfer of goods and ensuring that products reach distribution centers and ultimately consumers in a timely manner. In response to the logistical challenges and opportunities presented by this important transportation corridor, the City of Borås, in cooperation with about ten partners, has launched a major Swedish research and development project called AutoFreight (Autofreight, 2023). The focus of the project is the transportation of containers between the ports of Gothenburg and Viared Logistics Park in Borås using High-Capacity Transport (HCT) trucks which refers to the transportation of two 40/45-foot containers by truck. This significantly increases transport capacity, improves transport efficiency, reduces the environmental impact of transportation, and reduces the total number of trucks on the road. Previous studies have shown that total fuel consumption with duo-trailer trucks is about 80 percent of that of single-trailer trucks for two deliveries (Larsson et al, 2022).

According to Larsson et al. (2022), throughput at the Port of Gothenburg is very high, larger than is usual for similar ports elsewhere, meanwhile, the report also points out that imports at Borås are significantly larger than exports, estimated to be about one-tenth of its import volume. In 2016, the total container traffic between Gothenburg and Borås was 150 per week, but over time as more data became available, the total container traffic was around 200 per week. Imported containers at the Port of Gothenburg originate from various parts of the world, with a significant portion of the cargo coming from China, Thailand, India, and other countries. Among the containers, 40-foot units constitute about 80% of the total, 20-foot containers make up around 15%, and the remaining 5% are 45-foot containers (Larsson et al., 2022).

Table 2. number of container traffic per week

	Total	40-feet	20-feet	45-feet
# of containers	200	160	30	10

When containers arrive at Viared, they are transported to the designated consignee. The trailer carrying the container reverses into the consignee's loading area and remains there until the container is completely unloaded. If a single trailer is used for transport, it can drive directly to the consignee. However, if an HCT vehicle that carries two container trailers at once is used, each trailer must be decoupled separately before driving it to the consignee, as the different containers are usually destined for different consignees, and most consignees' terminals can only accommodate single trailers, making it impossible for the HCT vehicle to dock and turn around. Similarly, the trailer with the empty containers must be reconnected to the HCT vehicle before leaving Viared for the Port of Gothenburg.

Given this new context, there is a need for an area where container trailers carried by HCTs can be connected and disconnected. Additionally, there may be a requirement to temporarily park trailers with containers if the receiving station is not ready to accept them. For example, nighttime transportation became unfeasible due to the Port of Gothenburg being closed at night and the lack of customers in Viared able to receive containers during those hours. To facilitate operational tests for vehicle diversion and container storage, the City of Borås has designated an area in Viared as a so-called dry port. The dry port was initially envisioned at Viared to serve primarily Volvo buses, but this plan was put on hold when the 2020 pandemic impacted their exports. However, with the establishment of the new terminal at Ellos (one of the partner companies in the project), a large area of the terminal is now used as a transit area for container trailers during the day.

The approximate distance from the planned location of the dry port to the main customers is shown below:

Table 3. Distance between dry port and main customers (Google map, 2024)

Customer	Distance (km)
Volvo bus	5
Ellos	1
Kerrys Logistic	2
NetOnNet	4
Lager 157	5
Average	4

The average distance is therefore 4 km.

6.2.2 Vehicle setup

At an early stage of the project, it was decided the so-called A-double was used, which consists of a tractor, semi-trailer, and dolly, the number of individual units being indicated in table x. The full version of the model can be seen in Figure 12.

Table 4. The parameters of individual units

	Tractor	Semi-trailer	Dolly
Number of units	1	2	1
Length	*	13,6m	2m
Type	Volvo FH16 750 6x4	Parator	Parator

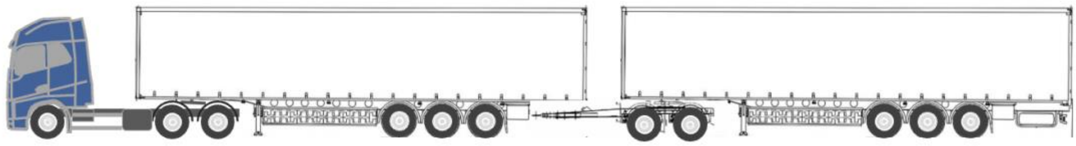

Figure 12. The setup of the vehicle

In Autofreight's project, the logistic-related parameters studied were deployed in the following configurations:

Table 5. Vehicle configurations

Parameter	
Types of Goods	Containers
Length (m)	32
Overall GCW (tons)	80
Distance travelled (km)	70
Fuel consumption saving	30%

Fuel consumption was extracted and consolidated from the project report as follows

Table 6. Fuel consumptions

Config	Fuel Consumption (GBG – Viared) (liter/100km)	Transport Efficiency excluding terminal operation (l/container)	l/container in %, Single trailer as reference
Single trailer	35,6	25	100%
A-Double	52,9	18,52	74%

6.3 Environmental impact - Data from other HCT cases

The Skogforsk ETT (En Trave Till) project, initiated in 2007, alongside Volvo's VETT (Volvo En Trave Till) project, aimed to evaluate the environmental impact of high-capacity vehicles (Fröjd et al., 2021).

According to the findings from Skogforsk, as illustrated in Figure 13, a 90-ton vehicle combination reduces CO2 emissions by approximately 20% compared to a 40-ton or 60-ton vehicle, in weight-restricted transport scenarios. The data clearly show that as vehicle capacity increases, CO2 emissions per ton-kilometer decrease significantly. Assuming that CO2 emissions for a 40-tonne vehicle combination are 120%, then for 60-tonne, 74-tonne and 90-tonne vehicle combinations the CO2 emissions per ton-km can be calculated as 100%, 90%, and 80% respectively. Additionally, the reduction in the number of vehicles required further contributes to lowering overall emissions.

Compared to the 40-ton vehicle combination, the 90-ton combination reduces the number of required vehicles by approximately 60%.

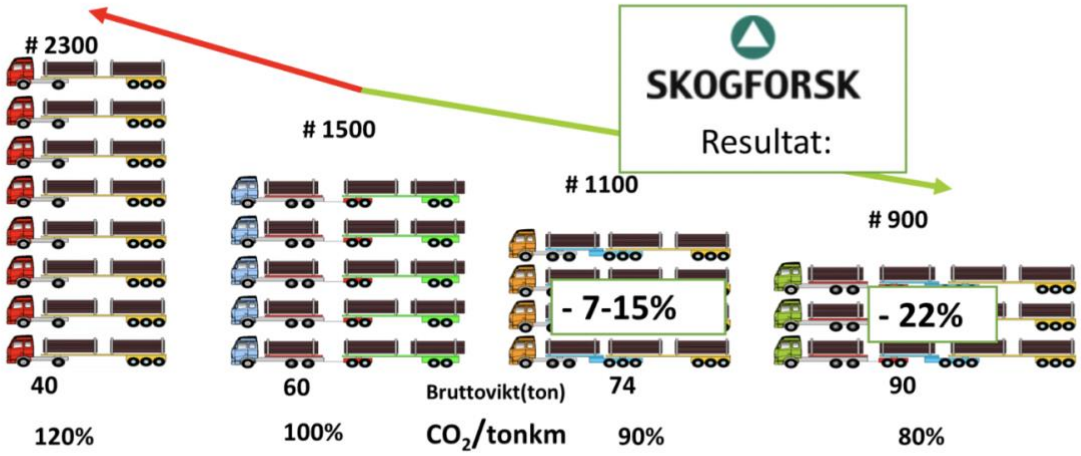

Figure 13. Hypothesis for the impact on CO2 emissions from roundwood transport in Sweden (Fröjd et al., 2021).

In the case of volume-restricted transport, the benefits of HCT also become clear. As shown in Figure 14, increasing the length of vehicle combinations without exceeding legal weight limits can also lead to a reduction in emissions. For a transport volume of 600 cubic meters with a density of 150 kg/m³, the CO2 emissions per cubic meter-kilometer decrease from 10.5 g for the semi-trailer to 7.5 g for the 32-meter DUO trailer which means a 32-meter DUO-trailer reduces CO2 emissions by 27% compared to a standard 16.5-meter semi-trailer.

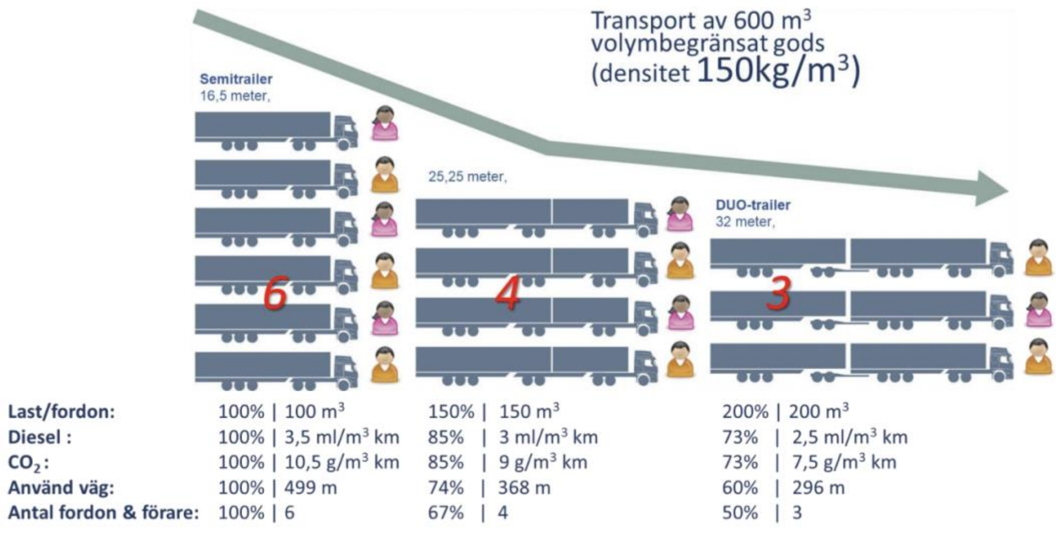

Figure 14. Calculation of the impact of HCT combinations on volume-restricted goods (Fröjd et al., 2021).

These empirical results from both weight- and volume-restricted transport scenarios demonstrate the reduction in the number of vehicles required. Thus, the implementation of HCT can potentially lead to a further reduction in overall emissions and road traffic.

6.4 Dry port applications

6.4.1 Falköping Dry Port Project

The Municipality of Falköping has close cooperation with both industry and academia and thus wishes to actively work on the establishment of an intermodal terminal in Skaraborg. The municipality also has an ongoing dialogue with the province of Västrajötland, the Swedish Transport Administration, and the Port of Gothenburg, which are the main partners in the Swedish Dry Port project. The project started with an extension and investment in the existing intermodal terminal, which was realized in cooperation with the Port of Gothenburg for the handling of containers.

At the same time, the terminal was improved to be able to support timber, bulk cargo, etc., this was the beginning of the dry port of Falköping. The Municipality of Falköping, in cooperation with private operators, manages these commercial activities under the concept of the "Skaraborg Logistics Centre", which offers a total logistics solution, integrating services such as inventory management and education. The construction of the new track and handover yard was completed in November 2010, with initial investments totaling approximately SEK 65 million, creating the material conditions for further expansion. Plans have also been drawn up for a new large-scale, multi-purpose intermodal terminal, which will include the construction of a dry port, and Södra Skogsägarna has invested SEK 20 million, with a contribution of SEK 7 million from the Municipality of Falköping. The new timber terminal is approximately 60,000 square meters, which will lay the foundations for the future development of the dry port.

Table 7. Investment summary

Investments	SEKs
Initial investments	65 million
Investment by Södra Skogsägarna	20 million
Total	85 million

In 2010, the Municipality of Falköping started working with a group of stakeholders to clarify the economic and operational relationship between the Harbour and the dry port. This work was initially carried out in cooperation with the then terminal operator, ISS Trafficare, and continued with the new operator, TBN Åkeri AB. The terminal signed a rail port agreement with the Port of Gothenburg to establish customs procedures for a containerized rail shuttle service due to start in 2013.

6.4.2 Jula case

Jula, a leading retail company headquartered in Sweden, embarked on a transformational journey to optimize its logistics operations by establishing an intermodal service for inbound flows. Working closely with Schenker Air and Ocean, Jula identified an opportunity to streamline the containerization process and improve efficiency across the supply chain. Jula operates a 150,000-square-metre distribution center in Skala, Sweden, and receives the majority of its cargo in imported containers, mainly from Asia. Before launching the intermodal service, Jula was faced with the challenge of effectively managing the container flow due to the increasing size of the containers, resulting in increased costs and logistical complexity, and due to the increasing storage costs for full containers at the Port of Gothenburg, Jula sought new alternatives to reduce the financial pressure. While the inland terminal in Falköping has effectively solved part of the problem by acting as a buffer between full and empty containers, Jula also launched an intermodal service in 2013. The service facilitates rail transport between the Port of Gothenburg and the Falköping Dry port, providing a cost-effective and sustainable solution for inbound container flows.

In 2012, Jula initiated the process of applying for an exemption from road restrictions for the transport of goods between the Falköping Dry port and its central warehouse in Skara. The implementation of the road haulage exemption introduced HCT vehicles to Jula's logistics operations. Overall, the experience with the HCT vehicles has been positive, thanks to the high-powered engines, and drivers have found the vehicles easy to maneuver. As of 2016, Jula Road Transport Services employs five drivers assigned to haulage service. Despite the efficiency of the HCT vehicles, the same conditions are encountered in transport, such as switching to single chassis transport on icy roads to ensure safety and reliability.

Jula used the Falköping dry port as an inland hub, which helped Jula to store and buffer containers closer to the central distribution center, this helped to reduce the lead time for delivering containers to the distribution center and also reduced the storage costs associated with having a large number of containers out of the port of Gothenburg. At the same time, Jula uses Chassis Management to manage the necessary chassis and transports in cooperation with the local haulage company ARJ Service AB, thus avoiding the need to invest in its fleet. Chassis management is where the chassis are pre-assembled at the terminal before the terminal closes. This allows the haulage company to continue delivering containers to the consolidation center outside of terminal operating hours, thus minimizing waiting times and maximizing operating hours, enabling the transporters to operate outside of terminal opening hours without delays. Jula has also entered into an open partnership with ARJ Service AB, which has resulted in transparency in cost management and operational goals Jula has also established an open partnership with ARJ Service AB to achieve transparency in cost management and consistency in operational objectives. This cooperation promotes continuous improvement, enabling daily performance tracking and regular financial reviews. These strategies have enabled Jula to significantly reduce last mile costs, improve service levels, and create a flexible, scalable logistics system capable of responding to seasonal demand fluctuations

7. Analysis

This chapter presents the costing model used to analyze the economic and environmental impacts of using single and double trailers in road freight transport. By showing the individual cost components, the chapter analyses the advantages and disadvantages of the options and the possibility of implementing a dry port.

7.1 Transportation cost structure

As we have mentioned in Chapter 5.2, the general transportation cost per shipment:

$$shipment\ cost = c_f + c_v * v * d$$

In our case, the shipment size refers to one vehicle combination, whether a single trailer or HCT. We will now break down that formula and put it back into our case for further cost analysis.

7.1.1 Operational cost

Based on the general shipment cost, the operational cost needs to consider the fixed costs and variable costs for transportation. Fixed costs typically include the cost of purchasing vehicles, administrative funds, employee wages, taxes, and insurance. This component of expenditure is usually fixed, but it is to be expected that different scales of operation will lead to different fixed costs. Also, due to the limited data available for this thesis, we will use the average of fixed costs obtained based on distance variation as the basis for fixed cost calculations.

Meanwhile, based on the references, variable costs include fuel costs, maintenance and repair, cost of tires, crew costs, and charges, which are also related to the distance traveled, but in our case, the fuel consumption will be calculated separately in the next section because we think that fuel consumption is an important part of the cost difference between single-trailer and double-trailer.

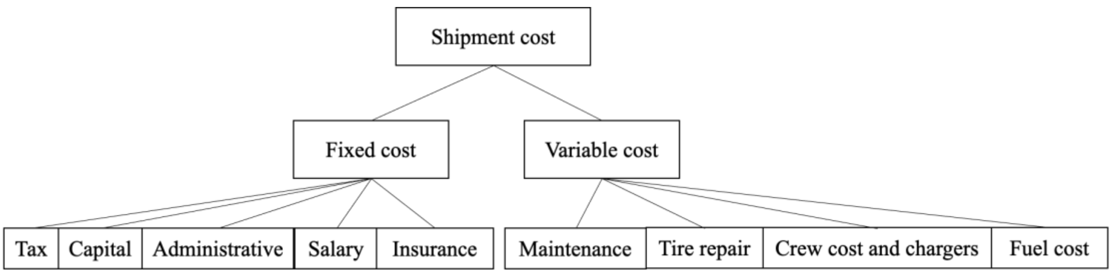

Figure 15. Shipment cost structure

The formula for calculating operating costs is as follows:

$$TC_o = C_f + C_v * d$$

TC_o = *Operational cost per shipment*
C_f = *Fixed cost*
C_v = *Variable cost without fuel consumption*
d = Distance

7.1.2 Fuel consumption cost

The fuel consumption cost can be described as follows:

$$TC_{fuel} = P_{fuel} * F$$

TC_{fuel} =*Total fuel consumption cost per shipment*
P_{fuel} = *Fuel price*
F = Fuel consumption per shipment

Here, the fuel consumption per shipment (F) can be calculated by multiplying the distance (d) and fuel consumption per 100 km:

$$F = \frac{d}{100} * fuel\ consumption\ per\ 100km$$

7.1.3 Handling cost

Handling costs refer to the expenses associated with labor, equipment, materials, and other resources required for transporting, storing, packaging, and handling goods. In our analysis, we assume that the calculation starts from the point where the container has already been loaded at the Gothenburg port. Therefore, the handling costs incurred at the Gothenburg port are excluded from our calculations and can be disregarded for the purposes of this study. Furthermore, when the double trailer arrives at the dry port, there is no need to unload the containers. Instead, shunting operations are performed, which involve disconnecting or reconnecting the trailer and the dolly.

7.1.4 Last mile cost

When using a double trailer for container transport, the double trailer cannot deliver the containers directly to the end customer, because the containers need to be separated at the terminal or dry port and then transferred to the end customer. In this section, it defaults that a double trailer will travel more distance than a single trailer when performing last-mile transport, because after the separation of the containers, the trucks need to deliver the goods to two different end customers instead of being able to deliver them directly as a single trailer can do, and here the difference in paths leads to an increase in distance. Therefore, double trailers increase the last mile cost compared to single trailers.

The last-mile cost can be viewed as the expense associated with the final part of a shipment's journey, which involves delivering goods directly to their destination, such as a customer's location or a retail outlet. This part of the logistics is often more complex and costly due to factors like urban traffic, varied delivery locations, and lower volume efficiency compared to long-haul segments. However, the underlying calculation of last-mile costs follows the same principles as other part of transportation. It includes factors like variable costs and fixed costs, just applied over shorter distances and potentially smaller shipment sizes. Thus, the calculation of the last mile cost can be expressed by the following equation:

$$TC_l = TC_o + TC_{fuel}$$

TC_l = *Total cost of last mile*

7.2 Dry port implementation cost

7.2.1 Dry port costs on the theoretical level

The last mile can be greatly facilitated by the use of dry ports, which can provide storage, handling, maintenance of containers, and many other services. However, the construction of dry ports requires the consideration of many factors, such as the large investment required before the construction and the subsequent maintenance and management costs. Flodén (2007) has categorized those costs as shared terminal costs and also as fixed costs. According to the Falköping Dry port case, dry ports require large one-time initial investments to support construction and equipment operations that do not vary with throughput. In addition, the wages required per worker are usually fixed and need to be paid even if there is no container handling at the dry port. This type of cost varies depending on the location of the dry ports, and government policies, but it is constant until the dry port operation expands, and is calculated as follows:

$$TC_{dpf} = TC_i + C_{dpf}$$

TC_{dpf} =*Total Fixed cost*

TC_i = *Total investment of dry port*

C_{dpf} = *Fixed cost of dry port*

When a dry port comes into operation, it is necessary to consider operating costs, such as utilities and equipment maintenance costs etc. However, as the number of containers in dry ports continues to increase, more resources are required to support operations, leading to an increase in operating costs, such as the cost of additional dry port equipment, cost of energy consumption, and management costs. At the same time, when the volume increases to a certain level, it is also necessary to consider the cost increase due to the subsequent expansion and expansion of the dry port. However, as written in the frame of reference, the rate of increase in operating costs of expansion decreases gradually, and k is used to refer to the rate of increase in operating costs, and the total operating costs are calculated as follows:

$$C_{dpo} = C_{dh} * V * k$$

C_{dpo} = *Total operational cost in dry port*

C_{dh} = *Operational cost per container*

V = *Number of containers*

k= *Growth rate of operating costs*

The total shared terminal cost in a dry port is the sum of the fixed cost and the total operational cost, which can be added together as:

$$TC_{dp1} = TC_i + C_{dpf} + C_{dh} * V * k$$

TC_{dp1}= *Total terminal cost of dry port*

The figure 16 is shown the image of the theoretical dry pot costs as follows.

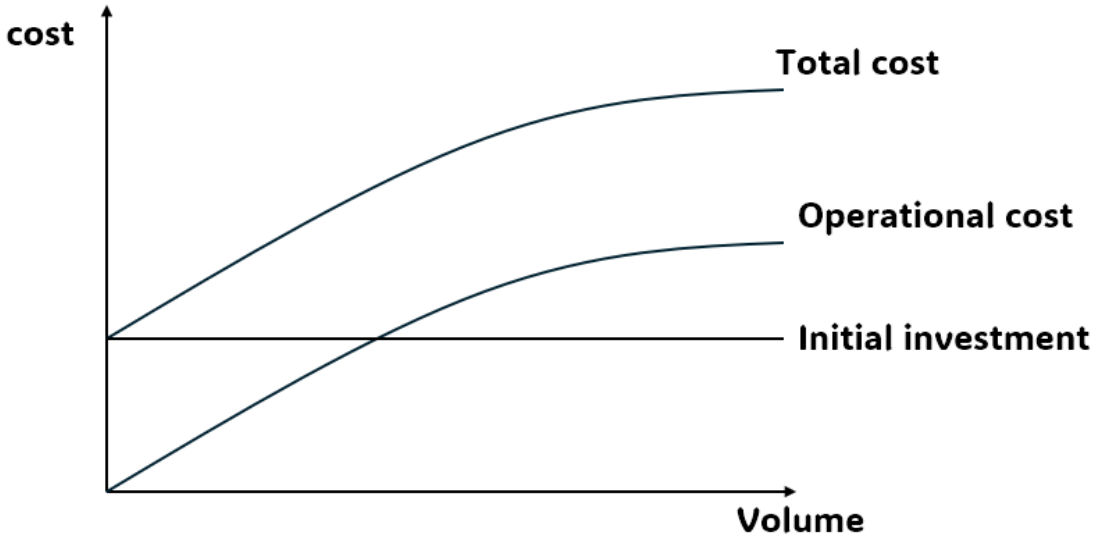

Figure 16. The theoretical costs of dry port

7.2.2 Dry port costs in our case

The key part of the research in this thesis is to compare the costs associated with transporting containers using a single trailer and a double trailer. The aim is to assess whether the use of double trailers reduces the cost per container. If the calculations show that double trailers are more cost-effective, then the resulting savings can be redirected to the construction and operation of dry port facilities. This leads to an important economic indicator that a dry port is only considered viable if the total cost of constructing and operating the dry port is less than the savings from switching to double trailers. That is, the cost of implementing a dry port must be less than or equal to the cost savings of transitioning from a single trailer to a double trailer.

$$C_{dp2} \leq TC_{single} - \frac{1}{2} TC_{double}$$

C_{dp2}=*The shared terminal cost per container in the dry port*

7.3 Data preparation

It is important to note that the data collected in our analysis is secondary data, from various reports. While this reliance on secondary data may introduce some limitations in terms of accuracy and alignment with real-world conditions, these sources remain valuable for our purposes. They serve as a practical example to illustrate the cost differences between double trailers and single trailers, offering insights that can aid in understanding the comparative economic impact of these transport options.

The parameters in our case are summarized in Table 5, and the data are referred from *Hossain (2009)*, *Preem (2024)*, and *Larsson et al. (2022)*. The data retrieved from *Hossain (2009))* were based on 2007, and we have adjusted the data by the cumulative inflation rate of 44,82% from 2007 - 2024 *(Alioth Finance, 2024*).

Hossain (2009) calculates the variable costs associated with 3 Axles-truck, including fuel costs. However, as mentioned in the previous section, we have chosen to separate fuel costs from other variable costs in our analysis. Therefore, it is necessary to extract the fuel cost from the overall variable cost before incorporating the adjusted numbers into our calculations.

Table 8. Parameter data

Parameters	W5	Value (2024)	Source
C_f	SEK/km	4,24	Hossain (2009)
C_v	SEK/km	5,61	Hossain (2009)
Diesel (exclusive VAT)	SEK/L	15,04	Preem (2024)
Fuel/km (single)	L/km	0,356	Larsson et al. (2022)
Fuel/km (double)	L/km	0,529	Larsson et al. (2022)

7.4 Scenario analysis

To provide an overview of the economic impact of using a trucking mode of transport from the Port of Gothenburg, this section compares a single-trailer truck with a double-trailer truck by modeling the total transport costs. Scenario 1 shows that all road transport of goods is done by a single trailer with a maximum permissible trailer length of 18,75 meters, which is loaded from the seaport of Gothenburg and then transported directly to the customer by road without any involvement of a terminal or dry port in the whole process. Scenario 2 involves road transport using twin trailers with a maximum length of 32 meters. Unlike Scenario 1, the A-double requires the use of a terminal or dry port for the separation of the trailers and the last mile of transport after separation. The distance from the port of Gothenburg to Viared is approximately 70km, according to Google Maps (2024). However, considering A-double is required to perform shunting and last-mile transport operations, we assume that the last-mile distance for each container averages 4 km.

Table 9. Calculation Scenarios

	Scenario 1	Scenario 2
Transport Distance	70 km	70 km
Average last-mile distance	—	4 km

Figure 17 shows the roadmap for the scenarios. Due to the different sizes of road freight vehicles, truck fuel consumption and speed can vary.

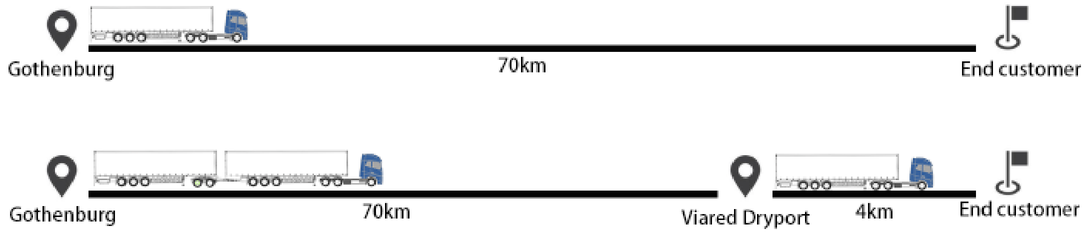

Figure 17. 2 Scenarios presentation

7.4.1 Total transportation cost

Based on the mathematical relationships established earlier, the total transport cost can be represented as the sum of the operational cost, fuel consumption cost, and last-mile cost. Thus, the total transport cost for a single trailer (TC_{single}) and A-double (TC_{double}) can be constructed according to the equations outlined above.

It is important to note that this calculation only accounts for the one-way trip, specifically the transport of the container from Gothenburg port to the end customer. Since the vehicle will connect new containers (either empty or loaded) for the return journey, we believe that the cost of the return trip should be allocated to those new containers. Therefore, the return trip costs are not included in this analysis.

$$TC_{single} = TC_o + TC_{fuel}$$

$$TC_{double} = TC_o + TC_{fuel} + \sum TC_l$$

7.4.2 Operational cost

In comparing the operating costs of single- and double-trailer transport, it is important to recognize the various expenditure categories that affect the costs. These categories include costs associated with the vehicle itself, driver wages, applicable taxes, insurance premiums, and ongoing vehicle maintenance costs. Both modes of transport share these core operating costs, but there are key differences in terms of upfront investment: the cost of equipment for a double trailer is significantly higher than for a single trailer. However, due to data limitations and collection constraints, we chose not to consider the difference in vehicle purchase costs between the two scenarios. As mentioned earlier, our cost calculations are based on data provided by Hossain (2009), adjusted for inflation to reflect current values. Table 10 below provides a breakdown of the recalculated operating costs for the single and double trailer transport scenarios.

Table10. Operational cost

	Scenario 1	Scenario 2
Fixed cost	297 SEK	297 SEK
Variable cost (without fuel)	393 SEK	393 SEK
Operational cost	690 SEK	690 SEK

7.4.3 Fuel consumption cost

In addition to equipment costs, another major difference between the two modes of transport is fuel consumption. Since single and double trailers differ in size and weight, their fuel consumption rates are necessarily different. Dual trailers are larger and heavier and typically consume more fuel than single trailers. This difference in fuel consumption usually affects the overall variable costs. However, we consider that differences in fuel consumption are important factors that deserve separate attention. We have therefore calculated fuel consumption costs separately for single and double trailer transport. By calculating these costs separately, we aim to gain a clearer understanding of how fuel consumption contributes to the overall cost difference between the two modes of transport. The results are shown in the following table:

Table 11. Fuel consumption

	Scenario 1	Scenario 2
Fuel consumption per shipment	25 L	37 L
Fuel consumption cost	376 SEK	557 SEK

7.4.4 Last mile cost

There is no need to consider a single trailer in the last mile calculation because a single trailer can transport the container directly from the Gothenburg harbor to the end customer without additional stops or shunting.

However, for double-trailers, last-mile delivery involves additional steps. While the factors contributing to costs—such as fuel consumption, labor, and vehicle operation—are similar to moving containers from the terminal to a dry port, the key difference lies in the distance traveled. A-doubles require the containers to be shunted at the dry port and then transported individually to different end customers. This increases the overall distance covered, unlike single trailers, which can deliver containers directly to their end destination.

The average last-mile distance in our case is set to 4 kilometers. Notably, delivering two containers to separate customers requires a total of three last-mile trips. The first trip is for delivering the first container, followed by the second trip back to the dry port, and finally, the third trip is to deliver the second container. Additionally, the cost of shunting at dry ports is not considered due to a lack of relevant data. The total cost of the last mile was calculated as shown in the following table:

Table12. Last mile cost

	Scenario 1	Scenario 2
Operational cost	—	37 SEK
Fuel consumption cos	—	23 SEK
Number of trips of last mile	—	3
Total cost of last-mile	—	180 SEK

7.4.5 Total transportation cost

Overall, based on the various types of cost expenditures calculated above, they are added together to obtain the total transport costs. The transportation costs of single trailer and A-double are calculated as follows:

Table 13. Total transportation cost

Transport method	Cost per trip/SEK	Cost per loading unit/SEK	Cost saving
Single trailer	1066	1066	0%
A-double	1427	714	33%

The results of the total costs based on the above calculations showed a saving of 352 SEK per loading unit for the A-double compared to using the single trailer, which also reflected the advantages of the A-double from an economic point of view.

In addition, the calculated savings of 352 SEK can be used to compensate for the additional costs incurred by the use of dry ports. This means that the combined use of A-doubles and dry ports is economically more viable than the traditional method of using a single trailer, as long as the total unit cost of handling containers at dry ports remains below 352 SEK. Accordingly, based on the calculation results, the quantitative relationship between costs at the dry port and container capacity can be calculated as follows:

$$TC_{dp2} \leq 352 * V$$

TC_{dp2} = *Total cost of shared terminal cost in dry port*

V = *Number of containers*

In addition to this, compared TC_{dp2} with the previous formula for costs in dry ports, the two formulas will intersect at some equal volume. TC_{dp2} denotes the change in transport expenditure savings with the number of containers when transporting with two trailers compared to a single trailer and that the use of a dry port will be economically efficient when the expenditure in the dry port is less than the savings. TC_{dp1}, denotes the total cost of shared terminals at a theoretical level, but because of data collection limitations, we do not have enough data to substitute into the formula.

However, it can be concluded that dry ports are economically efficient when the savings are higher than the theoretical operating expenses of the dry port. Conversely, if the costs incurred by using dry ports are higher than the savings from A-doubles, then the implementation of dry ports is not an efficient option from an economic point of view. However, in addition to the savings perspective at the transport level, dry ports have other advantages, such as the fact that in the Jula case the dry port of Falköping can be used for storage of containers to solve the high storage costs associated with storing containers in the seaport, and to provide greater flexibility for subsequent shipments.

7.5 Factors affecting the implementation of dry ports

In addition to economic factors, the dry port feasibility is further analyzed concerning geographic location, market demand, policies, and regulations as well as environmental impacts. Firstly, accessibility is an important competitive advantage. Viared is about 70 kilometers away from Sweden's largest port, Gothenburg, and is close to the railway and road network, which makes transshipment from the port to inland containers less costly, and also allows for quick connection to end-customers around the country, which significantly improves the efficiency of the entire supply chain. In addition, the area around Viared is an important manufacturing and logistics center in Sweden, with a large number of warehousing and logistics companies, as well as new industries such as e-commerce. The dry port provides these companies with convenient container and cargo transport services, which have obvious economic benefits. In recent years, the Swedish government has also given strong support to the development of sustainable transport and HCT (Åkerfeldt & Knutsson, 2019). The construction of a dry port in Viared will help develop the application of HCT and enhance the potential for sustainable development. Through low-carbon and environmentally friendly measures, the dry port is at the forefront of sustainable development, which will benefit its future in the Swedish supply chain. Despite the relatively high level of economic activity around Viared, the market in Borås is limited in size compared to the Swedish national market or even the Nordic market as a whole, while the viability of the Viared dry port is largely dependent on the Port of Gothenburg and the business of manufacturing companies in the region. If these companies reduce their reliance on the dry port or if the throughput of the Port of Gothenburg declines, the benefits of the dry port may also be affected. For the long-term development of the dry port, the growth in demand for containers may be somewhat limited, especially if the regional economy encounters downward pressure.

Overall, Viared, as an important inland logistics hub in Sweden, has several advantages such as proximity to the harbor, accessibility, government support, and sustainability, which together contribute to its viability as a dry port. However, despite this, the dry harbor faces potential challenges such as geographical distance, market limitations, and fierce competition. Moving forward, Viared Dry Port will need to continue to innovate and enhance its competitiveness, while focusing on expanding its market reach and optimizing its operational efficiency in order to maintain its important position among inland logistics hubs.

7.6 Last mile transportation

7.6.1 Last-mile transportation analysis

During the whole process, feasibility in the last mile is particularly important in transport issues, especially when containers are transported on A-doubles, and last-mile delivery issues need to be considered. For a trailer that can be transported directly from the APM terminal in Gothenburg to the end customer, this avoids additional "last mile" considerations as well as expenses. Additional labor and trucks are not required for this mode of transportation.

In deploying A-doubles for the entire transportation process, the trucks are first loaded with containers at the APM terminal and then transported to Borås Viared, where the containers need to be unloaded from the trucks and then reloaded for further distribution to the designated end customers. There are additional potential costs associated with such activities. These costs include the need for additional trucks and drivers, increased waiting times at the terminal or dry port, and possible scheduling conflicts. Furthermore, variable costs fluctuate with the number of containers being handled, as more containers may necessitate more trucks and drivers, thus increasing labor costs, fuel consumption, and other operational expenses.

7.6.2 Last Mile Scenario in the Case

In our case, there are two potential scenarios for managing the last mile operation of the A-double.

(1) Scenario 1

The first scenario is to have the same truck continue carrying the containers for last-mile delivery after the containers have been separated at the terminal (Figure 18). This approach is relatively straightforward to manage, as it does not involve additional costs related to staff salaries or waiting times, making it a cost-effective and easy-to-implement solution. The simplicity of this method can be advantageous, particularly when looking to minimize overhead and streamline operations.

However, this approach comes with some clear disadvantages. One of the main drawbacks is that this method of last-mile delivery can create bottlenecks in the distribution process, especially when there is a high volume of containers to be distributed. Since the same truck is responsible for multiple deliveries, a significant portion of the shipment may end up sitting idle, waiting to be dispatched. This delay can greatly reduce overall efficiency, causing the distribution network to slow down and struggle to meet demand. Furthermore, with the development of Viared into a dry port, an increase in the number of export containers is likely. If there is a simultaneous demand for last mile delivery and export transportation to the port of Gothenburg, these inefficiencies in the logistics chain will be further amplified.

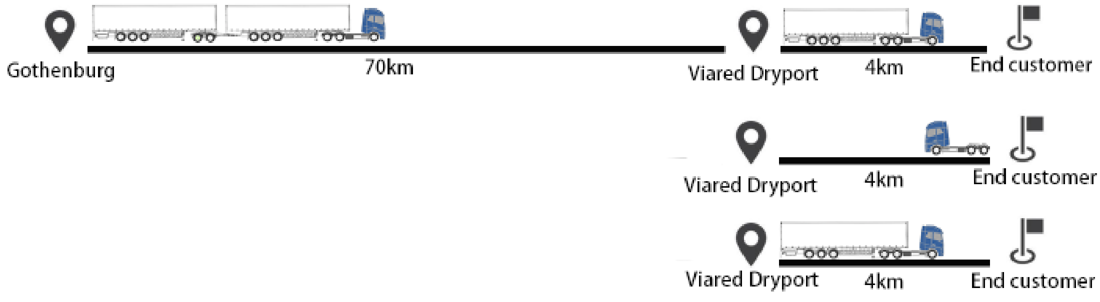

Figure 18. Scenario 1 road map

(2) Scenario 2

The second scenario for managing the last mile of a double-trailer operation is to assign additional trucks specifically for that purpose (Figure 19). This approach differs from the first in several keyways. The most obvious drawback is increased costs. Because using more trucks means increased investment costs for the facility as well as hiring more drivers for the additional vehicle portion of the operation, this also leads to increased employee payroll expenses. In addition, this approach can lead to inefficiencies during periods of low container traffic, such as trucks sitting idle while waiting for containers. During periods of low demand, these trucks are then under-utilized, resulting in unnecessary operational expenditure without a corresponding increase in productivity.

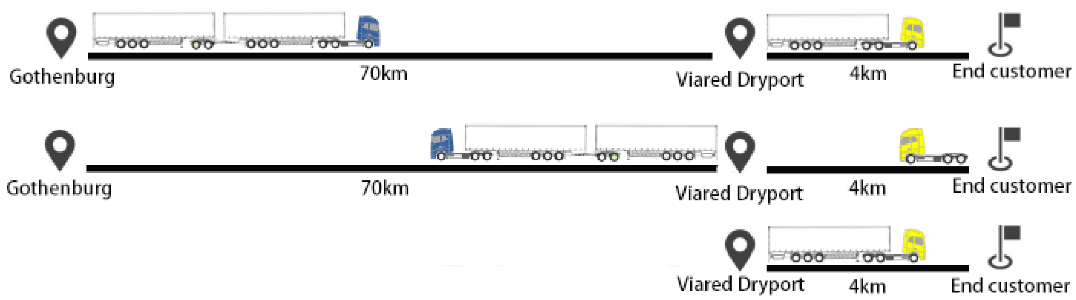

Figure 19. Scenario 2 road map

However, there are still significant advantages to using additional trucks when there is a high volume of container flow. In this case, additional trucks can significantly reduce the time required for last mile distribution and provide greater flexibility. Flexibility is reflected in time and by adding trucks, transport scheduling will no longer be limited to the capacity of a single vehicle. Different trucks can be used for flexible last-mile transport scheduling based on different time windows and distribution requirements. Even in the face of peak container traffic, it will still be possible to meet customer demand and ensure that containers can reach their destination in less time. From a geographical standpoint, by adding more trucks for last-mile transportation at the dry port, the service range can be significantly extended, encouraging inland customers to utilize the dry port services for their export needs. This expansion enables businesses located farther from the port to easier access the dry port, reducing the reliance on Gothenburg harbor and alleviating the congestion and operational pressure there. As a result, the dry port can act as a more effective hub, distributing container traffic more efficiently across the region. More active dry ports also imply higher utilization of truck fleets.

7.6.3 Other supporting options of last mile

It is analyzed in conjunction with existing cases, such as the Jula case, where Jula optimized last-mile transport using HCT through several strategies, in particular by integrating inbound logistics and transport processes. The chassis management allows the transport company to continue delivering containers to the consolidation center during the terminal's non-business hours, thus minimizing the waiting time for containers, minimizing the last mile time, and avoiding delays. This also gives a new option to use the Double trailer directly for last-mile transport.

The use of Double trailers in last mile distribution offers some potential advantages not available with single trailers. Double trailers can transport more containers than single trailers, which can reduce the number of trips and increase transport efficiency. This is an advantage when large quantities of containers need to be handled. However, the use of Double trailers in last mile distribution also faces certain challenges, such as the difficulty of traveling on narrow urban roads, the need for frequent parking, and the need to ensure safe and efficient handling of containers at the point of delivery, which has been the biggest obstacle to the implementation of this solution. Therefore, road infrastructure and transport flow management need to be upgraded and optimized if Double trailers are to be used in last mile distribution.

8. Conclusion

This chapter will answer the three sub-questions that have been researched in this thesis and from this will conclude how to choose between single and double trailers in road transport. Additionally, this chapter will outline some of the recommendations that can be drawn from the research on how dry ports and the last mile should be done.

Q1: Compared with the single trailer, is it more cost-effective to use double trailers for transport?

This thesis compared the economic impact of using single trailers versus double trailers for container transportation. The analysis reveals several significant advantages of double trailers, making them a more feasible solution for large-scale transport operations.

Firstly, in terms of cost per loading unit, although the cost per trip for a double trailer (1427 SEK) is higher than that of a single trailer (1066 SEK), the increased loading capacity of double trailers significantly reduces the cost per unit of container transported to 352 SEK. This indicates that double trailers are more cost-effective for transporting larger volumes of containers. Meanwhile, double trailers offer increased transport capacity, allowing for more containers to be transported in a single trip. This higher capacity leads to better utilization of transport resources and potentially fewer trips required to move the same amount of containers, thereby reducing overall operational costs and environmental impact. While double trailers consume more fuel due to their larger size, the fuel cost per unit of cargo is distributed over a larger number of units, resulting in lower fuel consumption costs per unit compared to single trailers.

It is important to note, however, that the distance factor plays a crucial role in determining the overall cost efficiency of double trailers. The cost advantages of double trailers become more pronounced over longer distances where their increased capacity and fuel efficiency per unit can be fully leveraged. On shorter routes, the higher initial cost per trip associated with double trailers may not be offset by the savings from their greater load capacity, leading to a smaller or even negligible price advantage compared to single trailers. This suggests that while double trailers are generally more economical for long-haul transport, their cost-effectiveness diminishes as the distance decreases. Therefore, the choice between single and double trailers should take into account the specific distance of the transportation route, as shorter distances may favor the use of single trailers.

In addition, the demand for last-mile delivery plays a significant role in influencing the feasibility of double trailers compared to single trailers. Last-mile deliveries typically require traversing urban areas or routes, whereas double trailers are larger and less maneuverable, and not all types of roads are capable of accommodating the movement of double trailers. In such cases, the use of double trailers may result in inefficiencies and increased costs. Single trailers, with their smaller size and greater flexibility, are often better suited to handle the complexities of last-mile transportation, especially in congested or inaccessible areas, because single trailers don't need to think about separations and connections and can be transported directly to the last mile. Therefore, when “last mile” deliveries are a key component of a transportation operation, single trailers may provide a more flexible, faster, and cost-effective solution, even if they are less efficient for the majority of the trip.

Q2: From an economic perspective, how volume of containers influence a dry port to become a viable option?

The application of dry ports can be approached from several different perspectives, firstly from an economic point of view, where the cost structure of dry ports is becoming more and more favorable as container throughput increases. Initially, the large investments required for infrastructure, equipment, and operations may seem prohibitive, but the capital for such one-off investments is constant. However, as container throughput grows, the trend of increasing operating costs slows down. Thus after finding the right container throughput on this basis, dry ports will become the most economically efficient ports.

Secondly, we observed that Viared's container freight services are dominated by imported containers from the port of Gothenburg and lack container export services. Even with a focus solely on imports, the annual container throughput at Viared has reached approximately 10,000 units. Thus, there is significant untapped potential to increase this value by expanding export operations. Enhancing export activities through the dry port would lead to a more balanced flow of containers, thereby reducing the frequency of empty container returns. Improving logistical efficiency in this way would also support the more efficient and sustainable use of high-capacity transport vehicles.

In addition, the dry port's warehousing services extend its strategic advantages and are particularly effective in easing the pressure of tight delivery times. By storing containers that need to be delivered urgently, dry ports support just-in-time (JIT) supply chains where timely delivery is critical. This capability is invaluable to industries that rely on precise delivery times to maintain operational efficiency.

Q3: How to effectively manage the vehicle used in last-mile transport services when using HCT as well as dry ports?

Each scenario has its advantages and disadvantages as described in the analysis section. For the first scenario, it is relatively cost-effective as it reduces the additional expenditure associated with staff wages and waiting times. It is also relatively simple to manage, helping to minimize overheads and streamline operations. However, there are obvious drawbacks to this method. As the same truck is responsible for all deliveries, it can lead to bottlenecks, especially when there are many containers to be distributed. This can lead to delays as many containers may sit idle awaiting delivery. As dry ports develop and container throughput increases, these inefficiencies may become more pronounced, especially if there is a simultaneous need for last-mile transport and export transport.

The second scenario is to dedicate additional trucks to last-mile transport. This approach has the potential for significant efficiency gains during periods of high container traffic, as it allows workloads to be distributed among multiple trucks, resulting in faster deliveries and improved service levels. However, this approach can also increase operating costs, including the need for more drivers and the complexity associated with additional loading and unloading processes. In addition, during periods of low demand, these extra trucks may be underutilized, leading to unnecessary expenditure without a corresponding increase in productivity.

In summary, effective last mile transport management, especially at dry ports, requires a balanced approach. When container traffic is high, additional trucks can be necessary to improve efficiency and customer satisfaction. Conversely, using the same truck throughout the delivery process may be more cost-effective and easier to manage in low-traffic situations. In addition to this, for HCT, the number of separations and combinations can be minimized to improve efficiency and save human resources and time. The key is to tailor the strategy to the specific needs and operating environment at a given time.

9. Limitations and discussion

This chapter discusses the limitations of this paper and the scope for future improvements. This includes a critical assessment of data accuracy and limitations of secondary sources. Also mentioned are concerns about alternative fuel trailers, sensitivity analyses of demand fluctuations, and logistical challenges that were not considered.

The most significant limiting factor in this thesis is the authenticity and accuracy of the data, as much of it is derived from secondary sources, such as other studies and reports. Given that these sources may be somewhat outdated, there is the possibility of a time lag in the data. Additionally, a specific cost model was developed for this thesis, but many of the factors used in this model, such as fuel costs, labor costs, and the policy environment, vary depending on economic conditions, regional differences, and regulatory situations. One key aspect that was not considered in our investigation is the use of alternative fuel-powered trailers, such as electric or hybrid engines. Different types of fuel and engine technologies can significantly impact the conclusions drawn in this thesis. For future research, incorporating a comparison of diesel, electric, and other alternative fuel trailers would provide a more comprehensive understanding of the cost and environmental implications of each option. At the same time, if want to optimize cost modeling for further research, it would be beneficial to incorporate more diverse economic variables that influence costs. This would make the analysis applicable to a wider range of transport environments. Additionally, gathering primary data through interviews with relevant stakeholders could enhance the integrity and accuracy of the findings.

Another area that requires further attention is environmental impact. The thesis lacks a comprehensive analysis of the environmental effects of the increased use of double trailers for transportation. For instance, while double trailers offer certain cost advantages, they could put more pressure on infrastructure development, particularly in terms of road maintenance due to increased wear and tear. Including an in-depth environmental impact assessment would help provide a clearer picture of the sustainability of these transport solutions.

Furthermore, the thesis draws conclusions based on the assumption of increasing port throughput. However, this does not account for unexpected changes in circumstances, such as seasonal fluctuations, economic recessions, or other unpredictable events that might lead to a significant decline in import volumes at the port. Overestimating demand could negatively impact the cost-effectiveness of double trailers or dry port operations. Conducting more in-depth sensitivity analysis on different demand scenarios would help predict the performance of these transport solutions under varying market conditions. This would create a more robust framework for decision-making when choosing between single and double trailers or when assessing the feasibility of dry port operations.

In addition to these factors, the complexity of implementing and operating double trailers also deserves consideration. While double trailers offer potential cost savings, they require highly skilled drivers, which could pose challenges in labor markets. Moreover, managing the logistics of coupling and decoupling trailers at ports can be intricate. Similarly, organizing last-mile transportation introduces additional layers of complexity. Thus, there is a need for more real-life case studies and the development of localized solutions that are adaptable to different logistical contexts. Addressing these operational challenges would help ensure the feasibility of double trailers and dry ports in practice.

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Appendix A Total transportation costs, Year 2024

Single trailer

Fixed cost	4.24 SEK/km
Variable cost	5,61 SEK/km
Distance	70 km
Operational cost	**690 SEK**
Diesel price	15,04 SEK/l
Fuel consumption per shipment	25 l
Fuel consumption cost	**376 SEK**
Total	
Cost per shipment	**1066 SEK**
Cost per loading unit	**1066 SEK**

A-double (double trailer)

Gothenburg – Viared	
Fixed cost	4.24 SEK/km
Variable cost	5,16 SEK/km
Distance	70 km
Operational cost	**690 SEK**
Diesel price	15,04 SEK/l
Fuel consumption per shipment	37 l
Fuel consumption cost	**557 SEK**
Last mile	
Viared – End customer	
Fixed cost	4.24 SEK/km
Variable cost	5,16 SEK/km
Distance	4 km
Operational cost	**37 SEK**
Diesel price	15,04 SEK/l
Fuel consumption per shipment	1,5 l
Fuel consumption cost	**23 SEK**
Number of last mile	**3**
The total last mile cost	**180 SEK**
Total	
Cost per shipment	**1427 SEK**
Cost per loading unit	**714 SEK**

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