ERASMUS UNIVERSITY ROTTERDAM

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Master Thesis Urban, Port and Transport Economics

Shifting cargo from the roads to the rail by using CargoBeamer

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1 Summary

To achieve the EU Green Deal climate goals, it is important that sectors commit to making production, transport, and other aspects, where greenhouse gases can be reduced, more sustainable. To make transport more sustainable there is a modal shift from road transport to more sustainable alternatives, such as inland shipping and rail needed. Nowadays there are new rail handling technologies, such as CargoBeamer, to make a modal shift to intermodal transport more attractive. However, it has not yet led to a real "breakthrough".

Purpose

The purpose of this modal shift is great. The highways are congested with trucks, and there is an increasing shortage of truck drivers. Furthermore, supply chains must become more sustainable. Reliable, competitive intermodal transport concepts are therefore essential, and these rail handling technologies could help encompass this.

Goals

The main objective of this study is to research new locations in Germany for the new rail handling technologies, which could increase the usage of intermodal transport in Europe. This will be done by analyzing German traffic data, which makes it clear where the greatest traffic density on the German highways is located and where a lot of road transport can therefore be moved to rail. In addition, interviews were conducted with stakeholders in the transport chain to determine which factors are important for a good transport service and a terminal location.

Research question

What are attractive locations that will have the best conditions for shifting cargo from road to rail by using an advanced inland terminal handling technology (CargoBeamer) in Germany?

Research process

Based on a literature study, a data analysis, and a number of interviews, this research has highlighted important factors for a good transport service and a terminal location and the difference between road transport, rail transport with conventional terminals, and rail transport by using CargoBeamer. In addition, to show this difference between the different transport modes there were scenarios created in which the lead time difference, cost difference and emission difference is presented. In this way it is clear what needs to be done to make the shift

to intermodal transport. In the interviews, these scenarios were presented to find out why they have not opted for intermodal transport, and what needs to change to make intermodal transport more attractive.

Results

The literature review shows that intermodal transport networks combine various modes like road, rail, sea, and air to move goods efficiently. They reduce costs, increase flexibility, and ease road congestion while promoting environmental sustainability. Coordination, integrated systems, and infrastructure investments are vital for their success. Dry ports connecting seaports with inland areas play a key role, and multiple dry ports with direct connections can enhance connectivity. Authorities can support intermodal transport through infrastructure development, legislation, price incentives, and tech innovations. Terminal handling technologies can significantly improve rail cargo volume and competitiveness. The selection of terminal locations is influenced by transportation costs, with proximity to major corridors, producers and distribution centers being beneficial.

The data analysis highlights traffic patterns and highway usage in Germany, emphasizing the significance of specific states, corridors, and highways. Autobahn 3 and Autobahn 8 are the busiest roads in Germany, both follow the Rhine-Danube corridor. Traffic is reduced on Sundays and holidays, affecting road-rail transport trade-offs. The interviews reveal companies consider the types of goods when choosing transport modes, with rail competitiveness linked to frequency, terminal location, and industry challenges. Lead time, price, and reliability are essential aspects of a transport service. Multimodal transport is favored due to less CO_2 emissions. The concluding scenario suggests Burghausen as an efficient terminal location, serving Passau, Salzburg, Munich, and potentially Nuremberg and Linz, with Kaldenkirchen serving the Ruhr area and parts of the Benelux. Collaboration among companies is crucial for efficient train service.

Recommendations

The rail handling technologies could increase the usage of intermodal transport, but then the network needs to become bigger. The EU and European governments could incentivize terminals to facilitate installing handling technologies on their terminals, so these handling technologies become more widespread in Europe. Furthermore, the transport companies could be more open-minded when choosing a transport mode to transport their goods.

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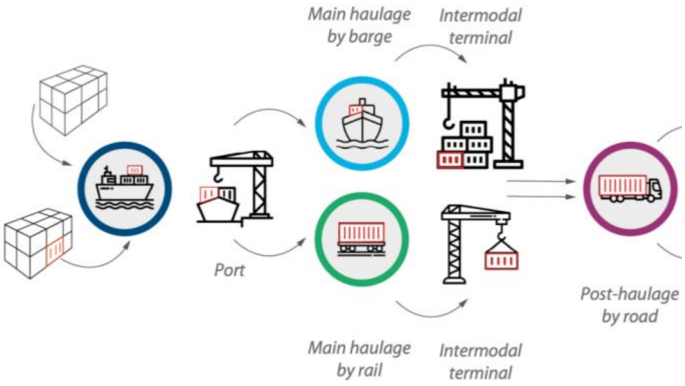
3 Introduction

Transport networks play a crucial role in connecting people, goods, and ideas across different regions and countries, enabling trade, commerce, tourism, and cultural exchange. However, transport networks face many challenges, including congestion, pollution, safety concerns, and climate change impacts, requiring innovative solutions to ensure long-term viability.

Intermodal freight transportation uses different transportation modes to move goods from the shipper to the receiver through intermodal loading units (ILUs). Marinov et al. (2014) defined the concept as follows: "*In its broadest interpretation, intermodality refers to a holistic view of transportation in which individual modes work together or within their own niches to provide the user with the best choices of service, and in which the consequences on all modes of policies for a single mode are considered.*" This complex process includes multiple actors, resources, and activities, and requires both technological and organizational capabilities. It is also dependent on other activity systems which, in Europe, is further complicated by a lack of formal systems management and shared objectives among actors. Figure 1 illustrates an intermodal journey, transporting the same cargo unit from the point of entry at the port to the ultimate destination of the goods. One specific intermodal transport approach is known as "combined transport." This method involves the transfer of goods within a single loading unit, utilizing two or more modes of transportation without physically handling the goods during the mode transitions. Combined transport typically refers to scenarios in which the primary portion of the journey occurs via rail, inland waterways, or sea, while any initial and/or final legs involving road transport are minimized in length as much as possible. Combined transport services are often provided by Combined transport operators who act as independent intermediaries or brokers between potential customer groups and railway undertakings (UIC, 2019). The CT operator usually purchase transport capacities from railway companies with volumes ranging from a wagon-by-wagon basis up to black trains for a single or multiple customer(s). The main reasons for this trend towards more vertical integration of the CT supply chain are that market players want to extend their value chain and secure and stimulate their core business, establish a direct connection to the customer, and exert more control on the services offered (UIC, 2019). In combined transport the goods are transported with one shipping document.

Figure 1

Example of an intermodal supply chain network

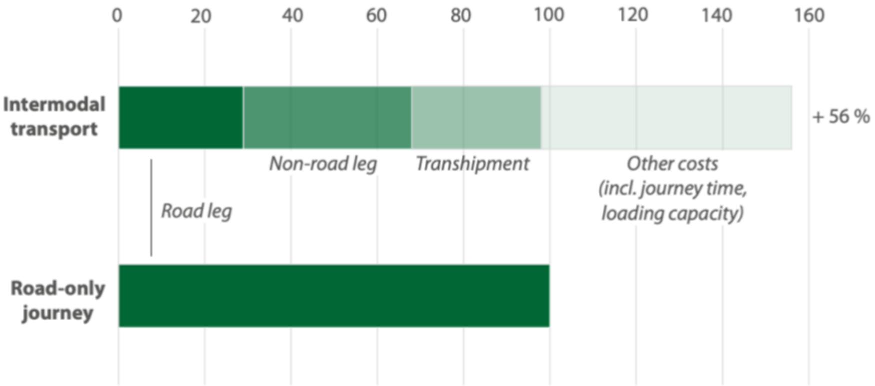


Source: ECA (2023, p. 6)

Road transportation offers the most flexibility when it comes to moving freight, offering a seamless door-to-door experience. Additionally, for numerous categories of cargo, it frequently is the fastest and most cost-effective method for delivering goods, even when covering extensive distances. According to the European Commission (2017), intermodal freight transport is typically 56% more costly than using road transport alone, without any accompanying support measures (see Figure 2).

Figure 2

Cost comparison between intermodal and truck transport

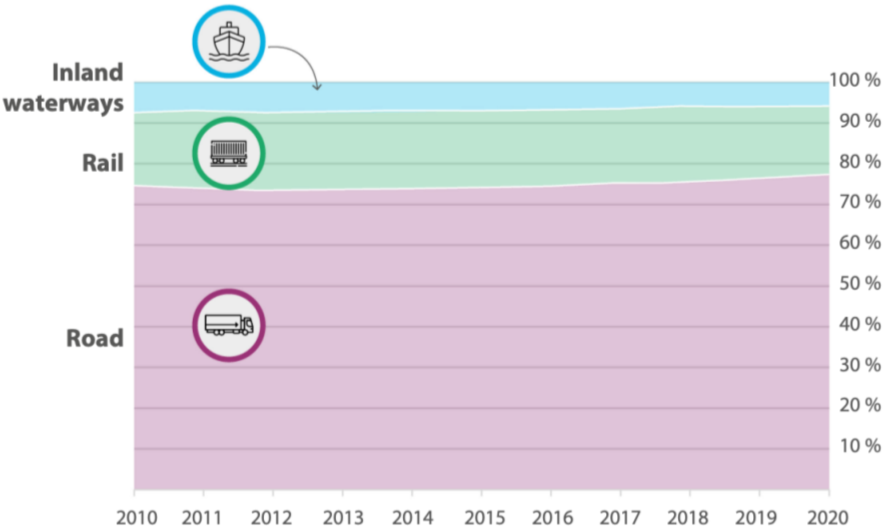


Note: the intermodal cost calculation represents a medium- to long-haul journey
Source: ECA (2023, p. 7)

Unlike road transport, alternative modes of transportation, such as rail or inland waterways, are characterized by their slower speed and lower flexibility. They depend on specific infrastructure that is not universally available at every shipping location. However, they come with the advantage of improved safety and environmental performance and can alleviate the burden on congested road networks. The concept of intermodality involves leveraging the strengths of various transportation modes to optimize freight movement. This concept originated from the maritime industry with the invention of the container in the 1960s and has since been adopted by other modes of transport (Marinov et al., 2014).

Figure 3

Modal split of EU inland transport (% of total ton-kilometers)



Source: ECA (2023, p. 8)

Table 1

Types of intermodal terminals and load units handled

Intermodal terminals	**Load units used**
Sea-rail combined terminals	Maritime containers
Road-rail combined terminals	Swap bodies or semitrailers

In the Table 1 above are the different types of intermodal transport presented, as well as the load units that are used in each type. European intermodal road-rail freight transport (EIT) is considered a potential solution to the challenges associated with road freight transportation and the financial difficulties encountered by national railway freight operations. Intermodal transport combines the efficiency of rail transport on longer distances with the flexibility of trucks on shorter distances, making it an attractive option from an economic perspective (Nelldal, 2014). For instance, the European Commission estimates that external effects from road transport in the EU cost €250 billion per year, with congestion accounting for half of that cost. In the Netherlands, it is reported that 10% of truck operating time is spent in congested conditions (Van Schijndel and Dinwoodie, 2000). Despite being supported and promoted by a variety of political instruments, EIT still faces an uneven playing field in competition with road transport. The industry has become disillusioned due to unfulfilled political promises, although initiatives such as the Marco Polo Programme, the German road toll (the LKW Maut), and the French subsidy to forwarders using EIT hold promise.

Various policy measures have been implemented to encourage a shift from road-only to intermodal transport (Meers & Macharis, 2015). Intermodal and multimodal transport infrastructures are expected to play vital roles in transportation systems in the 21st century, particularly due to sustainable mobility policies and growing demand for freight transport alternatives. Despite the growth of all European intermodal transport forms over the last decade (Bottani & Rizzi, 2007), the market share of rail transport and inland waterways remains limited (16.8% and 5.8%, respectively) in Europe (Eurostat, 2022b). However, creating a European intermodal transport network is a top priority of the European Community, as intermodality contributes to the European strategy for energy security and the use of less energy-consuming transport modes. Currently, the transport sector accounts for almost a quarter of greenhouse gas emissions in Europe, with road transport responsible for 72% of these emissions (European Commission, 2021). These emissions are considered a major cause of climate change. A modal shift away from roads and towards intermodal transport can make freight transport in Europe more environmentally friendly. In its 2011 White Paper, the European Commission set a target for reducing greenhouse gas emissions from the transport sector by 60% by 2050 compared to 1990 levels. However, contrary to other sectors, CO_2 emissions from transport increased by 24% between 1990 and 2019 (European Environment Agency, 2022b), with freight transport demand outpacing efficiency gains in heavy-duty vehicle transport. In 2019, the Commission called for an even greater reduction in transport-related greenhouse gas emissions (90% by 2050) in its strategic document tackling climate and environmental challenges (European Commission, 2019). The Commission's 2020 Sustainable and Smart Mobility Strategy further called for a significant shift towards rail, inland waterways, or short-sea shipping. As such, significant efforts must be made to properly design intermodal terminals, including the physical infrastructure and related equipment (such as rail, cranes, handling trucks, and information technology) where the transshipment of intermodal transport units between modes occurs (Bottani & Rizzi, 2007).

Furthermore, Europe is experiencing a growing shortage of truck drivers, which is expected to worsen as time passes. In 2021, 10% of truck driver positions remained vacant, affecting the timely delivery of essential goods. The transport sector has been struggling with this issue for the past 15 years, and it is predicted that nearly 30% of current transport employees, who are above 50 years of age, will retire within the next 10 to 15 years (Boer et al., 2018). The road transport industry has not been as successful as other sectors in attracting younger workers, partly due to the industry's unappealing image for employment. Additionally, new regulations require trucks to return to their home base at least every eight weeks, which could lead to more emissions since the trucks will have to travel across the continent every eight weeks (Cokelaere, 2022).

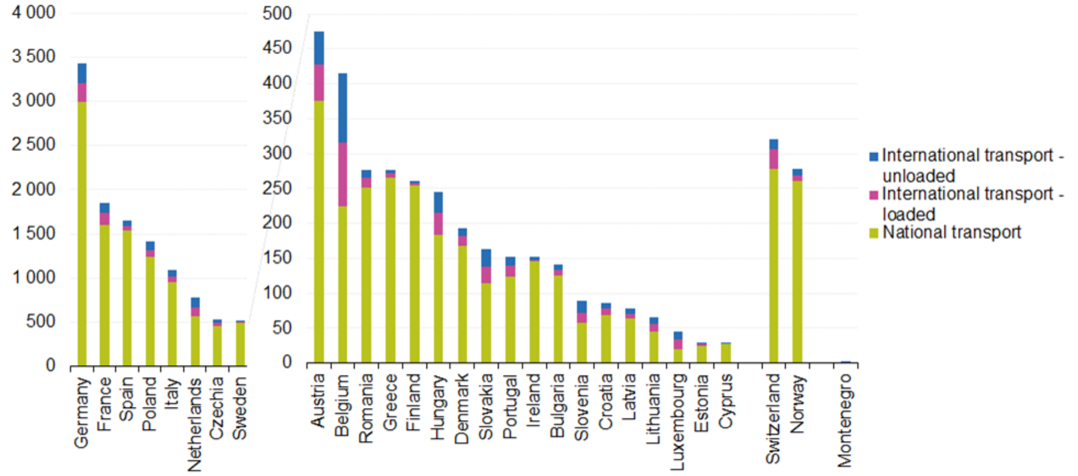
While inland shipping and rail transport may not be as equipped as road transport in meeting the demands of modern logistics, such as fast door-to-door transport and efficient cargo handling with minimal transshipment costs, there has been a prevailing notion that these modes of transportation are becoming outdated and will eventually fade away. However, this decline in the usage of inland shipping and rail transport has not been the case over the past two decades, and in fact, there has been a resurgence in interest in rail transport, partially due to the emergence of the New Silk Road connecting China and Europe.

Intermodal transport has already increased in absolute numbers, but the real breakthrough has yet to come. The modal split has not changed in favor of intermodal transport, so what needs to be done to reach this 'breakthrough'. To stimulate intermodality, and specifically transport by train, there have been developed new handling technologies for semi-trailers in the last decade. These handling technologies result in faster loading and unloading of the trains. The technology considered in this thesis is CargoBeamer. More than 60% of all trucks on the European motorways drive with semi-trailers. 98% of these semi-trailers cannot be loaded onto the railway for purely technical reasons. The new handling technologies can load all existing semi-trailers onto the train (Allianz pro Science e.V., 2010). This is a real opportunity in terms of transport policy to relieve the burden on the roads and the environment in Europe. The CargoBeamer technology is one of these technologies, there are more of these rail handling technologies, such as RoadrailLink from VEGA, Modalohr, Flexiwaggon and Megaswing.

The primary focus of this thesis is on intermodal transportation in Germany, a critical country in the freight transport network within Europe. Germany is strategically positioned as it is part of 5 out of the 9 major transport corridors in Europe, namely, the Rhine Alpine, North Sea-Baltic, Orient-East Mediterranean, Scandinavian-Mediterranean, and Rhine Danube corridors (European Commission, n.d.). Eurostat (2022a) reported that goods transported within Germany (national transport) or loaded/unloaded in Germany (international transport) accounted for approximately one-quarter (23.8%) of total tonnage transported within the EU. In 2021, Germany recorded the highest tonnage of goods transported by road within the EU. In terms of rail transport, Germany possesses the longest rail network in Europe, spanning 41,000 kilometers (Railway Technology, 2014). Additionally, Germany has connections to all wind directions of Europe (see Figure 5 below).

Figure 4

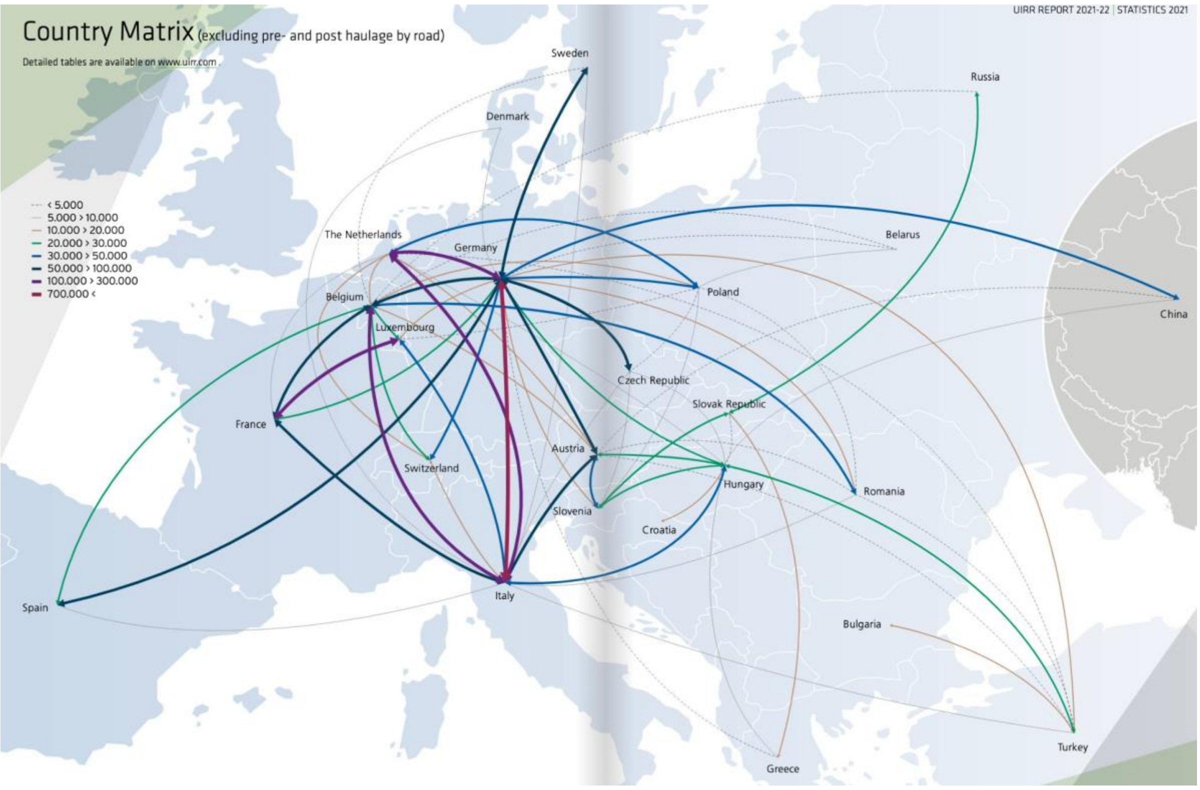
Transport of goods on country territory 2021 (million tonnes)



Source: Eurostat (2022a)

Figure 5

Combined transport network Europe



Source: UIRR (2021)

This research is interesting for the shipping and trucking companies, the EU commission and governments in Europe, and the companies of the new handling technologies. One of the European action plans to increase intermodality was the Marco Polo program between 2007 and 2013. The Marco Polo programmes aimed to relieve congestion on road networks and improve the environmental performance of Europe's freight transport system by providing financial assistance to use alternative methods of transport with lower environmental impacts, in particular railways, inland waterways, and short sea shipping. It is also interesting for transport operators that offer other modes of transportation. As these locations maybe become large cargo hubs where also other transport modes will be available, to switch from road to rail or from inland waterway to rail. And, for handling technology companies because they can use the research to start a plan to place their technology in those potential locations in Germany.

The research is mainly for practical applications, to stimulate the use of rail transport in Europe by researching potential new locations for more efficient handling of rail cargo and thereby reducing the lead time in Germany. There is also scientific relevance, at this moment the focus of hinterland research is mainly on the connectivity of a seaport with the hinterland. In this research, the focus is on the hinterland only and the connectivity within the hinterland. And lastly, the research has policy relevance. The European Union spends billions on corridor development and stimulating intermodal transport. With this research, hopefully, the handling technologies will extend their services to new places which may result in more intermodal transport.

This thesis aims at answering the research question: What are attractive locations that will have the best conditions for shifting cargo from road to rail by using an advanced inland terminal handling technology (CargoBeamer) in Germany? For this, you also need to answer the question of what makes a location attractive and what are the wishes of companies regarding a transport service. To answer these questions, an analysis of the truck movements in Germany is done. Furthermore, there are interviews executed with stakeholders of a transport chain. In these interviews, the main objective is to be able to look into the mind of a company with regard to a good transport service. What makes companies choose a particular transport mode or service? With these information sources, scenarios are constructed for transport by train and truck on a particular route. This study consists of 8 chapters. In Chapter 4, the current literature about intermodal transport and modal choice is reviewed and the rail handling technologies are explained. In Chapter 5, the methodology is described and there is a description of the data. In

Chapter 6, the results obtained from analyzing the data and the interviews are discussed. Finally, the results are discussed in Chapter 7 and summarized in the conclusion section, Chapter 8.

4 Literature review

An intermodal transport network refers to a system that involves the use of multiple modes of transportation to move goods or people from one point to another. This can include a combination of modes such as road, rail, sea, and air transportation, with the aim of leveraging the advantages of each mode to create a more efficient and cost-effective transport system. The benefits of intermodal transport networks include reduced transportation costs, increased flexibility, improved environmental sustainability, and reduced congestion on roads.

4.1 Intermodal transport networks

Intermodal transport networks require careful planning, coordination, and management to ensure that the different modes of transportation work together efficiently. This includes developing integrated transport systems that allow for seamless transfers between different modes, as well as investing in infrastructure such as terminals, hubs, and logistics centers to facilitate the movement of goods.

In the past 25 years, there has been a notable increase in business activity and policymaking concerning the hinterland transport of vehicles and unit loads that are cross-docked in ports. The concept of a *Dry port* was first introduced by the UN in 1982, highlighting the integration of services involving different modes of transportation under a single contract (Beresford and Dubey, 1990). Extensive research has been conducted on hinterland transport, with studies such as Notteboom and Rodrigue (2005), Rodrigue (2008), IBI Group (2006), Beavis et al. (2007), Woodburn (2006 and 2007), Gouvernal and Daydou (2005), van Klink and van den Berg (1998), Bundesamt für Güterverkehr (2005), Bergqvist et al. (2010), and Roso (2006) providing valuable insights. However, it is worth noting that these publications primarily focus on the container segment, often overlooking the significance of semi-trailers.

Dry ports, as highlighted by Roso et al. (2009), play a crucial role in enhancing the connectivity between a port and its hinterland. They facilitate operational linkages between the port and inland sites, as emphasized by Veenstra et al. (2012), Monios (2011), and Monios & Wang (2013). Unlike a competitive approach, dry ports foster partnerships between different stakeholders (Frémont & Franc, 2010). Moreover, their positive impact extends beyond immediate surroundings and can influence a larger and sometimes geographically fragmented area (Rodrigue & Notteboom, 2009). It is important to note that this system of interconnectivity is not limited to a single port-dry port dyad; it can be polycentric, involving multiple dry ports with direct port-to-port connections. According to Klink and van den Berg (1998) and McCalla (1999) promoting intermodal transport serves as a strategic approach for seaports to maintain their market share in the evolving European market and expand their hinterland to new regions. Encouraging intermodalism from gateways has the potential to enhance the overall efficiency of the transport system.

Robinson (2002) also emphasized the need for interlinkages and subsystems by describing the transformation of the role of ports from a monopoly to a dynamic component of the logistics chain. Wilmsmeier et al. (2011) differentiate between two development approaches: Inside-Out and Outside-In. Inside-Out development occurs when an inland facility is driven by an inland carriage company (e.g., railroad, barge, logistics service provider) or a public entity. Conversely, an Outside-In arrangement is initiated by port authorities, port terminal operators, or ocean carriers. The researchers found that the direction of development, whether Inside-Out or Outside-In, largely depends on proactive policies enacted by the public or private sector. The academic discourse predominantly adopts an Outside-In perspective, with seaports typically seen as the "leaders" and inland ports as the "followers", accommodating the needs and preferences of seaports. There are limited studies that explore the Inside-Out perspective, where the inland port assumes the leading role, with the seaport acting as the follower (Bask et al., 2014; Monios & Bergqvist, 2015).

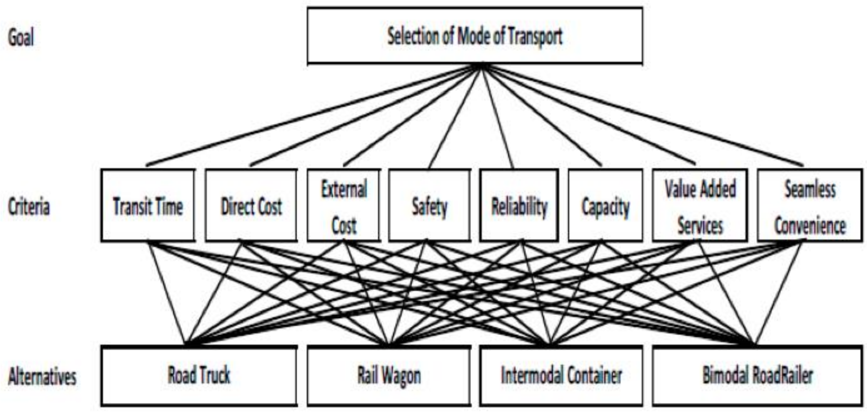
Intermodal freight transport, which utilizes alternative modes such as rail and inland waterways for the majority of the transportation journey while utilizing trucks for pre- and/or post-haulage, has been advocated by policymakers and scholars due to its perceived lower societal impact (Macharis et al., 2010). Encouraging the shift of freight from road transport to these alternative modes has been a policy goal of the European Commission in recent decades. Public authorities have various policy instruments at their disposal to promote the use of intermodal freight transport. As infrastructure providers, authorities can focus on developing an extensive and accessible infrastructure network, enabling more potential users to access intermodal transport chains. Legislative measures can facilitate seamless transport chains, while price incentives such as subsidies or internalization of external transport costs can increase the attractiveness of intermodal transport (Jensen, 2008; Macharis et al., 2010). Investments in technology and innovation can also contribute to a long-term increase in the modal share of intermodal transport.

Stoilova and Martinov (2022) evaluated semi-trailer rail transport technologies and identified the key criteria influencing their effectiveness. The study revealed that economic criteria, including investment costs, transshipment infrastructure costs, and wagon costs, accounted for 50% of the overall impact. Technological criteria, such as transshipment process handling time, parallel loading and unloading capabilities, operational restrictions, staffing requirements, transportation of other loading units, and the number or locations of operation lines, had a significant impact of 45%. In contrast, technical criteria, including maximum load capacity, wagon tare weight, maximum length, tare weight per load unit, area per module, and load limit per wagon, had a minimal impact of 5%.

Meers and Macharis (2015) identified different tools that can be employed in the preparatory phase to assess the potential for a modal shift in a region and identify the most suitable transport flows for such a shift. These measures collectively aim to promote and enhance the utilization of intermodal freight transport as a sustainable transportation solution. The modal shift potential is determined by transport price, post-haulage transport time, product type characteristics, and transport volumes. Scientific literature has extensively covered the topic of modal choice, as well as related areas such as route choice and carrier selection. Shippers employ various criteria to evaluate and determine the most suitable transport mode for their specific circumstances and cargo (see Figure 6 below) (Boer et al., 2018).

Figure 6

Model for selection of freight transport mode using criteria



Source: Vashist & Dey (2016)

According to Patterson et al. (2007), the decision-making process regarding the use of intermodal services is primarily influenced by shippers, who are considered the principal decision-makers in determining the demand for such services. Factors influencing modal choice can be categorized into shipper and shipment attributes, geographic and time characteristics, and carrier attributes, as identified by Dionori et al. (2015). Shipper attributes include firm size, accessibility to rail networks, and experience with different transport modes. Shipment attributes encompass factors such as the type of goods, density, value, perishability, and packaging. Carrier attributes and modal characteristics include total shipment costs, delivery time, infrastructure capacity, service reliability, safety, flexibility, frequency, availability of special equipment, customer service quality, handling operations, and environmental sustainability. Distance and flow rate also impacts the modal choice, with road transport often preferred for distances under 200 km due to cost and feasibility advantages, while rail transport faces limitations in terms of flexibility and competitiveness (Dionori et al., 2015). Shippers engage in an optimization process, considering the attributes of each transport option to select the most suitable carrier. Ultimately, the modal choice involves a trade-off and matching of various attributes.

CE Delft (2018) observe the same distance of 200 km for rail transport to become superior to road transport in terms of costs and feasibility for a wide range of commodities. However, the tipping point where rail transport becomes more competitive is around 300 km. Road transport offers advantages such as flexibility, speed, transparency, simplicity, and seamless border crossings, making it a challenging mode to compete with, particularly for short distances (Boer et al., 2018). According to Klink and van den Berg (1998), achieving the cost efficiency of road haulage in intermodal transport is contingent upon handling large volumes over relatively long distances. In such cases, it becomes feasible to develop an efficient transport system that can effectively compete with trucks. They found that intermodal transport becomes particularly appealing when distances exceed 500 kilometers, allowing for the recovery of additional handling costs and minimizing costs per kilometer. Moreover, a high transport volume enables the provision of frequent and attractive transport services.

Elbert and Seikowsky (2017) identified facilitators and barriers to the modal shift from road transport to intermodal road-rail transport across different categories. In the category of economics, barriers and facilitators are related to pricing and costs, including both transportation costs and factors such as shipment size and cargo properties. The quality category involves transport reliability, frequency, damage and loss, transit time, and flexibility. Infrastructure-related barriers and facilitators pertain to the physical requirements for intermodal road-rail transport, including terminal and rail infrastructures, as well as transshipment technologies. The management category is associated with managerial aspects of implementing intermodal road-rail transport, such as the availability of information and the willingness of decision-makers to shift modes. The facilitators and barriers in the policy category are related to political initiatives, with adjustments to regulations and funding guidelines influencing the decision to change transport modes. Lastly, in the sustainability category, facilitators and barriers primarily revolve around environmental considerations.

Inland terminals play a vital role in the overall transportation process by facilitating the crucial function of connecting ports with their hinterlands. This connection brings significant benefits to all stakeholders involved in the transportation chain. For an inland terminal to be classified as such, it must meet specific criteria outlined by FDT (2007). These criteria include:

- Establishing direct road, rail, and/or river connections with the associated port(s).
- Being located along a transport corridor with substantial capacity or positioned strategically on such a corridor.
- Being equipped with appropriate infrastructure and machinery that are compatible with the reference ports.
- Serving as a hub for collection and distribution activities at the local and regional levels.

Wilmsmeier et al. (2011) observed a trend in the literature emphasizing the use of inland terminals to expand the hinterland of seaports. This concept, originally proposed by van Klink and van den Berg (1998), involves integrating logistics services into the transport chain due to the growing significance of inland costs (both transportation and value-added services) in the overall door-to-door expenses (Notteboom and Winklemans, 2001). Notteboom and Rodrigue (2005) highlighted that inland costs could account for 40% to 80% of total container shipping costs, prompting shipping lines to view inland logistics as a crucial area for cost reduction.

4.2 Systems for transportation of semitrailers

Intermodal transportation can be categorized into two main types: accompanied and unaccompanied. Accompanied intermodal transportation involves transporting complete road vehicles, including the vehicles themselves and their drivers. Examples of accompanied systems include RO-LA (Rollende Landstrasse), LeShuttle-Freight (operated in Eurotunnel), and ferries. On the other hand, unaccompanied intermodal transportation focuses on transporting only intermodal loading units (ILUs) such as containers, swap bodies, and semi-trailers. In unaccompanied intermodal transport, three types of semi-trailers are commonly used: standard (non-craneable), intermodal (craneable), and bimodal. This thesis specifically focuses on unaccompanied intermodal transport, as it constitutes approximately 80% of the overall routings (UIRR, n.d.). There are two main principles of handling semi-trailers: horizontal and vertical. Horizontal systems, also known as Ro-Ro (Roll-on/Roll-off), allow for the transloading of any type of semitrailer, which offers significant benefits. Vertical systems, known as Lo-Lo (Lift-on/Lift-off), require either intermodal semi-trailers or specially designed transshipment systems for standard semi-trailers (Cempírek et al., 2020). In Europe, over 60% of trucks on motorways are equipped with semi-trailers. However, 98% of these semi-trailers cannot be loaded onto railways due to technical limitations (Allianz pro Science e.V., 2010). Therefore, this thesis focuses on the horizontal loading of trailers, aiming to address this challenge in intermodal transportation.

4.2.1 CargoBeamer

The CargoBeamer system offers efficient transshipment of semi-trailers between trains, particularly beneficial in terminals where different rail gauges intersect, such as at the France-Spain border or the Slovakia-Ukraine border. The complete transloading process between two trains takes approximately one hour, significantly shorter than the standard practice of 2-3 days for vertical transshipment. By eliminating this competitive disadvantage, the CargoBeamer system enhances rail transport compared to road transport (CargoBeamer AG, 2016).

Ideally, the CargoBeamer system is implemented in its horizontal transshipment form, where the detachable central part of a wagon, known as the loading platform or "pallet", is positioned radially next to the wagon. A tractor or terminal tractor pulls the semi-trailer onto the platform, which is then moved back onto the wagon (see Figure 7). The entire loading process for the entire train typically takes 15-20 minutes (CargoBeamer AG, n.d.). If necessary, vertical transshipment of semi-trailers is also possible, albeit less preferred due to the availability of specialized transloading equipment in the terminal.

The CargoBeamer project began in 1998, with a pilot project in Leipzig (Germany), where a terminal for three CargoBeamer wagons was constructed. Initial tests of the system were conducted on the route between Spain and Germany, primarily transporting semi-trailers with cargo for the automotive industry, including Volkswagen AG. Since 2015, the Kaldenkirchen (Germany) to Domodossola (Italy) line has been operational, having moved over 70,000 semi-trailers from road to rail (CargoBeamer AG, 2020). Additionally, on July 10, 2021, the Calais (France) terminal commenced operations, enabling fully automated unloading, and loading of trains with up to 36 semi-trailers within 20 minutes, while this normally takes 3-4 hours at a conventional crane terminal. From Calais, routes to Great Britain are available via Eurotunnel and ferries.

CargoBeamer routes:

- Domodossola (Italy) – Kaldenkirchen (Germany)
- Domodossola (Italy) – Calais (France)/Ashford (UK)
- Perpignan (France) – Calais (France)/Ashford (UK)
- Perpignan (France) – Kaldenkirchen (Germany)
- Rostock (Germany) – Kaldenkirchen (Germany)

Figure 7

The CargoBeamer technology

Source: Zasiadko (2022)

4.2.2 Modalohr

Modalohr is a transportation system developed in France that can transport either semi-trailers or semi-trailer-combinations, including drivers traveling in a couchette wagon coupled in a train. It has been in operation since 2003 and is used in both unaccompanied and accompanied intermodal transportation, with a primary focus on the unaccompanied version.

The core component of Modalohr wagons is a rotary loading deck, which can rotate approximately 45 degrees to the side. This rotation is facilitated by electric motors installed in the railway track at a terminal. The loading process involves pulling a semitrailer onto a wagon using a tractor or terminal tractor, which is then decoupled from the wagon. Subsequently, the central part of the wagon is turned back to its driving position (see Figure 8). This individual loading capability allows for the simultaneous loading of all wagons in a train. One of the major advantages of the Modalohr system is its exceptionally short transloading time, with the ability to load an entire train with semitrailers in approximately 30-40 minutes (Lohr Railway system, 2017) (LOHR, n.d.). This efficient and timesaving loading process is made possible by the innovative design and operation of Modalohr, as developed by the Lohr Railway system. The system has gained recognition and is widely implemented in the transportation industry. Stoilova and Martinov (2022) concluded, based on their findings that the Modalohr horizontal technology is the best variant of semi-trailer rail transport technologies.

Currently, these are the routes of the Modalohr system (VIIA, n.d.):

- Aiton (France) – Orbassano (Italy),
- Bettembourg (Luxembourg) – Le Boulou (France),
- Calais (France) – Le Boulou (France),
- Calais (France) – Orbassano (Italuy),
- Séte (France) – Paris (France) – Zeebrugge (Belgium),
- Barcelona (Spain) – Bettembourg (Luxembourg),
- Macon (France) – Calais (France),
- Macon (France) – Le Boulou (France).

On the route Barcelona – Bettembourg, it is estimated to save over 22,000 trucks/per year on the road, representing a reduction in CO_2 emissions of 23,070 tons per year (Todd, 2019).

The carrier, Modalohr, offers several advantages (Modalohr, 2003):

- Horizontal loading of trucks: The trucks can be loaded horizontally directly with the road tractor, eliminating the need for additional handling equipment.
- Simultaneous and fast transshipment: The lateral loading of trucks in a herringbone pattern enables efficient transshipment, with the entire train being loaded in less than 30 minutes.

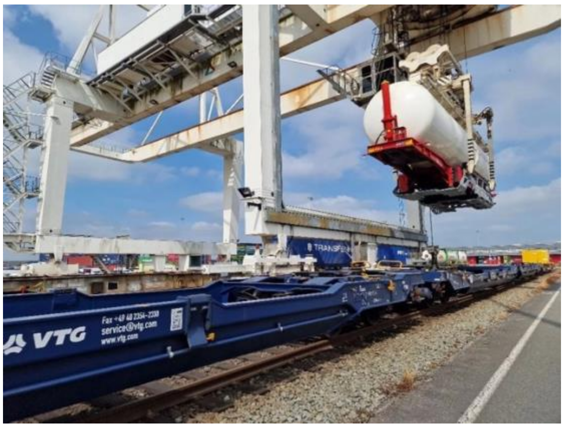
- Low floor design: Modalohr features a very low floor, allowing trucks up to 4 meters high to be loaded on existing gauges, providing greater flexibility, and accommodating taller vehicles.

Figure 8
The Modalohr technology

Source: Modalohr (2003)

4.2.3 RoadrailLink (r2l)

The r2l technology, a joint development by VTG and VEGA International, represents an innovative solution for transshipment and transport. It economically enables the lifting of various types of non-craneable semi-trailers onto rail freight wagons. This achievement is made possible through a fully galvanized r2L solution: a platform or ramp that terminal cranes and reach stackers can vertically lift onto and off double pocket wagons (see Figure 9). This process takes less than 5 minutes to load a trailer onto the train. For the whole train this process takes 180 minutes. Primarily, this technology is designed for the vertical handling and transportation of vehicles (VTG, n.d.).

Figure 9
RoadrailLink technology


Source: Raimondi (2023)

4.2.4 Flexiwaggon

Flexiwaggon introduces innovative solutions for intermodal freight transportation across railways and roads. This system enables the transportation of a wide range of vehicles, including lorries, buses, cars, and containers, all on the same wagon. Additionally, Flexiwaggon allows for individual loading and unloading of wagons, providing flexibility and convenience. When a train stops, the loading and unloading of Flexiwaggon can occur at nearly any location, provided that the railway is surrounded by a stable base capable of supporting the vehicle's weight (Flexiwaggon, n.d.). The process is driver-operated, allowing the driver to load or unload their own truck (see Figure 10). This loading and unloading process occurs horizontally, eliminating the need to consider overhead contact lines. Loading or unloading an entire train set using Flexiwaggon takes only 7 minutes, and there is no need for the vehicle to be reversed when driving on or off the wagon (Flexiwaggon, n.d.). For the whole train this takes 10-15 minutes. It is important to note that Flexiwaggon is not yet in operational use.

Figure 10

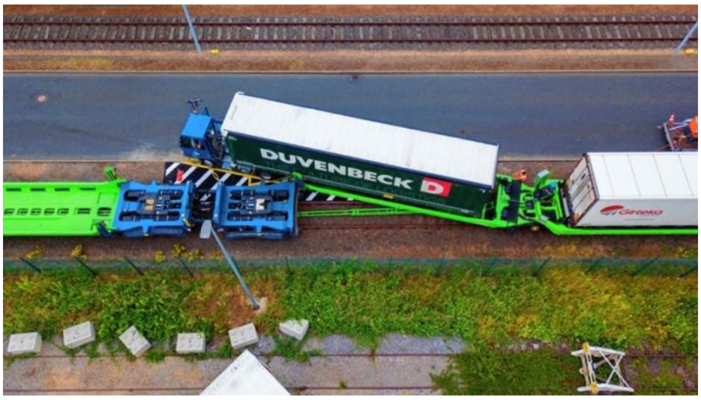
Flexiwaggon technology

Source: Flexiwaggon AB (2019)

4.2.5 Megaswing

The Megaswing wagons were originally developed by Kockums Industries in Sweden during the early 2000s. However, despite their innovative design, these wagons did not see widespread adoption by operators. The loading and unloading process for Megaswing wagons does not necessitate additional infrastructure such as a loading ramp. Instead, it requires a substantial paved surface and a generator. To load a vehicle onto the wagon, hydraulic supports are initially lowered to ensure stability. Then, the base of the wagon can be swung to the left or right. The semi-trailer is subsequently backed onto the platform, which is then swiveled back onto the wagon and slightly lowered to securely lock it in place. After this, the supports are raised, and the entire operation typically takes around 30 minutes (Burroughs, 2020) (see Figure 11).

Figure 11
Megaswing technology



Source: Swiss Life Asset Managers (2023)

4.3 The effect of the terminal handling technologies

The terminal plays a crucial role in the intermodal transportation system as it facilitates the smooth and secure transfer of cargo between different modes of transportation, including road, rail, inland waterway, and short sea shipping, including ferries (AGORA, n.d.). The analysis reveals that terminal costs make up around 40% of the total expenses in a typical intermodal transportation chain, with truck feeder transportation accounting for 30% and long-haul rail transport for approximately 30% (Nelldal, 2014). Therefore, improving terminal efficiency is of utmost importance. Maintaining low terminal costs is critical for enhancing the competitiveness of intermodal traffic.

An intermodal terminal can serve various functions beyond intermodal exchange, and it may not even be the primary function. The essential requirement for a freight terminal to qualify as an intermodal terminal is having the necessary space and equipment to receive cargo via one mode of transportation and ship it out using a different mode. During the transition between inbound and outbound movement, the cargo can be consolidated with other similar incoming cargo, divided into smaller shipments for outbound transport, or directly transferred between modes as part of a seamless intermodal shipment (Marinov et al., 2014). In a research project conducted at KTH, the focus was on analyzing the feasibility of implementing a rail-based intermodal transport system in the Stockholm-Mälaren region. Through a case study involving a shipper distributing daily consumables in the region, the potential for establishing a regional rail freight transport system was assessed. The findings emphasized the importance of efficient terminal techniques and high system utilization rates for the successful implementation of such a system (Kordnejad, 2013).

The effect of these terminal handling technologies on the number of rail cargo handled in Europe can be significant, as it offers several benefits that can make rail transport more attractive to shippers who may have previously relied solely on road transport. Firstly, the technologies offer significant time and cost savings in transshipment and terminal handling processes. These innovative solutions eliminate the need for specialized equipment like cranes, enabling efficient loading of semi-trailers and swap bodies onto rail wagons. This swift loading capability is particularly beneficial for time-sensitive goods, including perishable items like fresh food, market-value-sensitive goods such as fashion and computer components, as well as urgent deliveries like Covid masks and replacement parts. Typically, these goods are transported via faster modes like aviation and road transport. Rail and sea transport are generally slower and often used for less time-sensitive goods. Intermodal transport, on the other hand, can face challenges in competitiveness for shorter distances due to longer transit times compared to road transport. Investments in infrastructure and intermodal capacity can help bridge this attractiveness gap and improve the efficiency of intermodal transportation (OECD/ITF, 2022). Secondly, the technologies can help to reduce congestion and emissions associated with road transport. By enabling more efficient and sustainable intermodal transport, the technology can reduce the number of trucks on the road, and lower emissions associated with road transport. Overall, the terminal handling technologies can make rail transport more efficient, reliable, and sustainable, which can make it a more attractive option for shippers looking to transport cargo across Europe. As such, it has the potential to increase the number of rail cargo handled in Europe, particularly for semi-trailers and swap bodies.

4.4 Location attractiveness for the semitrailer handling technologies

To make the technologies fully operational in all corridors in Germany, the following assumptions are made to know how many terminals there need to be:

- It was assumed that at least two terminals per corridor per technology should be present. This requirement is the minimum condition to make each technology fully operational in all TEN-T Core Network Corridors. According to this requirement, it is therefore foreseen that in corridors that are not yet equipped with a specific technology, a minimum of two dedicated terminals are built at the beginning and at the end of the corridor (European Commission, 2022).
- It was furthermore assumed that per each technology a terminal should be available every 850km of corridor. A typical door-to-door intermodal chain is 1000 km long,

which can be further split into one leg of 850 km by train and two last mile legs by road of 75 km each (European Commission, 2022).

Based on these assumptions, Table 2 below provides the minimum number of terminals per technology that each TEN-T corridor should have. Overall, a minimum of 68 terminals per technology are required (European Commission, 2022).

Table 2

Minimum number of terminals required per rail handling technology and per corridor

TEN-T Corridor	Length of the network [km]	Minimum number of terminals per technology
Atlantic	5 762	8
Baltic-Adriatic	4 212	6
Mediterranean	7 858	10
North Sea-Baltic	4 871	7
North Sea-Mediterranean	4 461	6
Orient/East-Med	5 636	8
Rhine-Alpine	3 258	5
Rhine-Danube	5 505	7
Scandinavian-Mediterranean	8 756	11
Total	**-**	**68**

Source: European Commission (2022, p. 136)

Now that we know there need to be more terminals for each technology so they can be fully operational. We need to assess what new potential locations are for these technologies. To answer the question of what attractive locations are in Germany for these handling technologies, the question of what makes a location attractive for the handling technologies needs to be answered.

In the development of dry ports in emerging economies, one critical concern is the selection of an appropriate location. While minimizing setup and overall logistics costs is a fundamental aspect of dry port location analysis, there are also qualitative factors influenced by various stakeholders, including operators, users, and the local community (Notteboom and Rodrigue, 2009; Nguyen and Notteboom, 2016). Typically, dry ports are strategically positioned along well-established transportation corridors (Panova and Hilmola, 2015). The process of planning the location of a dry port necessitates careful decision-making, as relocating such a facility in the short-term can be prohibitively costly. Many location models for facilities assign significant importance to transportation costs when seeking the optimal site (Nguyen and Notteboom, 2016). These dry ports are commonly situated in strategic proximity to gateway seaports, industrial zones, or major transportation routes, serving crucial roles in optimizing logistics operations to ensure efficient cargo movement from one point to another (Juhel, 1999).

Inland terminals are typically situated in proximity to a port facility, often within the outskirts of its metropolitan area, typically less than 100 kilometers away (Notteboom et al., 2022). Their primary role is to provide service functions for the seaport, accommodating additional traffic and services that may be too costly at the port itself. These functions can include warehousing, empty container depots, or services that are less dependent on proximity to a deep-sea quay. In some cases, inland terminals primarily serve as transportation hubs, facilitating the transshipment of cargo between rail/barge and trucks (Notteboom et al., 2022). Inland terminals can also function as distribution hubs for local or regional markets, particularly in areas with high economic density. They form part of a multi-terminal cluster connected to the main port via regular rail or barge shuttle services. In gateways where imports are higher, inland terminals can play a significant role in transloading, where the contents of maritime containers are transferred into domestic containers or truckloads. Furthermore, inland terminals serve as significant load centers and key intermodal facilities that provide access to specific regional markets encompassing both production and consumption functions. These terminals are typically located within metropolitan areas and are characterized by their ability to simultaneously fulfill intermodal, warehousing, distribution, and logistics functions. Often, these activities are situated within logistics parks and free trade zones (Notteboom et al., 2022). Essentially, the inland terminal serves as a focal point for the collection and distribution of goods within a defined regional market. The importance of the load center is closely tied to the size and diversity of the market it serves. When strategically positioned, such as along a major rail corridor, these load centers facilitate freight distribution activities that cater to a broader and more varied market. And lastly, inland terminals play a crucial role in connecting extensive freight circulation systems, either within the same mode (such as rail-to-rail) or by employing intermodal approaches (like rail-to-truck or rail-to-barge). In instances of the latter, the inland terminal takes on the role of a load center. Here, the freight being handled originates from or is destined for locations beyond the terminal's immediate market area, related to the function of transshipment hubs in maritime shipping networks. These transshipment terminals are typically located in proximity to national borders, seamlessly integrating administrative procedures related to cross-border traffic with value-added logistics activities (Notteboom et al., 2022). While this function remains relatively limited in most regions, ongoing advancements in inland freight distribution, marked by the expansion and diversification of intermodal services, suggest that transshipment services are ready to gain greater prominence.

In OECD/ITF (2022) they say sufficient demand and usage are crucial for handling technologies to be effective. This requires significant interest from freight forwarders and logistics companies in utilizing the service within a well-utilized corridor. Reliability is paramount for shippers employing just-in-time supply chain strategies, as transport delays can disrupt production and sales processes. Unreliable transport necessitates increased buffer inventory capacity, leading to higher inventory costs. This issue becomes more pronounced when service frequency is limited, as the costs of unreliable transport are magnified. Shippers prioritize service frequency as it enables them to mitigate or recover from transport delays (Jansen & Kuipers, 2022). Services associated with transport infrastructure play a critical role in efficient transport networks, attracting more services due to increased connectivity, particularly in hub-and-spoke transport networks. Terminal infrastructures offering value-added services such as storage, refueling, recharging, repairs, and transport service providers are equally important (OECD/ITF, 2022). Moreover, the quality of infrastructure networks relies on the seamless integration of modal and terminal infrastructures. The potential for mode shift depends largely on the level of connectivity between terminals and modal infrastructure (OECD/ITF, 2022). Ports lacking on-dock railway connections or barge terminals face greater challenges in shifting cargo from trucks to trains or barges compared to ports with such connections. Consequently, a terminal that facilitates connections among inland waterway, rail, and truck services holds greater appeal (OECD/ITF, 2022). Additionally, research (Sandberg-Hanssen & Mathisen, 2011; Tavasszy & van Meijeren, 2011) suggests that rail usage for perishable goods increases when terminals are located closer to producers. Depending on the proximity of terminals to origin and destination regions, alternative transport modes can be attractive options to road transport, considering that pre- and post-haulage by road remains necessary in most cases. Therefore, a terminal situated near distribution centers would likely encourage more companies to utilize rail transport.

4.5 Conclusions literature review

From the literature review it was seen that an intermodal transport network is a system that combines multiple transportation modes, such as road, rail, sea, and air, to move goods or people efficiently and cost-effectively. This approach offers benefits like reduced costs, increased flexibility, environmental sustainability, and decreased road congestion. Intermodal transport networks require careful planning and coordination, including integrated systems and infrastructure investments. Dry ports, which connect seaports with inland areas, play a vital role in improving connectivity. These networks can involve multiple dry ports with direct connections. Encouraging intermodal transport is crucial for seaports to remain competitive and efficient. Research often focuses on seaports as leaders and inland ports as followers, but there is growing interest in the reverse perspective. Authorities can support intermodal transportation through infrastructure development, legislation, price incentives, and technological innovations. Modal choice for freight transport depends on various factors, including shipper attributes, shipment characteristics, geographic and time factors, and carrier attributes. Achieving cost efficiency in intermodal transport requires handling large volumes over longer distances, typically exceeding 500 kilometers. Facilitators and barriers to shifting from road to intermodal transport include economics, quality, infrastructure, management, policy, and sustainability considerations.

Intermodal transportation can be categorized into two main types: accompanied and unaccompanied. This thesis specifically focuses on unaccompanied intermodal transport. In Europe, most trucks on motorways use semi-trailers, but technical limitations prevent 98% of these semi-trailers from being loaded onto railways, which is a challenge for intermodal transportation. Therefore, the thesis emphasizes the horizontal loading of trailers to address this issue. Intermodal terminals play a crucial role in facilitating the transfer of cargo between different modes of transportation. Terminal costs account for a significant portion of the expenses in intermodal transportation, and improving terminal efficiency is essential for enhancing competitiveness. Terminal handling technologies, such as horizontal loading systems, can significantly impact the volume of rail cargo handled in Europe. These technologies offer time and cost savings, making rail transport more attractive, especially for time-sensitive goods. Examples of these handling technologies that are considered are CargoBeamer, Modalohr, Flexiwaggon, RoadrailLink and Megaswing. In Table 3 the most important characteristics are showed.

Table 3
Semi-trailer handling technologies

	CargoBeamer	Modalohr	RoadrailLink	Flexiwaggon	Megaswing
Market readiness	In operation	In operation	In operation	Not in operation	Not in operation
Countries in which the technology is in operation	Germany, UK, France and Italy	France, Belgium, Italy, Luxembourg and Spain	France, Spain, Germany, The Netherlands, Lithuania and Italy	-	-
Horizontal/vertical loading	Both	Both	Vertical	Horizontal	Horizontal
Duration of loading (whole train)	20 minutes	35 minutes	180 minutes	10-15 minutes	30 minutes
Simultaneous/sequential loading and unloading	Simultaneous	Simultaneous	Sequential	Sequential	Sequential

To fully implement these technologies in Germany, a minimum number of terminals per technology is required along the transportation corridors. The selection of attractive terminal locations is influenced by various factors, including transportation costs, proximity to major transportation routes, and their role in optimizing logistics operations. Inland terminals are located around port facilities, often within the outskirts of its metropolitan area, and can often be found at national borders. Sufficient demand, reliability, and connectivity are crucial for the effectiveness of handling technologies. Terminal location near producers and distribution centers can encourage more companies to use rail transport for their goods.

5 Methodology & Data

5.1 Methodology

To answer the question of what potential locations are for semi-trailer handling technologies, such as CargoBeamer, an analysis of the traffic density on highways in Germany and interviews with stakeholders of the transport chain are done.

The conceptual model that is used to define location attractiveness takes the form:

$$
\begin{aligned}
&Location\ attractiveness \\
&\quad = \beta_0 + \beta_1 Port + \beta_2 Metropolitan + \beta_3 Corridor + \beta_4 Border \\
&\quad + \beta_5 Infrastructure + \beta_6 DC - \beta_7 Transportation\ costs - \beta_8 Setup\ costs
\end{aligned}
$$

where Location attractiveness denotes the level of attractiveness of a potential inland terminal location; Port denotes the proximity of a port facility, a dummy variable, equal to 1 if the potential inland terminal location is close to a port facility and 0 if it is not; Metropolitan denotes the proximity of a metropolitan area, a dummy variable, equal to 1 if the potential inland terminal location is close to a metropolitan area and 0 if it is not; Corridor denotes if the location is along a well-utilized transport corridor, dummy variable, equal to 1 if the potential inland terminal location is along a well-utilized transport corridor and 0 if it is not; Border denotes the proximity of national borders, a dummy variable, equal to 1 if the potential inland terminal location is close to a national border and 0 if it is not; Infrastructure denotes the level of quality of the infrastructure around the potential inland terminal location; DC denotes the proximity of distribution centers, a dummy variable, equal to 1 if the potential inland terminal location is close to a distribution center and 0 if it is not; Transportation costs denotes the average transportation costs from this potential location to the destinations; Setup costs denotes the amount of costs to build a terminal in that location.

For this research it was assumed that the highest demand for rail cargo services will be on the highways with the highest quantity of trucks and other motor vehicles on them. These highways will most likely also be routes where there is congestion and therefore delay for the cargo transported by truck. So, the traffic density on highways in Germany is important to know to test where there is the most demand for alternative modes of transport. Attractive locations for the technologies will be dependent on the throughput time for the truck option and the rail option. The semi-trailer handling technologies will lower the throughput times of rail cargo services and therefore rail cargo services will be more competitive. This will result in less freight transport on the roads. This results from the data will lead to different scenarios for holidays, weekends, and workdays because the amount of traffic differentiates between these days. In some scenarios, the train can make an intermediate stop to load and unload cargo, but sometimes it is not possible because it adds too much time to the journey. The scenarios compare truck and train on the long-haul part of the journey, so without the pre- and post-haulage.

Further in this research, only the CargoBeamer technology will be assessed. CargoBeamer is one of the few handling technologies that is already in use in multiple routes and does have locations in Germany already. Because there was a dataset on the traffic density in Germany, the new terminal location will be in Germany and a company that has already routes in this country will be more likely to add more locations to their German network in the near future. In this way, the scenarios could start at a terminal that has already an installed CargoBeamer technology. CargoBeamer does have a vertical and horizontal loading technology, so it can be used in two ways which could be useful in the early phase of testing a new location. The horizontal loading technology is more expensive, so when testing a new location this could be done with the vertical loading technology and later install the horizontal loading technology for the most time-efficient result. These scenarios will be presented in the interviews and will be adapted to the preferences of the stakeholders. In these interviews there will be questions on different criteria to make transport by train more attractive for cargo handling companies and if these companies would consider the train option in this specific scenario. The questions that are asked can be found in Appendix A. In this way, there will be an ultimate scenario that could be executed in the future and shows the advantages and disadvantages of using train transport.

5.2 Data

To assess the traffic density on German roads, data from the automatic counting machines in Germany are used (BASt, 2021). The "Automatische Zählstellen" or automatic counting stations are a system of sensors and devices installed along highways and major roads in Germany. These counting stations are maintained and operated by the Federal Highway Research Institute or Bundesanstalt für Straßenwesen (BASt). The sensors installed at the counting stations measure various parameters such as the number of vehicles passing through the station, the speed of the vehicles, the length and weight of the vehicles, and the direction of travel. Depending on the type of device used, up to nine types of vehicles can be distinguished. The data collected from the sensors is then transmitted to a central database maintained by the BASt. The data from the automatic counting stations are used by traffic planners, engineers, and researchers to analyze traffic patterns, monitor traffic flows, and plan for road improvements and maintenance. The data is also used by government agencies and private organizations to develop policies related to transportation, energy, and the environment. The counting machine network on federal roads currently comprises 2,108 counting machines (1,227 on highways (*Autobahn*) and 881 on federal roads (*Bundesstraßen*)) (BASt, n.d.-a). The data is accessible from 2003 to 2021. In this thesis, the most recent data on the highways is used, from 2021.

The counting machines observe different types of vehicles (see Table B2 in Appendix B). Some counting machines differentiate 9 types of motor vehicles as shown in the last column in Table B2 in Appendix B, and other counting machines differentiate 6 types of motor vehicles shown in column 3. This does not matter for this research, because for this thesis the difference between heavy traffic (vehicles > 3.5 tons, blue colored in Table B2 in Appendix B) and other vehicles is used. To assess new potential locations for the rail handling technologies the most used freight flows need to be known. Freight is carried by trucks, and therefore it is important to differentiate between trucks (vehicles > 3.5 tons) and passenger vehicles. In Table B1 in Appendix B is shown which variables are used of this dataset.

Next to this, to find suitable terminals for the CargoBeamer rail handling technology the AGORA (n.d.) intermodal terminal database is used. In this database, there is information about the infrastructure and services of intermodal terminals in Europe. AGORA uses intermodal terminal owners and operators, ports, or logistics centers in which the terminals are located, regions or countries in which the terminals are located, intermodal operators, or other institutions to get their data.

6 Results

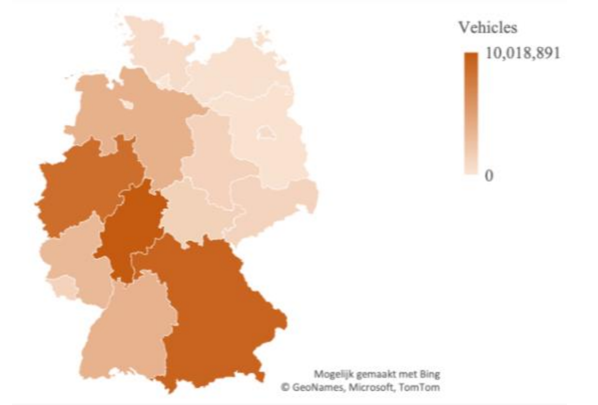
6.1 Results traffic density Germany

The data shows that there is for both, all motor vehicles, and trucks only, the biggest traffic stream through the German states: North-Rhine Westphalia, Hesse, and Bavaria (see Figure 12). With the state of Hesse being the state with the most traffic. Hesse is at the heart of things, in Germany and in Europe. The Rhine-Main area is one of Europe’s most economically powerful regions. Important sectors in Hesse are banking, the chemicals industry, insurance, car making, research, logistics, and telecommunications (Work in Hessen, n.d.). The Rhine-Danube, Rhine-Alpine, and Scandinavian – Mediterranean corridors follow (for a big part) this route through these three German states.

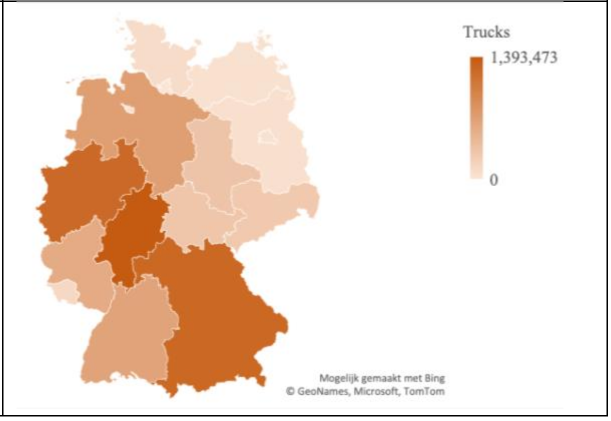
Figure 12

Average total number of motor vehicles and heavy traffic per day in the German states 2021

All motor vehicles



Heavy traffic



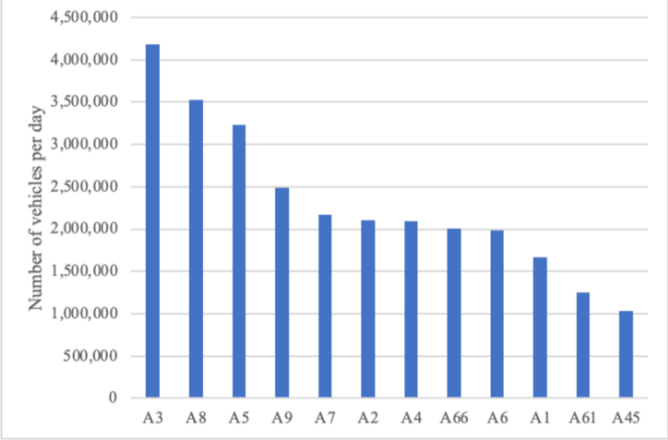
Source: BASt (2021)

When looking into the most-used autobahns, this shows the same pattern (see Figure 13). Highways that go through these states or follow the three above-mentioned corridors are used the most. Therefore, it is no surprise that Autobahn 3 is the most used autobahn by all motor vehicles and heavy traffic. The A3 runs from the Germany-Netherlands border near Wesel in the northwest to the Germany-Austria border near Passau, which goes through North-Rhine Westphalia, Hesse, and Bavaria. Major cities along its total length of 778 km include Oberhausen, Duisburg, Düsseldorf, Leverkusen, Cologne, Wiesbaden, Frankfurt, Würzburg, Nuremberg, and Regensburg. The A3 connects the Rhine-Ruhr area with southern Germany, resulting in a lot of traffic. However, for trucks this result is different. For heavy traffic, Autobahn 5 is one of the most important highways (but also for all motor vehicles). The A5 runs through Frankfurt, Mannheim, Karlsruhe, and Freiburg closely following the Rhine River (Rhine-Alpine corridor) and runs through the states of Hesse and Baden-Württemberg. Furthermore, the A8 is an important highway for all motor vehicles, which follows the Rhine-Danube corridor from Luxembourg via Karlsruhe, Stuttgart, Ulm, Augsburg, and Munich to Austria. The A8 is a significant east–west transit route. And lastly, the A7 and A9 are important highways for all motor vehicles. Autobahn 7 is the longest German Autobahn (Wikipedia contributors, 2022). It bisects the country almost evenly between east and west and therefore follows the Scandinavian-Mediterranean corridor. In the north, it starts at the border with Denmark. In the south, the autobahn ends at the Austrian border. The highway goes through Hamburg, Hannover, Kassel, Würzburg, and Ulm. The A9 is the highway connecting Berlin and Munich via Leipzig and Nuremberg also following the Scandinavian-Mediterranean corridor.

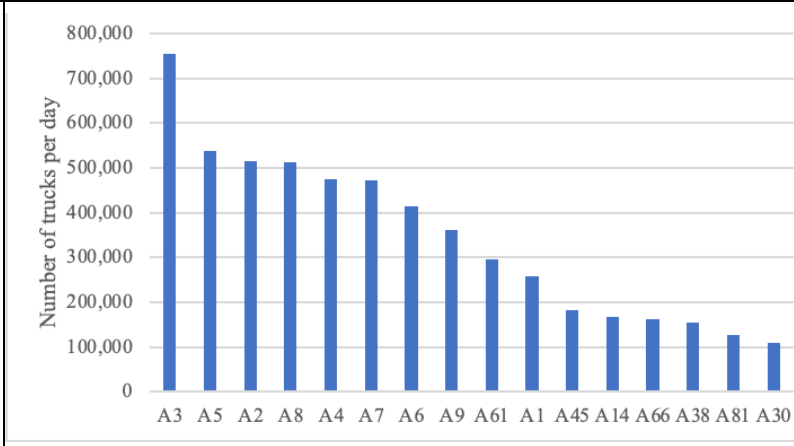
Figure 13

The average number of motor vehicles and heavy traffic per day on German highways in 2021

All motor vehicles



Heavy traffic



Source: BASt (2021)

From the individual counting machines, the following fragments of the Autobahns are characterized as busy (see the left side of Figure 14). The specific counting machines that made this map are listed in Appendix B Table B3. In red are the fragments that report more than 120,000 motor vehicles and more than 20,000 trucks, in orange the fragments that report more than 20,000 trucks, in yellow the fragments that report more than 120,000 motor vehicles, and in green the fragments that report between 15,000 and 20,000 trucks. Surprisingly, Autobahn 2 shows a long fragment with a lot of trucks, while adding up the total heavy traffic per autobahn the A2 just comes in at 3rd of all autobahns (see the right side of Figure 13). Most of the counting machines with a lot of vehicles/trucks passing each day are located on the corridors established by the European Parliament and Council (the black lines in Figure 14). It could be expected that there would be a lot of truck movements to and from the seaports of Germany, however, the data on the counting machines does not confirm this. This could be explained by the fact that the ports in Germany have invested already in the rail freight network in the ports.

6.2 Sensitivity analysis

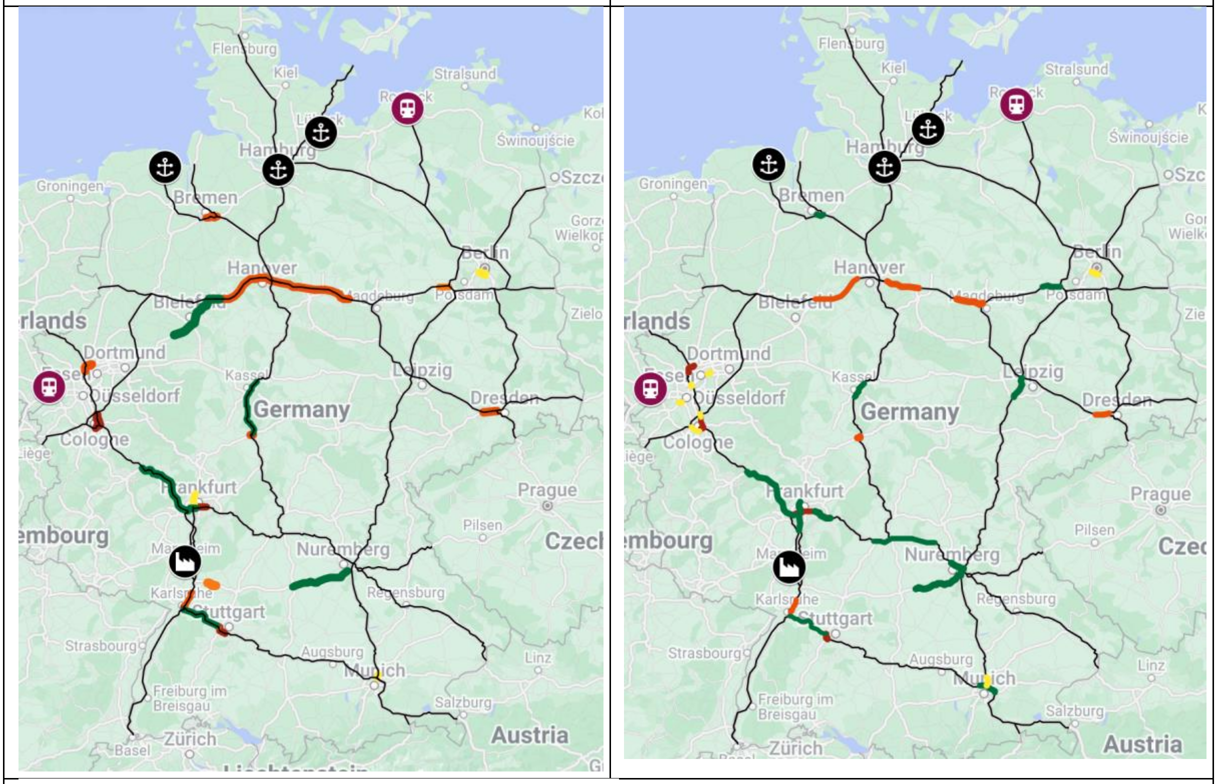
In this research, the year 2021 is used. In this year the effects of the COVID-19 pandemic are still present. To see what the effects of the pandemic are on traffic density in Germany, the year 2019 is also analyzed. The total number of vehicles is in 2021 9.4% lower than in 2019. For the number of heavy traffic this results in an increase of 5%. So, it can be concluded that the effect of the pandemic is much bigger on passenger transport than on freight transport in 2021, but both experience the same traffic on the highways.

In Figure 14 below the difference between the two years is clearly visualized. There is not much difference between the two years. There was more heavy traffic on A3 between Frankfurt and Nuremberg in 2019 compared to 2021 and on the A5 around Frankfurt am Main. But when looking at the A7 around Kassel and the A2 between Dortmund and Bielefeld there was more heavy traffic in 2021 compared to 2019. The increase in passenger traffic is mostly seen in the Nordrhein-Westfalen area.

Figure 14

Difference in traffic density in 2019 and 2021

2021	2019



- On average more than 20,000 trucks per day
- On average more than 120,000 motor vehicles and more than 20,000 trucks per day
- On average between 15,000 and 20,000 trucks per day
- On average more than 120,000 motor vehicles per day
- TEN-T corridors
- CargoBeamer rail terminals
- Ports
- Industry Ludwigshafen

Source: BASt (2019) & BASt (2021)

6.3 Congestion

The INRIX Germany Scorecard (2023) found that the worst traffic day is Thursday. On this day the morning and evening commute is the worst. The best week of the day for traffic is Friday. On Sundays and holidays (not the holiday season) the highways in Germany are less packed (see Figures B1 up to B3 in Appendix B), with 6.4 million motor vehicles on the A3 on workdays compared to 5.3 million motor vehicles on Sundays and holidays on the same highway. This means that during these days the trade-off between road transport and rail transport becomes different. The train could make fewer stops as it takes less time when the cargo would be transported by truck. This could result in higher costs because there are fewer points at which cargo could be loaded and unloaded which results in less cargo transported on a particular route. On weekdays there could be more stops as the truck will take more time on the same route. But the quantity of stops could also be the same as on days with less traffic on the highways. In this way the lead time difference between train and truck will become lower, and this could result in a higher attractiveness of the train. Therefore, there are different scenarios for these days and normal workdays. However, the most used highways on workdays and holidays are the same. The A3, A8, and A5 are also the most used highways on holidays.

6.4 Scenarios

In the interviews two routes will be assessed: one for the A3 and one for the A8. These are the most-used highways and follow the Rhine-Danube corridor and one train route could serve both of these routes. These routes could connect Germany to more Eastern European countries and these are opportunities as these are great distances in which transport by train is more competitive. And within these two routes, there are 2 scenarios for train and truck: one for workdays and one for Sundays and holidays. In all scenarios, the route starts at the CargoBeamer terminal in Kaldenkirchen. At the terminal in Kaldenkirchen, there is not yet the horizontal loading technology of CargoBeamer installed, but only the vertical loading technology. So, semi-trailers can already be handled at the terminal. In this way, there will be more destinations added from Kaldenkirchen that now only serves Rostock, Perpignan, and Domodossola. The two routes and the scenarios will be presented below.

6.4.1 A3 route

For the A3 route, the end destination is Passau on the German-Austrian border. As mentioned before, on workdays you need to take into account traffic on the highways in Germany. In the workdays scenario, the departure time by truck (and train) will be on Thursdays at 07:30 and for the Sunday and holiday scenario the departure will be on Sunday at 07:30. As mentioned before on Thursdays there is the most traffic, and therefore the worst scenario for truck transport. The truck option, therefore, suffers a delay of 38 minutes (Falk, n.d.), without any traffic this route takes 9 hours and 16 minutes (which is expected to be the case on Sundays and holidays) and on Thursdays, at 07:30 this route is expected to take 9 hours and 54 minutes by truck (Impargo, n.d.). For the train option, this means that the train can take less time on Sundays and holidays, which translates into a route between Kaldenkirchen and Passau without any stops. In the scenario of workdays, there is an intermediate stop for the train route, and this will be in Frankfurt. There is a lot of heavy traffic moving between Kaldenkirchen and Frankfurt am Main as shown in Figure 14 above and the industrial area around Mannheim (such as Ludwigshafen) is well connected to Frankfurt, so at Frankfurt, there will be a lot of demand for loading and unloading cargo. This will decrease the costs by 30% per ton-kilometer as the train will carry more freight over the whole route. De Kemmeter (2022) found that longer trains (increasing from 740 m to 1500 m) carry more semi-trailers, and therefore can reduce the cost per train-km by 30%. For every journey, there is a total of 40 minutes needed to load and unload the cargo with the CargoBeamer technology at Kaldenkirchen and Passau. This will be included in the time for the train scenarios, as this is an extra step compared to the truck transport mode. Loading a train without the CargoBeamer technology takes about 3 hours (CargoBeamer AG, n.d.). EU Court of Auditors (2016) reports an average speed of international rail transport over the whole route of 18-30 km/h, but also speeds of 50 km/h have been reported for the rail freight Rhine-Alpine corridor. Therefore, it is assumed in this research that the average speed of freight trains over the whole route is 30 km/h. When adding a stop, this will add 20 minutes to the journey time as this is the time it takes for the CargoBeamer technology to load and unload all the cargo. For the train scenario without the CargoBeamer technology, adding a stop adds 6 hours as it takes 3 hours to load the train and 3 hours to unload the train. This results in the CargoBeamer train being approximately 15 hours slower in both scenarios compared to the truck, and the conventional train being at least 20 hours slower. But the costs show that the train is a lot cheaper than transportation by truck (0.017 and 0.115 euros per tonne-kilometer respectively), for longer trains, which is the case when the train will make a stop in Frankfurt, this difference is even bigger. In this case, the costs for the train will decrease to 0.0119 euros per tonne-kilometer. The downside of making an extra stop is that the terminal costs of the terminal where the additional stop takes place are also added, which is more than the decrease in costs when handling extra cargo. Transportation by train emits less than a quarter of the CO_2

emissions compared to transportation by truck. In addition, the CO_2 costs are also calculated, but this is only a small part of the total costs (30 euros per ton of emitted CO_2 (DEHst, 2023)). However, these costs will play a bigger role in the future. Over 3 years these CO_2 costs will amount to 55 to 65 euros per ton of emitted CO_2, and this will maybe even increase further in the future (DEHst, 2023). Table 4 below shows the results for the different scenarios for the A3 route between Kaldenkirchen and Passau.

Table 4

Scenarios for the A3 route

	Truck (workdays)	**Truck (Sundays and holidays)**	**CargoBeamer train (workdays)**	**CargoBeamer train (Sundays and holidays)**	**Train (workdays)**	**Train (Sundays and holidays)**
Starting point	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen
End point	Passau	Passau	Passau	Passau	Passau	Passau
Intermediate stops	Not applicable	Not applicable	Frankfurt am Main	None	Frankfurt am Main	None
Distance (km)	715.3	715.3	702.2	702.2	702.2	702.2
Time	09:54	09:16	24:24	24:04	35:24	29:24
Costs (in euros) per ton	82.26	82.26	8.36	11.94	8.36	11.94
Terminal costs (in euros) per load unit	-	-	152.50	81.50	152.50	81.50
Toll costs (in euros)	134.14	134.14	-	-	-	-
CO_2 emissions (in kg) per ton	86.55	86.55	12.64	12.64	12.64	12.64
CO_2 costs (in euros) per ton	2.60	2.60	0.38	0.38	0.38	0.38

Note: The CO_2 emissions per ton kilometer are based on CE Delft (2021): 18 g/tonne-km for rail transport and 121 g/tonne-km for road transport (see Table B4 in Appendix B). The costs per tonne-kilometer are based on Van der Meulen et al. (2020): 0.017 euros per tonne-km for shorter trains (without stops), 0.0119 euros per tonne-km for longer trains (with 1 stop), and 0.115 euros per tonne-km for truck and trailers (see Table B5 in Appendix B). For the CO_2 costs the amount of the year 2023 is used, 30 euros. The terminal costs are showed in Table B6 in Appendix B.

Source: for the distance and toll costs for the truck scenario (Impargo, n.d.), for the trucking time and delay (Falk, n.d.), for the distance by train (BRouter, n.d.), the costs (Van der Meulen et al., 2020), the terminal costs of Frankfurt am Main and Passau (CMA CGM, n.d.) and for Kaldenkirchen (TX Logistik AG, n.d.), the CO_2 emissions are based on CE Delft (2021) data, and the CO_2 costs are based on DEHst (2023).

6.4.2 A8 route

On the A8 route, the end destination will be Salzburg just over the border in Austria. This route is almost 100 kilometers longer by truck than the A3 route. On this route, the delay for truck transportation on workdays amounts to 44 minutes, and unlike the A3 route, there is also a delay of 10 minutes on Sundays and holidays (Falk, n.d.). By truck, it takes thus 10 hours and 59 minutes to get from Kaldenkirchen to Salzburg via the A8 on workdays and 10 hours and 25 minutes on Sundays and holidays (Impargo, n.d.). For the same reason as before, there is only an intermediate stop by train on workdays. The intermediate stop is, the same as in the A3 route scenarios, Frankfurt am Main. This results for the truck being approximately 16 hours faster than the CargoBeamer train in both scenarios, and at least 23 hours faster than the conventional train. However, as seen in the A3 route, the costs when transporting by train are much lower than transporting by truck. Here the length of the train route is much shorter than the truck route, this route length difference is bigger than in the A3 route. This results in a bigger cost and CO_2 emissions difference between train and truck. The terminal costs of Salzburg are lower than those of Passau, which results in the terminal costs being at all time lower than the toll costs. All information on these scenarios is shown in Table 5 below.

Table 5

Scenarios for the A8 route

	Truck (workdays)	Truck (Sundays and holidays)	CargoBeamer train (workdays)	CargoBeamer train (Sundays and holidays)	Train (workdays)	Train (Sundays and holidays)
Starting point	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen
End point	Salzburg	Salzburg	Salzburg	Salzburg	Salzburg	Salzburg
Intermediate stops	Not applicable	Not applicable	Frankfurt am Main	None	Frankfurt am Main	None
Distance (km)	809.8	809.8	773.3	773.3	773.3	773.3
Time	10:59	10:25	26:47	26:27	37:47	31:47
Costs (in euros) per ton	93.13	93.13	9.20	13.15	9.20	13.15
Terminal costs (in euros) per load unit	-	-	115.50	44.50	115.50	44.50
Toll costs (in euros)	154.86	154.86	-	-	-	-
CO_2 emissions (in kg) per ton	97.99	97.99	13.92	13.92	13.92	13.92
CO_2 costs (in euros) per ton	2.94	2.94	0.42	0.42	0.42	0.42

Note: the CO_2 emissions per ton kilometer are based on CE Delft (2021): 18 g/tonne-km for rail transport and 121 g/tonne-km for road transport (see Table B4 in Appendix B). The costs per tonne-kilometer are based on Van der Meulen et al. (2020): 0.017 euros per tonne-km for shorter trains (without stops), 0.0119 euros per tonne-km for longer trains (with 1 stop), and 0.115 euros per tonne-km for truck and trailers (see Table B5 in Appendix B). For the CO_2 costs the amount of the year 2023 is used, 30 euros. The terminal costs are showed in Table B6 in Appendix B.

Source: for the distance and toll costs for the truck scenario (Impargo, n.d.), for the trucking time and delay (Falk, n.d.), for the distance by train (BRouter, n.d.), the costs (Van der Meulen et al., 2020), the terminal costs of Frankfurt am Main and Salzburg (CMA CGM, n.d.) and for Kaldenkirchen (TX Logistik AG, n.d.), the CO_2 emissions are based on CE Delft (2021) data, and the CO_2 costs are based on DEHst (2023).

As mentioned before Kaldenkirchen is already a terminal with the vertical loading technology of CargoBeamer. So, in these scenarios, it is all about extending the CargoBeamer network towards the east/southeast. The only locations where there needs to be a terminal built or an existing terminal where the CargoBeamer technology needs to be installed are around Frankfurt am Main, and Salzburg or Passau.

6.5 Results interviews

At this moment, the scenarios were made with the available information but to see how a modal shift can actually happen on these busy transport routes, interviews were done with people from 8 companies (see Table 6). These were transport companies (Tieleman Logistics, Neele-Vat, Van Thiel Transport, Contargo, and Samskip) with and without experience with intermodal transport, one company that uses transport services to import and export their clients' products (Royal FloraHolland), one company that is encouraging companies to participate in a modal shift (Joint Corridor Off Road) and an interview with CargoBeamer itself. The main topics that are discussed are listed in Appendix B Table B7. The results below are referenced to the interviews by means of numbers. The number before the colon references the number of the interview and the number after the colon references the subject.

Table 6

Interview participants

Interview #	Date	Interviewee	Company
1	12/06/2023	Eline van de Berg	Royal FloraHolland
2	13/06/2023	Manuel Woeste & Anna Müller	CargoBeamer
3	21/06/2023	Koos Oosterwijk	Neele-Vat
4	22/06/2023	Davey Boone	Tieleman Logistics
5	22/06/2023	Frans van den Boomen	Joint Corridor Off Road
6	23/06/2023	Peter Oude Avenhuis	Van Thiel Transport
7	23/06/2023	Michel van Meurs	Contargo
8	07/07/2023	Martijn La Maitre & Gert-Jan Meijer	Samskip

In these interviews, the main objective is to be able to look into the mind of a company with regard to a good transport service. What makes companies choose a particular transport mode or service? One thing that came forward in these interviews was the reason that a company chooses another transport mode than the truck is often that there is a person in the organization that is progressive, open-minded, and investigating all its options before choosing a transport mode (1:4 and 5:2). In a lot of organizations, they are not willing to adapt to another transport mode and will thus stick to road transport as they are already using that and in a lot of cases this transport mode works for them. With good planning, much is possible and that is why it is important to involve the whole chain that is involved with a modal shift (1:4).

This modal shift is important for the future because there is a growing problem which is already mentioned before, the truck driver shortage. It was mentioned that until now they could fix this problem by hiring drivers from Eastern European countries (3:4, 5:4 and 7:4). In 2026 there will be a shortage of 2.3 million truck drivers in Europe, which means the Eastern European drivers will go back to their own country as this problem will also emerge there (5:4). One of the reasons there is a shortage is because there is a rising amount of truck drivers that do not want to drive internationally and be from home for multiple days. Therefore, moving the cargo from the road to the train or barge would fit perfectly with this trend and the current work field (3:4). With a modal shift the only parts which require a truck are in the last-mile transport which are short national routes. The international part of the route will be covered by train or barge. In conclusion, a modal shift is an important factor in solving the driver shortage problem and will fit better in our society in the future.

After constructing the scenarios (see Tables 4 and 5 above) it is clear that choosing between transport by train or transport by truck results in a trade-off between time and costs or CO_2 emissions. From the interviews, it is important to get to know what is important for an organization that uses transport. Do they think that it is important to minimize costs, minimize CO_2 emissions, or does the lead time need to be as short as possible? This subject resulted in different answers in the interviews. First, every interview mentioned that it depends on the kind of product that is being transported. Companies that transport perishable or capital-intensive goods for example will want to optimize the lead time (2:1, 5:1, 6:1 and 7:1). In their case, transport by truck will be the most attractive transport mode. Many companies that choose transport by train are more flexible in terms of timing (2:1). Congestion is not the biggest part of the total delay time. Delay comes mostly from congestion at the terminal or at the loading/unloading locations. Some mentioned that nowadays costs are more important than lead time (1:1 and 3:1) and it was even emphasized that in the transport world everything resolves around costs and prices (3:1). There was also an interview where it was said that they are pushing sustainability and often organizations say they want the same thing, but when the transporting company communicates the price, the organizations often decline (8:1). But availability was also mentioned as the most important thing in logistics (5:1). Goods and raw materials need to be available when they are needed (5:1). Availability is a combination of three factors: reliability, lead time and frequency (5:1). It is important that goods are delivered on time and according to specifications, lead times need to be acceptable (a train cannot take a week longer than truck) and the frequency must be high enough (5:1). Then there are also interviews in which the companies say they experience that clients prefer lead time before costs, but also accessibility of the transport service is important (4:1 and 6:1). The conclusion that can be made from all interviews is the fact that reliability is a decisive factor (1:1, 4:1, 5:1, 6:1 and

7:1). But reliability is partly a perception (8:1), it depends on the agreements that are made. Trucks are more reliable, and this will probably not change. One way to make a train service more reliable is to control as many elements of the service as possible (2:1 and 8:1). A well-functioning terminal is one of the key components in such a service, which can stop the ripple effect of a delay (2:1). The advantage of transport by truck is the fact that when there is a delay, this delay is mostly limited to a few hours. When there is a delay in the train transport chain it will result in a delay of at least 24 hours (4:1). The reason for this is the fact that trains (and barges) have schedules and slots in which they can ride and use the tracks or waterway. When they are delayed, their slot is over and it needs to wait until the respective company that operates the train has another slot (2:1). These schedules also result in the train being less flexible than truck (2:1). For the client this means that they will need to adjust their process to the schedule of the train. An upside of train transport in terms of flexibility is the possibility to hold the container or trailer on the rail terminal until the company needs the cargo (5:1 and 8:1). Companies think this is a nice feature of transporting their cargo by train (5:1). CargoBeamer is an example that has still some kind of flexibility as they offer multiple departures on one day and they sell slots until a few minutes before departure, so companies can book a space on the train last-minute (2:1). This is a big difference with regard to the reputation of transport by train, which is inflexibility. Frequency of a train service is important. Frequency increases the flexibility of a train service and makes it more competitive to transport by truck. A train can only compete with road transport when there is a departure 5 to 6 times a week. In this way, the client does not have too many fluctuations in their production process (8:1).

From the interviews it was being said that containers have already largely shifted to multimodal transport (3:4). Part of the reason for this is that container transport by road is much more expensive because the container must be placed on a semi-trailer and the container in its entirety remains with the customer. This ensures that the tractor must have a new full container nearby to take back with it, otherwise, it will drive back empty. Inland shipping or transport by train is much cheaper here than by road (3:4). Semi-trailers are often used for transportation to Scandinavia. Semi-trailers are more expensive because they have more moving parts and that makes it riskier to load on a train or barge. The advantage of a trailer is that you can load the cargo on multiple sides (8:4). Non-craneable trailers on the train are certainly interesting for cargo that must be delivered to the market immediately or quickly after the arrival of the train, such as fresh products (meat, fish, vegetables, and plates) due to limited freshness (shelf life). The buyers (retail, wholesale, processing companies) are often set up to receive trailers with an unloading platform and cannot receive and unload containers (5:1). Therefore, CargoBeamer is also an important factor in shifting cargo from the roads to rail, as the technology makes it possible for trailers to be loaded onto a train.

Next to general questions on the preferences of the companies on transport services, there were also route-specific questions being asked in the interviews. From the interviews, it was confirmed that the route between Kaldenkirchen and Passau/Salzburg was a busy route with a lot of freight traffic. Especially on the A61 towards Mannheim and on to Stuttgart, this is an industrial area with Ludwigshafen (4:2). On these routes there are a lot of traffic jams during the rush hours, but this decreases outside the rush hour (4:2). It was found that on the train routes already offered, there were no intermediate stops. A reason for this is that the intermediate stop takes too much time. In this scenario, Frankfurt is only 3 hours by truck from Kaldenkirchen. Every stop by train will take approximately 3 to 4 hours, so no customer will take this service from Kaldenkirchen to Frankfurt, they will just take the truck as this is easier (2:2). From an efficiency perspective of rail, train rides typically are at least 500 kilometers long and the longer the journey gets, the more efficient will the train be (2:2). So, from a cost and operational perspective, it is not recommended to insert an intermediate stop (2:2). In the literature CE Delft (2018) and Dionori et al. (2015) found other distances to be efficient, but Klink and van den Berg (1998) also mentioned 500 kilometers.

To decide which end terminal to use there is one big difference between Passau and Salzburg. Salzburg is just over the border in Austria and Passau is still on the German side of the border. This is an important factor because crossing borders bring bureaucratic problems for rail transport (2:2). It would be better to locate the terminal on the German side of the border, around Freilassing for example. From the infrastructure perspective, Passau is the better choice, but Salzburg has a bigger demand region (2:2). A terminal is not built for one route but for multiple connections and directions. From Salzburg, you have the advantage that you can go across the mountains and go further to the Balkans, or to Italy (2:2). 80-90% of the clients are located between 10-200 kilometers from a terminal. The average distance around the terminal is around 125 kilometers (8:2). To generate a better competitive position towards seaports, it is advised to locate a terminal further from the seaport and the larger port city. This entails less costs as terminals in smaller cities will be used which are often cheaper than a terminal in bigger cities (8:2). According to CargoBeamer (2:3) important aspects of a terminal are a good customer base and good infrastructure around the terminal. The terminal is around 740 meters long with enough space to build parking spots for the trucks. The location of a terminal is ideally at a highway crossing and a crossing of the railroad. Furthermore, there need to be balanced services, so enough demand but also enough supply of goods in the region (2:3). The advantage of the CargoBeamer technology is the fact that you can test new terminals without building the whole horizontal loading technology first (2:2). When CargoBeamer tests a new terminal, they only use the CargoBeamer railcar and a traditional reach stacker, which is already installed at the existing terminal. This makes the non-craneable trailers already craneable, but instead of using the horizontal loading process, they use the vertical loading process. In this way they can cheaply test if there is enough demand for the service in the region and if the route is profitable and then install the horizontal loading technology there (2:2).

In the interviews, it was often said that in Germany there is a lot of ongoing construction on the tracks, which influences the reliability of train transport. More train transport will also come with challenges. Freight trains are still not given priority over passenger trains and that remains a problem (7:4). In addition, the capacity for rail handling at the deep-sea terminals is also limited because they are almost at maximum capacity there and new shuttles are very difficult to add because there is no room for them (7:4). The train capacity is therefore limited, which puts pressure on the price. The capacity for trucks is a lot larger, so the prices of trains and trucks will grow to each other. In some cases, the truck is even cheaper. In recent years, a reverse modal split is emerging (7:4). The train has to deal with high electricity costs, which leads to a worse competitive position. Due to those high electricity prices and a market that is declining, there is less volume and more truck capacity, which means that truck rates are being driven down considerably. This means that the competitive position on the rail is difficult. There are also road transport providers that prefer to offer below cost price to keep driving than, for example, reduce capacity (8:1).

6.6 Conclusions

6.6.1 Conclusion traffic data and interviews

The data analysis reveals key insights about traffic patterns and highway usage in Germany. The Rhine-Danube, Rhine-Alpine, and Scandinavian-Mediterranean corridors closely align with the high-traffic routes through these German states. These corridors play a crucial role in shaping traffic patterns. Autobahn 3 (A3) is the most heavily used highway for both all motor vehicles and heavy traffic. Autobahn 8 (A8) serves as an important highway for all motor vehicles, following the Rhine-Danube corridor. Reduced traffic on Sundays and holidays can impact the trade-off between road and rail transport. In summary, the data analysis underscores the significance of specific states, corridors, and autobahns in shaping traffic patterns in Germany, with implications for transportation choices and logistics planning.

In summary, the interviews revealed that companies consider various factors, including the nature of their goods, reliability, cost, and the driver shortage, when making decisions about transport mode. The competitiveness of rail transport hinges on factors like frequency, terminal location, and the ability to address challenges in the rail industry. The preferences of the retailer/client depend on the kind of goods they want to transport. The most important aspects of a transport service are lead time, price, reliability, availability, scalability, flexibility, and frequency. Companies are increasingly choosing for transporting their goods by multimodal transport. The reason behind this is often because of trying to reduce CO_2 emissions in the supply chain. The biggest part of the delay in road transport is not congestion on the highways, but congestion at the terminal. The costs for train transport are not lower than road transport, because of road transport providers reducing their tariffs below the cost price. Furthermore, there are higher electricity prices which have consequences for train costs. For the scenarios, it was found that intermediate stops are not normally done on a train service and that it is beneficial to locate the terminal on the German side of the border as this avoids bureaucratic problems.

6.6.2 Conclusion scenario

The information gathered from the traffic data and interviews results in the following scenario (see Table 7 below). The best location for a terminal is the intermodal terminal in Burghausen. The whole route will be around 750 kilometers, which is following the literature and the interviews an efficient distance for train transport. This terminal is located in-between Passau and Salzburg, both cities are reachable below 100 kilometers so there will be demand from both demand regions. From this terminal, there could be connections through the Alpes and on to the Balkans, for example. This is an already existent intermodal terminal, so the vertical loading process of the CargoBeamer could be installed to test if this connection will be profitable and if so, install the horizontal loading process for an even more efficient service. Burghausen has 4 tracks, 3 reach stackers and 2 gantry cranes. There is a storage capacity available of 1200 TEU, and they already handle semi-trailers (AGORA, n.d.). The only downside of Burghausen is that it is not well connected to the rail network, and this is most likely the case as it is situated right on the border with Austria, but it is close to highway A94 (7 kilometers away) which connects with Passau. Because it is situated on the German side of the border, it has the advantage of not crossing the border by train and it has fast truck connections to Austria. The terminal is also not situated in a big city which, following the interviews, would result in lower terminal costs compared to terminals in bigger cities (see Table B6 in Appendix B). In the train scenario, there will not be an intermediate stop, as this will not increase the amount of freight the train carries on the whole journey. There will not be any company that uses the train to transport their goods from the starting point to the intermediate stop, as there is not enough distance between them. The whole journey will not be long enough to add an intermediate stop. There must be at least 500 kilometers between two stops to be efficient by train.

Using the information that all companies are located around 10-200 kilometers from the terminal, the terminal in Kaldenkirchen results in customers located in the Ruhr area with big cities such as Cologne, Düsseldorf, Essen, and Dortmund but also reaching Osnabrück (see Figure B4 in Appendix B). Furthermore, the terminal will also serve parts of the Benelux. The terminal in Burghausen will serve the demand regions of Passau and Salzburg, but also the big demand region of Munich and maybe even Nuremberg and Linz (Austria) (see Figure B5 in Appendix B). The only way a train service works is if companies work together to achieve enough capacity to have a train at least 5-6 times a week on this route. No company can do this on its own.

Table 7

Resulting scenarios

	Truck (workdays)	Truck (Sundays and holidays)	CargoBeamer Train	Train
Starting point	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen	Kaldenkirchen
End point	Burghausen	Burghausen	Burghausen	Burghausen
Intermediate stops	Not applicable	Not applicable	None	None
Distance (km)	770.8	770.8	731.1	731.1
Time	10:27	09:41	25:02	30:22
Costs (in euros) per ton	88.64	88.64	12.43	12.43
Terminal costs (in euros) per load unit	-	-	42.50	42.50
Toll costs (in euros)	145.35	145.35	-	-
CO_2 emissions (in kg) per ton	93.27	93.27	13.16	13.16
CO_2 costs (in euros) per ton	2.80	2.80	0.39	0.39

Note: the CO_2 emissions per ton kilometer are based on CE Delft (2021): 18 g/tonne-km for rail transport and 121 g/tonne-km for road transport (see Table B4 in Appendix B). The costs per tonne-kilometer are based on Van der Meulen et al. (2020): 0.017 euros per tonne-km for shorter trains (without stops) and 0.115 euros per tonne-km for truck and trailers (see Table B5 in Appendix B). For the CO_2 costs the amount of the year 2023 is used, 30 euros per ton emitted CO_2. The terminal costs are showed in Table B6 in Appendix B.
Source: for the distance and toll costs for the truck scenario (Impargo, n.d.), for the trucking time and delay (Falk, n.d.), for the distance by train (BRouter, n.d.), the costs (Van der Meulen et al., 2020), terminal costs for Burghausen (KombiTerminal Burghausen GmbH, n.d.) and for Kaldenkirchen (TX Logistik AG, n.d.), the CO_2 emissions are based on CE Delft (2021) data, and the CO_2 costs are based on DEHst (2023).

7 Discussion

The data that was used in the analysis of traffic density in Germany was from 2021. This is the year after Covid-19 developed in Europe and Germany. In this year there were still leftover consequences of the pandemic on the economy. It can be expected that after the pandemic the transport world slowly recovers to pre-pandemic levels and therefore 2021 could be a non-representative year. However, after comparing the year 2019 with 2021 on traffic density in Germany with the same data source it was discovered that these years do not differentiate much from each other. During the pandemic years, the freight traffic stayed at approximately the same level, and this matters the most to this research. The quantity of total motor vehicles was larger in 2019 compared to 2021 and this could have effects on the delay in the scenarios. However, this is decided to not be a big consequence for the outcome.

The numbers in the scenarios are not accurate. The costs or CO_2 emissions are case-specific and therefore the numbers in the scenarios are indicative. The costs in the scenarios are the transportation and terminal costs, but there are a lot of other types of costs that are associated with these scenarios, such as costs the transportation company charges. Furthermore, last-mile trucking is not included in the train scenarios as this is different for all customers of the service. The only thing that is compared is the long-haul part of the total route. Therefore, the lead time of the journey is not accurate, also because of the external factors that have an influence. Furthermore, in the methodology chapter there was a regression with factors that influences the attractiveness of a terminal location. Burghausen nor Kaldenkirchen was chosen by means of this regression, because of a lack of data. These terminals are qualitatively chosen by the German traffic data and Kaldenkirchen was already a CargoBeamer terminal. So, recommendations for further research on this topic could be to select new CargoBeamer terminals by using the regression on location attractiveness.

The research could be improved by doing more interviews with, also, companies that import or export their goods. They decide which transport company to reach out to and what they expect of them. As mentioned before different goods require different kinds of transport methods and therefore it would be better to interview companies that produce different kinds of goods. Because of this reason, it is difficult to formulate one conclusion as the preferences for a transport service are different for companies exporting and importing different kinds of goods. These are general findings that are applicable to most customers using a long-haul transportation service, not based on a particular case.

This study has made some contributions to the current literature. It focused on the inside-out approach wherein, the inland ports are the leaders and not the seaports (Wilmsmeier et al., 2011). The focus is on developing the inland network, so the connection between inland ports and not from a seaport to the hinterland. Next to this, there were interviews done with different stakeholders in a transport supply chain. From road transporters to multimodal transporters and a company that transports mainly fresh products to transport companies transporting shelf-stable products. This gives a variety of aspects that are important in a transport service and ways to make intermodal transport more attractive to use. Furthermore, this study gives insights into intermodal transport, especially train transport, and the CargoBeamer handling technology that can enhance the use of the train. However, it still has some limitations that could be improved in future research on this topic.

For starters, more interviews with companies producing different kinds of goods could improve the variety of answers and could improve the general conclusions. Another option could be to focus on one specific case, including pre- and post-haulage. This could make the scenarios more accurate regarding the amount of costs, time that it takes on the whole route for both transport modes, the reliability on the route and the amount of CO_2 emissions. Then the differences between the two transportation methods on a particular route could really be assessed and a conclusion could be made on how to improve the train scenario and what the effect is of CargoBeamer on the attractiveness of intermodal transport. Next to this, selecting the terminals could be done by using the regression on location attractiveness. And lastly, the year of the used data could be assessed more thoroughly.

8 Conclusion

This thesis aimed to answer the research question: what are attractive locations that will have the best conditions for shifting cargo from road to rail by using an advanced inland terminal handling technology? Based on quantitative evidence from the German traffic density data and qualitative information from interviews with stakeholders in the transportation chain the following conclusions can be made. Intermodal transport, also known as multimodal transport or combined transport, refers to the movement of goods using multiple modes of transportation within a single journey. Intermodal transport offers an efficient, sustainable, and seamless movement of goods across various transport networks. The factors retailers/clients find important in a transport service depend on the kind of goods they want to transport. The most important aspects of a transport service are lead time, price, reliability, availability, scalability, flexibility, and frequency. If the intermodal transport service scores good on these aspects, it can compete with transport by truck. Companies are increasingly choosing for transporting their goods by multimodal transport to reduce their CO_2 emissions. From the traffic density data, it became clear that the route following the Rhine-Danube corridor is one of the busiest regarding freight transport in the country. For this reason, the scenarios were focused on the routes following the A3 and A8. In these scenarios the lead time was analyzed, which is one of the important factors to shift cargo from the roads to the rail. The starting point of this route will be in Kaldenkirchen because the CargoBeamer technology is already installed there in its vertical form. There is a difference in the traffic time on weekends and holidays, and weekdays but from the interviews, it was discovered that this delay on weekdays is not a decisive factor, and this will not make train transport necessarily more attractive. Therefore, after the interviews, the intermediate stop at Frankfurt am Main is removed, as this will not result in cost or operational efficiency. For the endpoint, it was important to find a location on the German side of the border and at the crossing of railroad. This resulted in a route between Kaldenkirchen and Burghausen. From the literature it was found that terminals are often found near national borders, a metropolitan area, a seaport, distribution centers, and a transport corridor. In this case Kaldenkirchen and Burghausen are close to the border, the metropolitan Ruhr area and Munich and are on the Rhine-Danube corridor. CargoBeamer also has more terminals at national borders, such as Calais, Perpignan, and Domodossola. One reason for this is that a lot of administration is involved to allow a train to cross the border and in addition, the locomotive and driver often do not cross the border. The route between Kaldenkirchen and Burghausen is around 750 kilometers long, which is following the interviews and the literature an efficient length. From these terminals, among others, the big demand regions of the Ruhr area, Munich, Passau, and Salzburg can be served. In the future, there could be connections through the Alps to Italy or further eastwards to the Balkans and Turkey. Serving big demand regions as a terminal is important as there needs to be a train riding 5-6 times per week to be efficient and to compete with road transport. To achieve this, companies around the terminals need to collaborate to fill the trains. At first, the vertical loading process of the CargoBeamer could be installed at the already existing intermodal terminal in Burghausen to test if the route is profitable and if there is enough demand for this connection the horizontal loading technology could be installed at the terminals in Kaldenkirchen and Burghausen.

As mentioned in the introduction, this study is relevant for practical, but also scientific applications. For transport planners within companies, it is important which factors are the most important when choosing a transport service, such as lead time, frequency, reliability, etc. Therefore, for transport companies it is interesting to see the difference between the two modes and what the effect of a rail handling technology could be on the choice of a transportation mode. As mentioned in the interviews, a reason why companies do not use intermodal transport is because they do not want to change what is working for them, in this case road transport. So, to increase the use of intermodal transport, companies could be more open-minded to alternative transport modes. For the companies behind the handling technologies, it is good to know on what routes the traffic density is the biggest and where the most demand for a rail service could be. In this way, they could expand their network with new locations which will eventually increase the use of intermodal transport.

For the governments in Europe and the EU commission it is relevant, because in this study it was mentioned what factors are important to successfully shift the cargo from the roads to intermodal transport. Policy makers would like to know how to improve the intermodal network with these handling technologies. After this study, the EU commission could, for example, incentivize terminals to facilitate installing rail handling technologies on their terminals, so these handling technologies become more widespread in Europe. Furthermore, the EU and the European governments could improve the infrastructure and build more train infrastructure as in Germany there are a lot of problems with the passenger traffic and cargo traffic on the rails.

The findings in this study challenge the current literature on intermodal transport by interviewing businesses involved in the supply chain on the topic and expanding the network of an inland terminal handling technology that will stimulate the growth of intermodal transport. Furthermore, at this moment the focus of hinterland research is mainly on the connectivity of a seaport with the hinterland. In this research, the focus is on the hinterland only and the connectivity within the hinterland.

In conclusion, competition between train transport and road transport is an ongoing dynamic in the freight industry. Each mode has its unique advantages, and the choice between them depends on factors such as the nature of the cargo, the distance to be covered, cost considerations, and environmental considerations. To optimize freight transportation, intermodal solutions are increasingly embraced to create a more efficient and sustainable supply chain. This is increasingly stimulated by governments as there is a Green Deal on the table since 2019 which needs to be achieved, and intermodal transport can be a part of this. Next, the increasing truck driver shortage is and will play a big role in the transport world. Therefore, it is important to research new connections and make intermodal transport more attractive for companies to choose from. The handling technologies could be facilitating this shift from the roads to the rail.

References

AGORA. (n.d.). Intermodal Terminals in Europe [Dataset]. In *Intermodal Terminals in Europe*. https://www.intermodal-terminals.eu/database

Allianz pro Schiene e.V. (2010, September 27). *CargoBeamer bringt Lkw das Bahnfahren bei* [Video]. YouTube. Retrieved January 12, 2023, from https://www.youtube.com/watch?v=DbSIAvx3kYk

Bask, A., Roso, V., Andersson, D. I., & Hämäläinen, E. (2014). Development of seaport–dry port dyads: two cases from Northern Europe. *Journal of Transport Geography*, *39*, 85–95. https://doi.org/10.1016/j.jtrangeo.2014.06.014

BASt. (n.d.-a). *Automatische Straßenverkehrszählung*. https://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/zaehl_node.html

BASt. (n.d.-b). *Erfassungsarten nach TLS*. Bundesanstalt Für Straßenwesen. https://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/pdf-dateien/erfassungsarten.pdf?__blob=publicationFile&v=4

BASt. (2019). Automatische Straßenverkehrszählung 2019 [Dataset]. In *BASt*. https://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Daten/2019_1/Jawe2019.html?nn=1819490

BASt. (2021). Automatische Zählstellen 2021 [Dataset]. In *Automatische Straßenverkehrszählung*. https://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Aktuell/zaehl_aktuell_node.html?nn=1819516&cms_strTyp=A&cms_map=1

Beavis, P. A., Black, J. H., MacGill, I., Woxenius, J., & Moore, S. S. (2007). Interface design for the coordination of container freight infrastructure with urban logistical services. *The 11th WCTR– World Conference on Transport Research, UC Berkeley, 24-28 June 2007*.

Bergqvist, R., Falkemark, G., & Woxenius, J. (2010). Establishing intermodal terminals. *World Review of Intermodal Transportation Research*, *3*(3), 285. https://doi.org/10.1504/writr.2010.034667

Boer, L., Aalberts, J., Tol, E., Hoen, M., & Essen, H. (2018). *Modal Choice Criteria in Rail Transport: Assessment of Modal Choice Criteria in Various Rail Transport Market Segments*. https://ce.nl/wp-content/uploads/2021/03/CE_Delft_4S52_Modal_choice_criteria_in_rail-transport_Def.pdf

Bottani, E., & Rizzi, A. (2007). An analytical methodology to estimate the potential volume attracted by a rail-road intermodal terminal. *International Journal of Logistics*, *10*(1), 11–28. https://doi.org/10.1080/13675560600819668

BRouter. (n.d.). *Train route planner*. Retrieved May 23, 2023, from http://brouter.de/brouter-web/#map=7/48.980/10.767/standard&lonlats=6.202812,51.327394;6.202812,51.327394;8.647957,50.102084;8.647957,50.102084;8.410721,48.995762;8.410721,48.995762;12.989273,47.831942;12.989273,47.831942&profile=rail

Bundesamt für Güterverkehr. (2005). Marktbeobachtung Güterverkehr – Sonderbericht zum Seehafen-Hinterlandverkehr. In *Hydraulic Engineering Repository*. https://henry.baw.de/server/api/core/bitstreams/3f7b353e-bb1b-4932-b4b3-b6f87d6bd52d/content

Burroughs, D. (2020, March 25). *New European multimodal freight route swings into action*. International Railway Journal. https://www.railjournal.com/in_depth/new-european-multimodal-freight-route/

CargoBeamer AG. (n.d.). *Technology*. Retrieved March 12, 2023, from https://www.cargobeamer.com/what-we-do.html

CargoBeamer AG. (2016, February 9). *Cargo Beamer teaching trucks to use the railways* [Video]. Dailymotion. Retrieved March 12, 2023, from https://www.dailymotion.com/video/x3r5076

CargoBeamer AG. (2020, July 20). *Groundbreaking for CargoBeamers first own multi-modal terminal in Calais*. CargoBeamer. Retrieved March 12, 2023, from https://www.cargobeamer.com/news/groundbreaking-for-cargobeamers-first-own-multi-modal-terminal-in-calais.html

CE Delft. (2018). Modal choice criteria in rail transport: Assessment of modal choice criteria in various rail transport market segments. In *CE Delft*. https://ce.nl/wp-content/uploads/2021/03/CE_Delft_4S52_Modal_choice_criteria_in_rail-transport_Def.pdf

CE Delft. (2021). STREAM Goederenvervoer 2020. In *CE Delft*. Retrieved May 24, 2023, from https://ce.nl/wp-content/uploads/2021/03/CE_Delft_190325_STREAM_Goedervervoer_2020_DEF_Versie2.pdf

Cempírek, V., Rathouský, B., & Jirsák, P. (2020). INTERMODAL TRANSPORTATION OF SEMITRAILERS. *Perner's Contacts*, *15*(2). https://doi.org/10.46585/pc.2020.2.1650

CMA CGM. (n.d.). TARIFF Inland Terminals Import Storage Costs 2023. In *CMA CGM*.

Cokelaere, H. (2022, February 2). *New trucker rules shake up European logistics*. POLITICO. Retrieved February 2, 2023, from https://www.politico.eu/article/trucker-rules-europe-logistics-monility-european-commission/

De Kemmeter, F. (2022, March 29). *The optimal length of freight trains*. Mediarail. Retrieved May 23, 2023, from https://mediarail.wordpress.com/more-needs-to-be-done-to-promote-rail-transport-2/

DEHst. (2023, March 31). *Understanding national emissions trading*. German Emissions Trading Authority. Retrieved May 31, 2023, from https://www.dehst.de/EN/national-emissions-trading/understanding-national-emissions-trading/understanding-nehs_node.html

Dionori, F., Casullo, L., Ellis, S., Ranghetti, D., Bablinski, K., Vollath, C., & Soutra, C. (2015, March). *FREIGHT ON ROAD: WHY EU SHIPPERS PREFER TRUCK TO TRAIN*. European Parliament. Retrieved March 29, 2023, from https://www.europarl.europa.eu/RegData/etudes/STUD/2015/540338/IPOL_STU(2015)540338_EN.pdf

ECA. (2023, March 27). *Intermodal freight transport: EU still far from getting freight off the road*. European Court of Auditors. Retrieved April 25, 2023, from https://op.europa.eu/webpub/eca/special-reports/intermodal-freight-transport-08-2023/en/

Elbert, R., & Seikowsky, L. (2017). The influences of behavioral biases, barriers and facilitators on the willingness of forwarders' decision makers to modal shift from unimodal road freight transport to intermodal road–rail freight transport. *Journal of Business Economics*, *87*(8), 1083–1123. https://doi.org/10.1007/s11573-017-0847-7

European Commission. (n.d.). *The corridors*. European Commission | Mobility and Transport. Retrieved March 12, 2023, from https://transport.ec.europa.eu/transport-modes/rail/ertms/contributing/corridors_en

European Commission. (2003). Final Report: Actions to Promote Intermodal transport. In *European Commission*. Retrieved February 2, 2023, from https://trimis.ec.europa.eu/sites/default/files/project/documents/20060727_155159_96220_RECORDIT_Final_Report.pdf

European Commission. (2011). Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. In *European Commission*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:en:PDF

European Commission. (2017, November 18). *COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT accompanying the document Proposal for a directive of the European parliament and of the Council amending Directive 92/106/EEC on the establishment of common rules for certain types of combined transport of goods between Member States*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2017:0362:FIN:EN:PDF

European Commission. (2019). The European Green Deal. In *EUR-Lex* (No. 52019DC0640). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN

European Commission. (2020). Sustainable and Smart Mobility Strategy – putting European transport on track for the future. In *EUR-Lex* (No. 52020DC0789). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789

European Commission. (2021). *EU transport in figures: statistical pocketbook 2021*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/14d7e768-1b50-11ec-b4fe-01aa75ed71a1

European Commission. (2022). *Comparative evaluation of transhipment technologies for intermodal transport and their cost : final report.* Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/d37790ea-b6ef-11ec-b6f4-01aa75ed71a1

European Court of Auditors. (2016). Rail freight transport in the EU: Still not on the right track. In *Publications Office of the European Union* (Special Report No. 8). Retrieved May 23, 2023, from https://op.europa.eu/en/publication-detail/-/publication/b7620628-2c71-11e6-b497-01aa75ed71a1/language-en

European Environment Agency. (2022a, September 7). *Reducing greenhouse gas emissions from heavy-duty vehicles in Europe*. https://www.eea.europa.eu/publications/co2-emissions-of-new-heavy

European Environment Agency. (2022b, October 26). *Greenhouse gas emissions from transport in Europe*. https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-transport

Eurostat. (2022a, September). *Road freight transport statistics*. Retrieved March 12, 2023, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Road_freight_transport_statistics&oldid=583881#In_2021.2C_Germany.2C_France.2C_Spain.2C_Poland_and_Italy_accounted_for_almost_two_thirds_of_the_total_tonnage_transported_in_the_EU

Eurostat. (2022b). Key figures on European transport. *Eurostat*. https://ec.europa.eu/eurostat/documents/15216629/15589759/KS-07-22-523-EN-N.pdf

Falk. (n.d.). *Route Planner*. Retrieved May 23, 2023, from https://www.falk.de

FDT. (2007, January 31). *Feasibility Study On The Network Operation Of Hinterland Hubs (Dry Port Concept) To Improve And Modernise Ports' Connections To The Hinterland And To Improve Networking*. Scribd. Retrieved March 31, 2023, from https://it.scribd.com/document/102637257/Feasibility-Study-Dry-Ports#

Flexiwaggon. (n.d.). *About Flexiwaggon*. Retrieved September 4, 2023, from https://www.flexiwaggon.se/about-flexiwaggon/

Flexiwaggon AB. (2019). *Flexiwaggon Short*. YouTube. https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3Df0FHAQBVIxg&psig=AOvVaw1M1tppoqukcwRVbCDUXhhU&ust=1694078030114000&source=images&cd=vfe&opi=89978449&ved=0CBAQjhxqFwoTCNjygNDSlYEDFQAAAAAdAAAAABAD

Frémont, A., & Franc, P. (2010). Hinterland transportation in Europe: Combined transport versus road transport. *Journal of Transport Geography*, *18*(4), 548–556. https://doi.org/10.1016/j.jtrangeo.2010.03.009

Gouvernal, E., & Daydou, J. (2005). Container Railfreight Services in North-west Europe: Diversity of Organizational Forms in a Liberalizing Environment. *Transport Reviews*, *25*(5), 557–571. https://doi.org/10.1080/01441640500072127

IBI Group. (2006). *Inland container terminal analysis*. https://www.academia.edu/42278279/INLAND_CONTAINER_TERMINAL_ANALYSIS_FINAL_REPORT?auto=download

Impargo. (n.d.). *Truck route planner*. Retrieved May 23, 2023, from https://apps.impargo.de/dashboard

INRIX Germany Scorecard. (2023, March 14). *Global Traffic Scorecard | INRIX Global Traffic Rankings*. Inrix. Retrieved May 19, 2023, from https://inrix.com/scorecard/

Jansen, M., & Kuipers, B. (2022). VERSnellen modal shift in verslogistiek: Samen onderweg over betrouwbare en duurzame vers corridors. In *Smartport*. https://smartport.nl/wp-content/uploads/2022/04/SmartPort_VersnellenModalShift_final.pdf?utm_source=Google

Jensen, A. (2008). Designing intermodal transport systems: a conceptual and methodological framework. In *The Future of Intermodal Freight Transport*. Edward Elgar Publishing. https://doi.org/10.4337/9781848441392.00017

Juhel, M. H. (1999). THE ROLE OF LOGISTICS IN SIMULATING ECONOMIC DEVELOPMENT. *China Logistics Seminar*, 28–29. https://trid.trb.org/view/691888

KombiTerminal Burghausen GmbH. (n.d.). *Price list: valid from 1 January 2023*.

Koopman, G. (1995). Economic instruments for sustainable mobility: the case of freight transport. *World Transport Policy and Practice*, *1*(2), 18–27. https://doi.org/10.1108/13527619510079158

Kordnejad, B. (2013). *Regional Intermodal Transport Systems: Analysis and Case Study in the Stockholm- Mälaren Region* [Licentiate Thesis]. KTH Royal Institute of Technology.

Larsson, F., & Kohn, C. (2012). Modal shift for greener logistics – the shipper's perspective. *International Journal of Physical Distribution & Logistics Management*, *42*(1), 36–59. https://doi.org/10.1108/09600031211202463

LOHR. (n.d.). The Lohr system. In *LOHR*. Retrieved March 12, 2023, from https://www.lohr.fr/uploads/2023/04/d16589c-plaquette-modalohr-en.pdf

Lohr Railway system. (2017, March 24). *Efficient LOHR Railway System (timelapse)* [Video]. YouTube. Retrieved March 12, 2023, from https://www.youtube.com/watch?v=MTvSOrTXFzw

Macharis, C., Van Hoeck, E., Pekin, E., & Van Lier, T. (2010). A decision analysis framework for intermodal transport: Comparing fuel price increases and the internalisation of external costs. *Transportation Research Part A-policy and Practice*, *44*(7), 550–561. https://doi.org/10.1016/j.tra.2010.04.006

Maps & directions. (n.d.). *Meet de straal van een cirkel op een kaart*. Maps & Directions. Retrieved July 19, 2023, from https://www.mapsdirections.info/nl/cirkel-straal-kaart/

Marinov, M. A., Di, G. L., Bellisai, G., Clevermann, J., Mastellou, A., Victoria, D., & Deleva, L. (2014). Analysis of rail yard and terminal performances. *Journal of Transport Literature*, *8*(2), 178–200. https://doi.org/10.1590/s2238-10312014000200008

McCalla, R. J. (1999). Global change, local pain: intermodal seaport terminals and their service areas. *Journal of Transport Geography*, *7*(4), 247–254. https://doi.org/10.1016/s0966-6923(99)00017-4

Meers, D., & Macharis, C. (2015). Prioritization in modal shift: determining a region's most suitable freight flows. *European Transport Research Review*, *7*(3). https://doi.org/10.1007/s12544-015-0172-6

Monios, J. (2011). The role of inland terminal development in the hinterland access strategies of Spanish ports. *Research in Transportation Economics*, *33*(1), 59–66. https://doi.org/10.1016/j.retrec.2011.08.007

Monios, J., & Wang, Y. (2013). Spatial and institutional characteristics of inland port development in China. *GeoJournal*, *78*(5), 897–913. https://doi.org/10.1007/s10708-013-9473-2

Nelldal, B. (2014). CCT – An intermodal terminal handling system for horizontal transfer: Effects on costs, logistics, energy consumption and greenhouse gases. In *Digitala Vetenskapliga Arkivet* (No. 0000-0003-2415–9676). https://www.diva-portal.org/smash/get/diva2:1651844/FULLTEXT01.pdf

Nguyen, L. C., & Notteboom, T. (2016). A Multi-Criteria Approach to Dry Port Location in Developing Economies with Application to Vietnam. *The Asian Journal of Shipping and Logistics*, *32*(1), 23–32. https://doi.org/10.1016/j.ajsl.2016.03.003

Notteboom, T., Pallis, A., & Rodrigue, J. (2022). Chapter 2.3 – Inland Ports / Dry Ports. In *Port Economics, Management and Policy*. Routledge.

Notteboom, T., & Rodrigue, J. (2005). Port regionalization: towards a new phase in port development. *Maritime Policy & Management*, *32*(3), 297–313. https://doi.org/10.1080/03088830500139885

Notteboom, T., & Rodrigue, J. (2009). Inland Terminals within North American and European Supply Chains. *Transport and Communications Bulletin for Asia and the Pacific*, *78*, 1–39. https://www.unescap.org/sites/default/files/bulletin78_Article-1.pdf

OECD/ITF. (2022). *Mode Choice in Freight Transport*. https://www.itf-oecd.org/sites/default/files/docs/mode-choice-freight-transport.pdf

Panova, Y., & Hilmola, O. (2015). Justification and evaluation of dry port investments in Russia. *Research in Transportation Economics*, *51*, 61–70. https://doi.org/10.1016/j.retrec.2015.07.008

Patterson, Z., Ewing, G., & Haider, M. (2007). Shipper preferences suggest strong mistrust of rail. *Transportation Research Record*, *2008*(1), 67–74. https://doi.org/10.3141/2008-09

Railway Technology. (2014, February 19). *The world's 10 longest railway networks*. Retrieved March 12, 2023, from https://www.railway-technology.com/features/featurethe-worlds-longest-railway-networks-4180878/

Raimondi, M. (2023, June 29). *VEGA introduces r2L system for non-cranables in France*. RailFreight. https://www.railfreight.com/railfreight/2023/06/29/vega-introduces-r2l-system-for-non-cranables-in-france/

Rodrigue, J. (2008). The Thruport concept and transmodal rail freight distribution in North America. *Journal of Transport Geography*, *16*(4), 233–246. https://doi.org/10.1016/j.jtrangeo.2007.08.003

Rodrigue, J., & Notteboom, T. (2009). The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management*, *36*(2), 165–183. https://doi.org/10.1080/03088830902861086

Roso, V. (2006). *Emergence and significance of dry ports* [Licentiate Thesis]. Chalmers University of Technology.

Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: connecting container seaports with the hinterland. *Journal of Transport Geography*, *17*(5), 338–345. https://doi.org/10.1016/j.jtrangeo.2008.10.008

Sandberg-Hanssen, T., & Mathisen, T. A. (2011). Factors facilitating intermodal transport of perishable goods – Transport purchasers viewpoint. *75-89*, *49*, 75–89.

Stoilova, S., & Martinov, S. V. (2022). Evaluation of semi-trailer rail transport technologies by using multi-criteria analysis. In *Engineering for Rural Development*. https://doi.org/10.22616/erdev.2022.21.tf219

Swiss Life Asset Managers. (2023, August 10). More trailers on rails and fewer trucks on the road. *Swiss Life Asset Managers*. https://www.swisslife-am.com/en/home/hub/2023/q3/helrom.html

Tavasszy, L. A., & Van Meijeren, J. (2011). Modal shift target for freight transport above 300 km: an assessment. In *ACEA*. https://www.acea.auto/files/SAG_17.pdf

Todd, S. (2019, February 26). *Lorry Rail launches Barcelona-Luxembourg shuttle*. Lloyd's Loading List. Retrieved March 12, 2023, from https://www.lloydsloadinglist.com/freight-directory/news/Lorry-Rail-launches-Barcelona-Luxembourg-shuttle/73839.htm#.ZA3b3i-iG3U

TX Logistik AG. (n.d.). *TERMINALKONDITIONEN 2023*. Retrieved September 7, 2023, from https://www.txlogistik.eu/service/downloads-road-rail/

UIC. (2019). 2018 Report on Combined Transport in Europe. In *International Union of Railways* (No. 978-2-7461-2798–2). International Union of Railways.

UIRR. (n.d.). *Unaccompanied services*. International Union for Road-Rail Combined Transport. Retrieved March 12, 2023, from https://www.uirr.com/en/road-rail-ct/ct-offers/unaccompanied-services.html

UIRR. (2021, May 27). *UIRR report 2021-2022*. Retrieved March 12, 2023, from https://www.uirr.com/en/media-centre/annual-reports/annual-reports/mediacentre/1582-uirr-annual-report-2019-20.html

Van der Meulen, S., Grijspaardt, T., Mars, W., Van der Geest, W., Roest-Crollius, A., & Kiel, J. (2020, April). *Cost Figures for Freight Transport – final report*. StuDocu. Retrieved May 23, 2023, from https://www.studocu.com/vn/document/truong-dai-hoc-kinh-te-thanh-pho-ho-chi-minh/international-business/costfiguresforfreighttransport-finalreport-123-abc/20340195

Van Klink, H. A., & Van Den Berg, G. C. (1998). Gateways and intermodalism. *Journal of Transport Geography*, *6*(1), 1–9. https://doi.org/10.1016/s0966-6923(97)00035-5

Vashist, J. K., & Dey, A. K. (2016). Selection Criteria for a Mode of Surface Transport: An Analytic Hierarchy Process Approach. *Amity Global Business Review, 11*, 86–95.

Veenstra, A. W., Zuidwijk, R., & Van Asperen, E. (2012). The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics and Logistics*, *14*(1), 14–32. https://doi.org/10.1057/mel.2011.15

VIIA. (2019, April 2). *Our history : learn how VIIA began and understand our evolution*. Retrieved March 12, 2023, from https://www.viia.com/en/who-are-we/our-history/

VTG. (n.d.). *Combined transportmade easy*. Retrieved September 4, 2023, from https://www.vtg.com/news-and-insights/stories/combined-transport-made-easy

Wikipedia contributors. (2022). Bundesautobahn 7. *Wikipedia*. https://en.wikipedia.org/wiki/Bundesautobahn_7

Wilmsmeier, G., Monios, J., & Lambert, B. L. (2011). The directional development of intermodal freight corridors in relation to inland terminals. *Journal of Transport Geography*, *19*(6), 1379–1386. https://doi.org/10.1016/j.jtrangeo.2011.07.010

Woodburn, A. G. (2006). The non-bulk market for rail freight in Great Britain. *Journal of Transport Geography*, *14*(4), 299–308. https://doi.org/10.1016/j.jtrangeo.2005.06.002

Woodburn, A. G. (2007). The role for rail in port-based container freight flows in Britain. *Maritime Policy & Management*. https://doi.org/10.1080/03088830701539032

Work in Hessen. (n.d.). *Sectors*. https://www.work-in-hessen.com/working-in-hessen/sectors/#:~:text=South%20Hessen%20is%20particularly%20characterised,and%20pharmaceuticals%2C%20and%20communication%20technology.

Zasiadko, M. (2022, February 11). *Cargobeamer aims to build over 30 terminals for combined transport*. IntermodalNews.eu. Retrieved May 18, 2023, from https://intermodalnews.eu/2022/02/11/cargobeamer-aims-to-build-over-30-terminals-for-combined-transport/

Appendix A

- What is your role within the company?
- Can you explain what kind of services your company offers? Does your company offer intermodal transport services?
- I made scenarios for the route Kaldenkirchen and Passau/Salzburg. In these scenarios, it was observed that the train took much longer to cover the same route compared to a truck, but that the train is much cheaper and emits less CO_2 than transport by truck. This, therefore, results in a trade-off between time vs. costs/CO_2. In your experience, what is more important for the customer, time, or costs/CO_2, and has this changed in recent years?
- How important is reliability for your clients regarding a transport service?
- Is there a difference regarding reliability between truck and train transport? Why is there a difference?
- Do you think that reliability is the key factor in choosing a transport mode and therefore often choosing road transport?
- Are there any other criteria that are important for a transport service?
- Do you have experience on the route between Kaldenkirchen and Passau/Salzburg over the A3 or A8? What is your experience on this route, is this a busy route with a lot of freight traffic?
- Which end point of this route would you recommend, and why?

Appendix B

Table B1

Summary variables autobahn 2021

Variable	Observations	Mean	Std. Dev.	Min	Max
Average daily traffic volume of motor vehicles (all days, both directions)	888	51,829	26,856	819	166,261
Average daily traffic volume of heavy traffic (all days, both directions)	819	8,745	5,242	60	24,168
Share heavy traffic (%)	819	17.32	7.62	2.20	48.60
Average daily traffic volume of motor vehicles (workdays, both directions)	888	53,675	27,917	1043	169,441
Average daily traffic volume of motor vehicles (holiday workdays, both directions)	888	55,360	28,667	398	178,400
Average daily traffic volume of motor vehicles (Sunday and holidays, both directions)	888	40,345	21,784	506	139,249

Source: BASt (2021)

Table B2

Types of vehicles in the dataset

<table>
<tr><th>1</th><th>2</th><th>5+1</th><th>8+1</th></tr>
<tr><td rowspan="9">Motor vehicle</td><td rowspan="4">Passenger vehicle</td><td>Unclassifiable vehicles</td><td>Unclassifiable vehicles</td></tr>
<tr><td rowspan="3">Passenger vehicle type</td><td>Motorcycles</td></tr>
<tr><td>Passenger vehicle without trailer</td></tr>
<tr><td>Delivery trucks without trailer</td></tr>
<tr><td rowspan="5">Goods vehicle</td><td>Passenger vehicle with trailer</td><td>Passenger vehicle with trailer</td></tr>
<tr><td>Truck (>3.5 ton) without trailer</td><td>Truck (>3.5 ton) without trailer</td></tr>
<tr><td rowspan="2">Truck (>3.5 ton) with trailer/semi-trailer truck</td><td>Truck (>3.5 ton) with trailer</td></tr>
<tr><td>Semi-trailer truck</td></tr>
<tr><td>Bus</td><td>Bus</td></tr>
</table>

Note: Heavy traffic consists of the blue types (truck with/without trailer, semi-trailer truck and bus)

Source: BASt (n.d.-b)

Table B3

Automatic counters to construct Figure 11

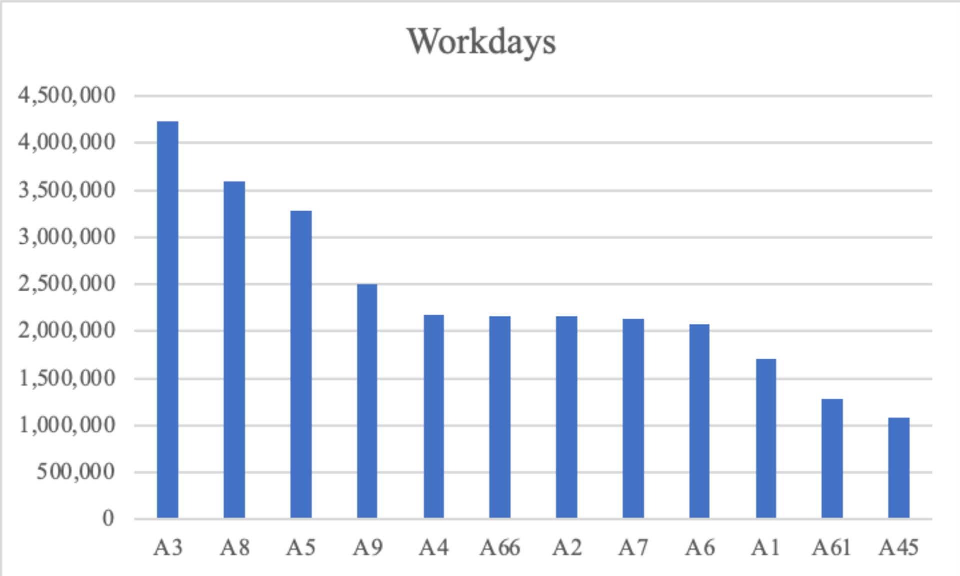
Number of counter	Name of counter	Bundesland	Road name	Daily number of motor vehicles	Daily number of heavy traffic (> 3.50 tons)	Share of trucks (%)
More than 120,000 vehicles and more than 20,000 heavy traffic						
6872	Frankfurter Kreuz (O)	Hessen	A3	127,900	21,533	16.8
5676	AK Leverkusen (S)	Nordrhein-Westfalen	A3	150,596	22,766	15.1
5672	AD Heumar (N)	Nordrhein-Westfalen	A3	166,261	24,168	14.5
6959	Heusenstamm	Hessen	A3	148,281	23,262	15.7
5004	Leverkusen	Nordrhein-Westfalen	A3	143,917	20,212	14.0
5049	Rheinbr. Rodenkirchen	Nordrhein-Westfalen	A4	126,870	21,400	16.9
8023	Karlsruhe 1	Baden-Württemberg	A5	131,269	23,599	18
8073	Stuttgart-Vaihingen	Baden-Württemberg	A8	139,776	21,759	15.6
More than 20,000 heavy traffic						
2411	HB-Mahndorfer See	Bremen	A1	96,006	20,904	21.8
2401	HB-Weserbrücke	Bremen	A1	113,320	20,355	18.0
3837	Alleringersleben	Sachsen-Anhalt	A2	68,962	23,350	33.9
3421	Beienrode	Niedersachsen	A2	73,302	21,835	29.8
3429	Braunschweig-Flughafen	Niedersachsen	A2	74,951	20,706	27.9
3492	Groß-Munzel	Niedersachsen	A2	85,043	22,172	26.1
3439	Hannover-Bothfeld	Niedersachsen	A2	102,307	21,742	21.3
3433	Hannover-Ost	Niedersachsen	A2	81,494	20,091	24.7
3489	Immensen	Niedersachsen	A2	89,161	23,373	26.2
3305	Lauenau	Niedersachsen	A2	77,925	22,073	28.3
3486	Meerdorf	Niedersachsen	A2	82,139	22,148	27,0

5026	Oberhausen-Sterkrade	Nordrhein-Westfalen	A2	110,264	22,466	20.4
3306	Peine	Niedersachsen	A2	82,966	22,331	26.9
3487	Peine-Ost	Niedersachsen	A2	73,314	20,848	28.4
3495	Rehren	Niedersachsen	A2	71,879	21,610	30.1
3496	Rinteln	Niedersachsen	A2	67,597	20,865	30.9
3485	Schwülper	Niedersachsen	A2	85,342	22,867	26.8
3484	Watenbüttel	Niedersachsen	A2	85,688	22,510	26.3
5070	Oberhausen-Holten	Nordrhein-Westfalen	A3	109,130	22,293	20.4
4105	Rothschönberg	Sachsen	A4	79,154	22,319	28.2
8020	Büchenau	Baden-Württemberg	A5	91,829	20,533	22.4
8021	Karlsruhe-Hagsfeld	Baden-Württemberg	A5	115,913	22,711	19.6
6808	AD Hattenbach	Hessen	A7	81,231	22,878	28.2
8140	Warmbronn	Baden-Württemberg	A8	96,184	20,151	21.0
More than 120,000 vehicles						
6822	Rödelheim	Hessen	A5	120,276	14,641	12.2
6923	Frankfurt-Niederrad	Hessen	A5	126,864	15,777	12.4
6821	AK Frankfurt NW (N)	Hessen	A5	132,170	17,807	13.5
9115	AK München-Nord (N)	Bayern	A9	120,763	-	-
2014	Britz	Berlin	A100	124,096	6,926	5.6
2006	Friedenau (N)	Berlin	A100	135,182	8,168	6.0
Roads with high heavy traffic density						
3601	Lehnin	Brandenburg	A2	53,272	15,123	28.4
8158	Sinsheim-Steinsfurt	Baden-Württemberg	A6	59,033	16,810	28.5

Source: BASt (2021)

Figure B1

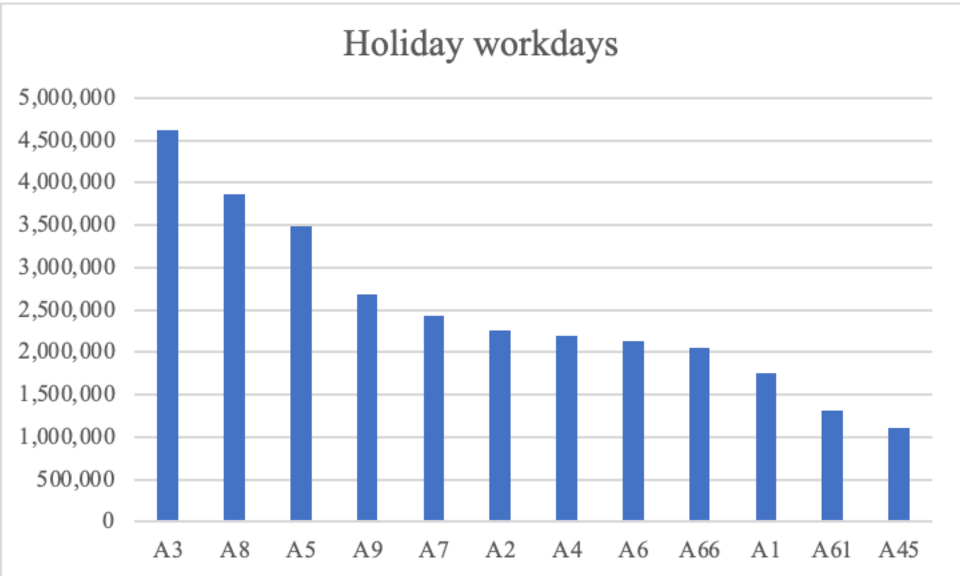
The average number of motor vehicles per day on the German highways on workdays in 2021



Source: BASt (2021)

Figure B2

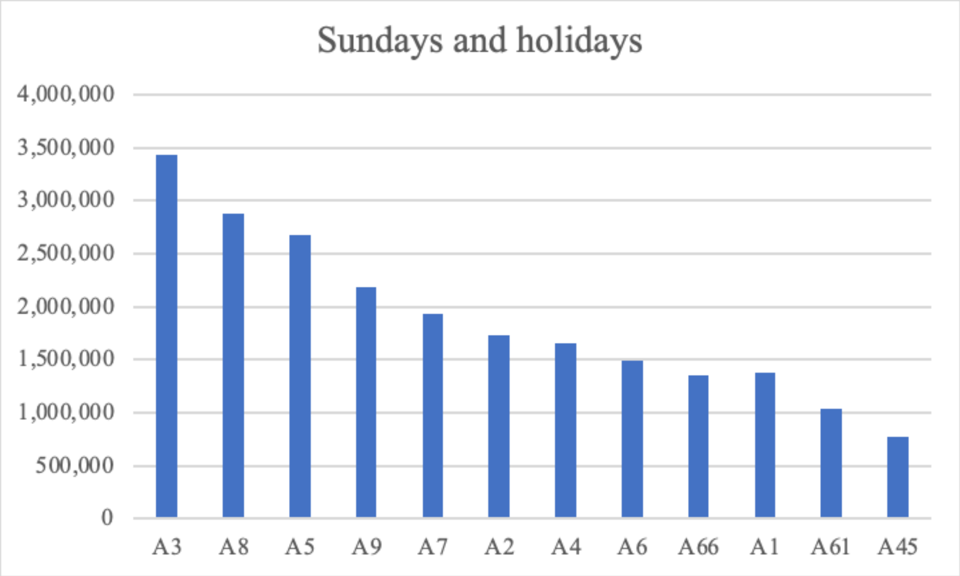
The average number of motor vehicles per day on the German highways on holiday workdays in 2021



Source: BASt (2021)

Figure B3

The average number of motor vehicles per day on the German highways on Sundays and holidays in 2021



Source: BASt (2021)

Table B4

CO_2 emissions (g) per tonne-km for container transport

Transport mode	CO_2 emissions (g/tonne-km)
Rail (73% electric, 27% diesel)	18
Road	121

Source: CE Delft (2021)

Table B5

Cost figures for the railway transport and trucks + trailers in 2018

Costs (€) per tonne-kilometer	Truck + trailer	Train
Fixed costs	0.009	0.006
Variable costs	0.043	0.003
Staff costs	0.051	0.002
Mode-specific costs	0.001	0.004
General operating costs	0.011	0.002
Total costs per ton-km	0.115	0.017

Source: Van der Meulen (2020)

Table B6

Terminal costs

Terminal	Costs (in euros)
Kaldenkirchen	14.50
Frankfurt am Main	71
Passau	67
Salzburg	30
Burghausen	28

Note: the terminal costs of Kaldenkirchen are assumed to be the same as for the terminal of Venlo

Source: KombiTerminal Burghausen GmbH (n.d.) for Burghausen, CMA CGM (n.d.) for Frankfurt am Main, Passau and Salzburg, and TX Logistik AG (n.d.) for Kaldenkirchen/Venlo

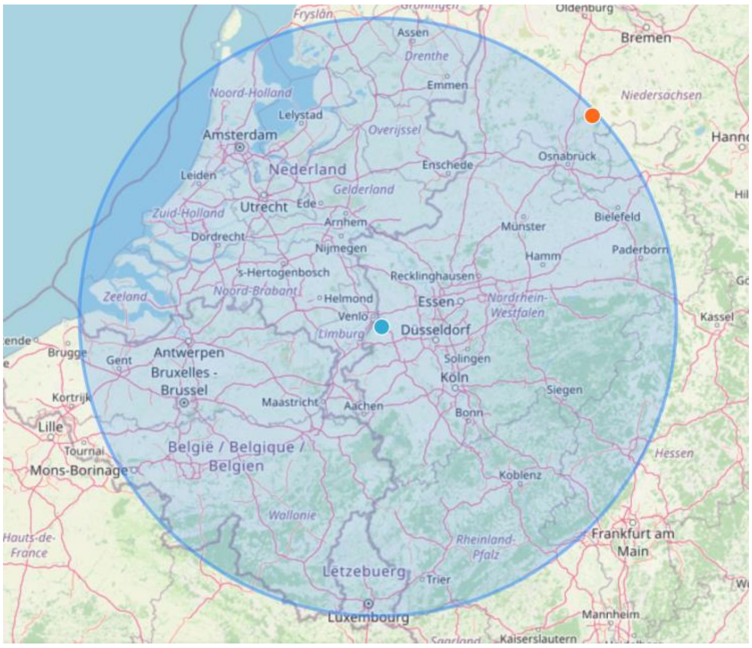
Table B7

Main subjects in the interviews

Subject ID	Main subject
1	Important aspects of a transport service
2	Route specific
3	Rail terminal
4	Transition to intermodal transport
5	Multimodal transport

Figure B4

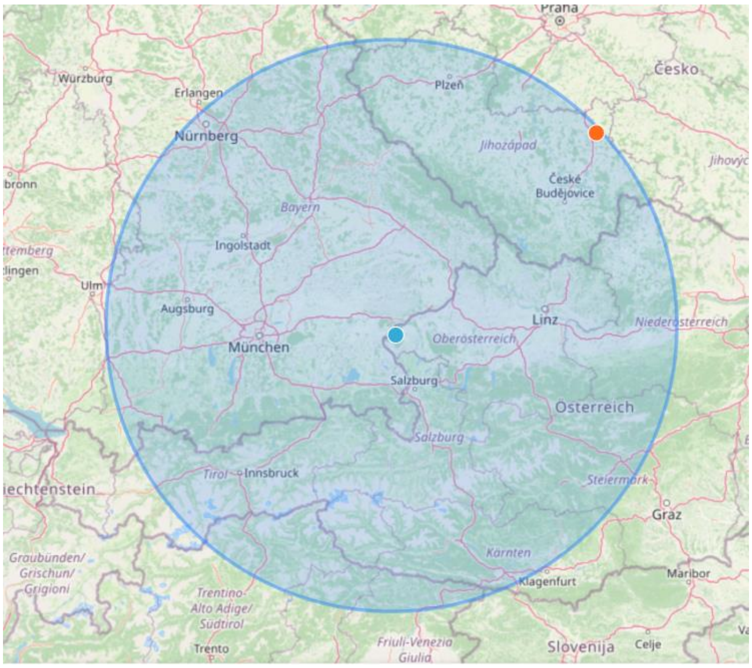
200 km radius around the terminal in Kaldenkirchen



Source: Maps & directions (n.d.)

Figure B5

200 km radius around the terminal in Burghausen



Source: Maps & directions (n.d.)