Feasibility of an intermodal transport solution towards Northern Europe using Portuguese ports

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Comparative study of Maritime versus rail network transport systems for containerized cargo The

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Abstract

Global maritime freight transportation systems are dynamic, expansive, and integrated. The same is true regarding local and regional systems. Therefore, analyzing the sections requires an understanding of all the components that supply chain has and understanding how to apply the relative cost associated with each dynamic activity.

The overall complexity of the supply chain, related to this freight transport system with intermodal networks leads to many questions related to time, costs of containerized goods transported, planning, and investments. In the intermodal case the study reviews the components affecting maritime and rail transport.

This thesis presents a case study on comparative results of the transportation of goods from different regions to Europe using maritime route and the intermodal link to German terminals. The case study analyses the total costs associated with rail sections in the various countries along the Atlantic rail freight corridor RFC4. This is compared to the resulting values by transporting freight through rail freight corridor RFC2 to Germany. In the analysis of the routes from South America to Western European ports, the analysis is to find the combined intermodal unitary cost through maritime connection nodes of Northern European ports, and rail transport to Germany. The main aim is to create a distinction in route options and analyze the unitary cost associated with intermodal travel. In this context, the comparisons of the routes are in association with the arrival of freight at the Portuguese ports with focus on Sines and Lisbon. The options are in relation to the supply of containerized cargo to Mannheim in Germany from the Portuguese ports either by the current rail trajectory through Vilar Formoso or the projected route development of Badajoz. Goods transported from maritime terminals at Northern European Ports are then transported the respective ports to Köln.

The second route option consists of transporting goods directly to the port of Sines and then additional shortsea to Rotterdam. Comparisons are made of the unitary cost per container cargo on the combined intermodal route. The various route options are compared. These include the options of transportation to Portuguese ports and the other the routes to the Dutch port of Rotterdam by either conventional or Betuwe lines.

The thesis makes a review of routes from South Africa to the Portuguese ports of Sines and Lisbon where the rail section then travels through either Vilar Formoso or Badajoz to Mannheim. The other makes use of a route going from South Africa to Rotterdam. The container then travels to Köln by either conventional rail route or compared to alternative Betuwe-line. The analysis was made additionally to the expected time of arrival of the first and last containers. Effects of emissions on the various intermodal routes are reviewed.

In a similar manner, the route between. The route between the North American port of New York and the Portuguese ports of Sines and Lisbon was compared to the transportation of goods to the port of Rotterdam and to Köln. The review was made into the associated maritime costs of the vessels and the associated costs in the transportation of reefer cargo.

This thesis objective was the creation of a modeling framework that dealt with the analysis of the transport networks from Portugal to hinterland Europe. The main analyses were on the containerized freight cargo from the South-America, North America, and Africa to Europe by selection of directly traveling to either Portuguese ports or to northern European ports. The analysis was to determine the costs of sea vs intermodal transport. This analysis carried out cost estimation and projections related to project completion along the Atlantic corridor rail network route. The models which were developed have the objective of evaluating the feasibility of using the Portuguese ports to convey containerized cargo towards Northern Europe.

Keywords:

Intermodal transport, Maritime transport, Logistics, Rail transport, Freight costs, Greenhouse gases emissions

Resumo

Os sistemas globais de transporte marítimo de mercadorias são dinâmicos, expansivos e integrados. O mesmo acontece com os sistemas locais e regionais. Portanto, a analise dos sistemas de transporte requer uma compreensão de todos os componentes que a cadeia de abastecimento tem e compreender como aplicar o custo relativo associado a cada atividade dinâmica.

A complexidade geral da cadeia de abastecimento, relacionada com este sistema de transporte de mercadorias com redes intermodais, leva a muitas questões relacionadas ao tempo, aos custos de transporte de mercadorias transportadas, ao planeamento e aos investimentos. Como tal, estudos e analises de sensibilidade sobre o transporte marítimo e ferroviário, dentro destas cadeias de abastecimento são do maior interesse.

Esta tese apresenta um estudo de caso sobre resultados comparativos do transporte de mercadorias da rota marítima existente da América do Sul para a Europa e do link intermodal para os terminais do *hinterland* alemão. O estudo de caso analisa os custos totais associados às secções ferroviárias dos vários países do corredor ferroviário. O corredor ferroviário do Atlântico (rede RFC4 ferroviário), em comparação com os valores resultantes do corredor 2 RFC2 a partir da conexão dos portos do norte da Europa através da conexão marítima ao conjunto Toda a rede ferroviária, com o objetivo de transportar fretes para a Alemanha. Os modelos e análises são utilizados para análises do transporte marítimo de mercadorias da Costa Leste da América do Sul, para os portos da Europa Ocidental. O objetivo principal é criar uma distinção nas opções de rota e analisar o custo unitário associado à viagem intermodal nas atuais versões. Neste contexto, as comparações das rotas estão em associação com a chegada do frete nos portos portugueses com foco em Sines e Lisboa. As opções estão em relação ao fornecimento de carga em contentores para Mannheim, na Alemanha, a partir dos portos portugueses, quer pela trajetória ferroviária atual através do Vilar Formoso, quer pelo desenvolvimento da rota projetada de Badajoz. Na opção de transporte até Roterdão, as mercadorias são transportadas dos respetivos terminais terrestres da Colonia.

A segunda opção de rota de transporte de mercadorias diretamente para o porto de Sines e, em seguida, viagens de mar curta adicional para Roterdão. Serão feitas comparações ao custo unitário para cada contentor na rota intermodal combinada. As várias opções de rota são comparadas. Estas incluem as opções de transporte para os portos portugueses e a outra as rotas para o porto holandês de Roterdão, seja por linhas convencionais ou Betuwe.

A tese faz uma revisão das rotas da África do Sul para os portos portugueses de Sines e Lisboa, onde a seção ferroviária passa através de Vilar Formoso ou Badajoz para Mannheim. A outra opção, faz uso de uma rota que vai da África do Sul a Roterdão. O contentor, em seguida, viaja para Colónia através de uma rota ferroviária convencional, alem de que comparado com a utilização da linha Betuwe alternativa. A análise foi feita adicionalmente ao horário esperado de chegada do primeiro e último contentor. Os efeitos das emissões nas várias rotas intermodais são revistos.

De forma semelhante, a rota entre o porto norte-americano de Nova York e o norte da Europa os portos portugueses de Sines e Lisboa, foi comparada ao transporte de mercadorias para o porto de Roterdão e dai para Colónia. A analise inclui os custos marítimos associados aos navios e os custos associados ao transporte ferroviário de carga.

O objetivo da tese foi a criação de modelos de viagem, que tratam da análise das redes de transporte marítimo para Portugal e para o interior da Europa. As principais análises incidem sobre a transporte de contentores da América do Sul, América do Norte e África para a Europa, através da seleção de viagens diretas para os portos portugueses ou para os portos do norte da Europa, os custos do transporte marítimo e ferroviário. Este analise foi integrada no contexto da estimativa de custos de investimento e das projeções relacionadas à conclusão do projeto da rede ferroviária do corredor Atlântico. Os modelos desenvolvidos têm como objetivo determinar qual a viabilidade de utilizar os portos portugueses para escoar carga contentorizada para o Norte da Europa.

Palavras-chave:

Transporte intermodal, Transporte marítimo, Logística, Transporte ferroviário, Custos de frete, Emissões de gases com efeito de estufa

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Acronym List

CES: Constant Elasticity of Substitution
CIS: Charging Information System
CO_2: Carbon Dioxide
CREG: Commission de Régulation d´Electricité et du Gaz
DWT: Deadweight
ECA: Emmission Control Areas
EICIS: European Infrastructure Charging Information System
ERTMS: European Rail Traffic Management System
ETS: Emission Trading System
FC: Fluorocarbons
GDP: Gross Domestic Product
HFO Heavy Fuel Oil
IMO: International Maritime Organization
ITU: Intermodal Transport Unit
LoLo: Lift on, Lift off ships (container ships)
MDO: Marine Diesel Oil
NOx: Nitrogen Oxides
OD or O-D: Origin-Destination
OSS: One Stop Shop
P&I: Protection and Indemnity (insurance)
PM: Particulate Matter
RFC: Rail Freight Corridor
RMG: Rail Mounted Gantry
RNE: Rail Net Europe
RNC: Rail Network Corridor
RTG: Rail Tire Gantry
SECA: SOx Emission Control Area
SC: Straddle Carrier
SOx Sulphur Oxides
SO2: Sulphur dioxide
SSS: Short Sea Shipping
STS: Ship to Shore Crane
TIS: Train Information System
TEN-T: Trans-European Network
TEU: Twenty-Foot Equivalent Transport Unit
UIC: International Union of Railway gauge (Union International des Chemins de Fer)
ULSFO: Ultra Low Sulphur Fuel Oil
VOC: Volatile Organic Compound

1. INTRODUCTION

1.1 Background and Motivation

Maritime transport is of paramount importance accounting for most of the global trade. Continued globalization increased the interdependence of nations resulting in new economic and environmental challenges for regional economic development. Globalization, economic growth and the rising economies in the third world and the BRICS countries (Brazil, Russia, India, China and South Africa) have tremendously increased the intercontinental flow of goods.

Annual growth rate of container flows currently and until 2020 is expected to rise, this after the previous global slow down. High pressure on ports and on their hinterland connections are expected from the changes arriving from additional supply and from the growth of ships and, as such, infrastructure developments for ships and intermodal connectivity are needed. This situation also highlights the need for forecasting tools and decision support systems.

Continental regionalization is a more constant occurrence This is particularly true of Europe with the developments of the European Union. Ports are increasingly being regionalized particularly in the European framework for unified flow. This has also led to Portuguese ports being included in greater supply chains, as well as the Northwest European ports. Furthermore, the terminals compete to gain their market share on the hinterland market. Finally, the European Union Commission policy is to promote the development of a unified transport sector.

These challenges lead to a need to develop models to help forecast and allow for the adaptation of transportation entities along ever increasingly complex and larger supply chains. As such development and implementation of freight transport tools that can consider intermodal and diverse nature of the supply and transport network is of increasing importance. freight transport needs to be analyzed in an integrated manner, where systems should be treated with a unified methodology.

The challenges run deeper still when confronted with rapid supply chain structure changes occurring from either commodity market dynamic else wise by the logistical and technological advancements. In general, attempts to model freight transportation systems have been purpose-made and suited for a specific analysis type. Freight transport modeling is considered by several authors to severely lag passenger transport in what regards both theoretical investigation and practical applications (Alho, 2011). Issues that led to this situation are the complexity of decision making process, the lack of a standardized modeling framework and the inherent limitations of disaggregated data availability.

The previous reasoning has led the desire to particularly look at the possibilities and status of infrastructure developments across Europe and the viewpoint from Portugal. This viewpoint was to gain a better quantitative review of ports of Portugal and key ports of Sines and Lisbon in relation to transshipment from maritime routes coming from regions along the Atlantic coast: North America, Africa, and South American East Coast. The motivation was to further investigate the possibility of rail transport from Portugal to the German hinterland market, to gauge the effect of rail transport.

The North American continent has had a great benefit from rail freight transport, whose economic success can be highly attributed to its early development in the 1800s. A coordinated network continues to reap dividends as the overloaded west coast now transfers capacity to the east coast whilst being able to maintain supply to the center of the continent through an efficient coordinated rail transport network. This thesis will elaborate on the rail freight corridor infrastructure status in western Europe.

The regional location of Portugal is at a meeting point of many of the motorways of the sea. This means that a very significant amount of shipping traffic passes off the Portuguese coast following established shipping lanes and routes described by the networks created to form the supply logistic network of shipping agents, ship owners, charters and shipping lines. The interest is reviewing just how significant the logistical position of Portuguese ports is with respect to liner services and how much potential it has.

A well-structured and understood freight network system allows for better supply chain analyses which in turn provides a stronger platform towards knowing where bottlenecks will occur and as such better coordination can be envisaged regarding congestion and market demands. The requirements for coordinated data to be available to analyze the impacts on the economic scale and further towards environmental and global macroeconomic effects are very slim in content.

The maritime structure in Europe is well established with feeder ports and with structured timetabling and capacities understood towards being feeder ports for Europe’s largest ports, feeding the hinterland European markets. In comparison to the scheduled maritime network system, the rail system portrays a very uncoordinated and disorganized network particularly in the European context since there is no real complete European railway system.

Freight transportation costs for maritime routes of established scheduled lines from; the South American East Coast, South Africa and North America, New York to Northern European ports were calculated. In a similar fashion the costs of freight transportation of projected maritime routes to Portuguese ports were calculated. The intermodal costs of the routes from respective European port to the German inland terminal was calculated. The purpose was to obtain a combined cost per unitary cargo transportation. The focus will be made on making comparisons on the supply from the current routes on offer to the proposed routes. The procedure reviews the costs, time and emission effects of the combined rail and maritime routes to transport dry and reefer cargo to the German hinterland.

The review is to evaluate the cost value per ITU of the transportation from the ports of departure from the respective continents to either Northern European ports and subsequently to the German hinterland market.

The options for intermodal transport units are for maritime routes which in the South American analysis, have goods travelling from Lisbon to Rotterdam. The containerized freight is then transported to Köln. In a similar way, the second options for the North American and African Route are to transport the goods directly to Rotterdam from the last port of departure of the respective continent Cape Town and New York. In similar fashion, the comparison is made for the intermodal transportation but traveling through Portuguese ports of Lisbon and Sines and then to Mannheim.

A review of the status of railway freight transport in Europe is made in this thesis. The review is to consider the economic, logistical environmental effects and attractiveness of utilization of the Atlantic corridor railways section. In addition, a review is done on the investments of Corridor 2. Further investigations will consider effects of emissions (primary energy inputs, CO2-emissions, other emissions), and the significant financial deficits of many railways. The market of economically viable railway transports in Europe is highly concentrated on a well-defined region and some related corridors.

Currently, the rail network is fragmented across Western and Central Europe, many countries are relatively small compared to such distances so that national railway freight transport is on the edge of profitability in several countries. Thus, it appears to be a perfect idea to dedicate railways, particularly for the international freight transports. That is why the EU has covered Western and Central Europe with a grid of international rail freight corridors to be further developed which also serve as a starting point for a future multimodal core freight transport network. The implementation of these freight corridors is a further step forward in a long history of policy measures to foster inter- and multimodality such as, for instance, the Second Railway Package of 2004 (European commission, 2002) which aimed at opening all European railway networks to freight trains from other countries. This is underpinned by EU’s TSI policy (Technical Specifications for Interoperability) for a better interoperability of freight rolling stock and infrastructure. The European Union´s new strategy for job creation and growth has an essential factor of the internal rail market and freight to sustainable mobility. A new structure and directive were established in November 2012 as Directive 2012/34/EU of the *European* Parliament and Council.

The implementation of rail freight corridor network, is to be consistent with Trans-European Transport Network (TEN-T) and the European Rail Traffic Management Service (ERTMS). The Atlantic Corridor 4 was established on the 10 of November 2013, envisaged that the corridor extension shall reach Mannheim and Strasbourg. This corridor crosses the international borders of France, Germany, Portugal, and Spain (European Economic interest group, 2015).

1.2 Atlantic Corridor Nº4

The main technical specifications for the Atlantic Rail Corridor for goods should be:

- Electrification of the entire route (25,000 V)
- Track gauge UIC (1,435 mm);
- Loading gauge UIC-C;
- Maximum axle weight: 25 tons;
- Maximum length of trains: 1,500 m;
- Maximum inclination grade: 12 %;
- Safety system: ERTMS;
- Interoperable locomotives and wagons;
- Bypass routes for the great urban agglomerations;
- Service 24 hours x 365 days;
- Infrastructure usage fares that are homogeneous and reasonable.

The electrical power supply and command and control systems, are not harmonized across Europe, driving up locomotive cost (from changing locomotives or by the additional costs of deploying multi-system locomotives). The same holds especially for the freight wagons, with associated difficulties with manual couplings, unfavorable bogies, and brake systems; the latter ones also causing substantial troubles of noise.

International train requires coordination of two or more infrastructure managers. Moreover, there are deficiencies in parts of the infrastructure (like bottlenecks or temporary downgrades), and particularly within big network nodes. These causes contribute significantly to the explanation of the stagnation of EU rail freight.

1.3 Objectives

The objectives of this thesis are to do a review of the literature, to determine the feasibility and opportunities on offer for Portuguese ports of Lisbon and Sines in relation to containerized cargo coming from South America, Africa, and North America to be transshipped to the hinterland market in Germany. The focus will be on the maritime route and the infrastructure developments in rail that have and are to be accomplished along the Atlantic Corridor route.

The routes in question are for the continental origins of either South American East Coast, North America from New York, and South Africa. The vessel will travel to either the ports of Sines and Lisbon (Portugal), the alternative route is to Rotterdam. Alternatively, there is a unitary containerized cost comparison of these routes and the short sea option of transportation from Sines to Rotterdam and then onto the German hinterland market as opposed to the transportation of freight through the Atlantic Corridor to German hinterland market from the Port of Sines. This is for the South American East Coast analysis for comparison of costs associated with using principally Northern European ports of call.

The other two routes are a North American route from New York direct to Rotterdam and then onward to Köln either by conventional route or by the Betuwe. This is compared to the traveling from New York to Portugal by Sines and Lisbon. The next route is the comparison of traveling from South Africa to Sines and Lisbon compared to that of Rotterdam. The rail routes from Portugal compare the projected Badajoz route to Mannheim in comparison to the route through Vilar Formoso currently utilized.

The review of the containerized transport network of the Atlantic corridor section of Europe has the flowing procedure.

- Review of maritime costs from ports of departure to ports of destination from respective continents;
- Review of rail freight costs from Northern European ports to Köln and from Portuguese ports to Manheim;
- Review and comparison for the combined sum of the maritime and rail components to the terminals of offloading in Germany;
- Assessment of handling capacities of respective ports;
- Determination of annual cost of combined intermodal transport for respective routes;

1.4 Outline of the thesis

The thesis is organized into five chapters and four appendices.

Chapter 1-introduction, introduces the topic to be discussed the related background and including the goals and structure of the work

Chapter 2-Litrature Review, contains the description of the TEN-T 4 Rail Network infrastructure. The chapter will discuss dedicated aspects of maritime and rail transportation. Chapter 2 will elaborate on the rail and maritime aspects of intermodal transportation and its relation to routes traveling to the western European ports of call along the Atlantic corridor 4 and Rhine-Alpine Corridor 2. The European regional economic division is discussed, and the relative influences and difficulties associated with developments along the Atlantic corridor. Chapter 2 also discusses the current rail problems encountered on the corridor 4 rail network. The corridor 4 planned status of projects and the forecasts of the project completion are also revised, and the subsequent effects for container cargo are indicated. The chapter includes the results of non-completion of the Ten-T4 route and its influence on employability

Chapter 3-Methods used for Cost, Transit Time and Emission Calculations, introduces the methodology used in this Thesis, by presenting the architecture and a functional description of each of the components. Every component part will be discussed and the related philosophy and the mathematical formulation for each of the different sections of the evaluation method are undertaken. This chapter will give the description of how the development of cost calculation estimations for the fixed costs, variable, and tariff related charges that are in association with the journey costs. The voyage costs will be the cargo handling costs, port charges, and fuel. The fixed costs are then evaluated from associated capital costs, and operating costs. The chapter elaborates on how each country´s tariff charges are calculated. It also displays the costs structure associated with variable and fixed costs and how these were determined.

Chapter 3 also elaborates on how the quantity of TEU have been delivered at each port and the total quantity supplied in accordance with the equipment and time spent at each relevant port along the maritime route. The chapter explains how the fuel consumption was calculated and how the purchase price of acquisitions was determined.

Chapter 4-Results, displays the results of the calculations described in the methodology chapter. It begins with results of research on each of the specified maritime routes. It displays the results of the costs associated with maritime transport on each specific maritime route. The results for each maritime route are then developed further through the display of results of the associated rail routes where cargo offloaded at the respective ports of call are then transported by rail by either corridor 2 or 4 to the German hinterland terminals of Köln and Mannheim respectively.

The comparative results from the source material for both rail and maritime-associated costs are displayed in this section. The calculated costs associated with operating and capital costs are shown. This chapter shows for each maritime route the costs of handling, port dues and fuel consumption, with respective costs and sensitivity to price and speed of operation for the aforementioned fuel consumption. The tariff charges for rail and comparative variable and fixed costs are shown in this chapter with the resulting combined cost and effective cost per intermodal unit transported to Germany by the respective routes.

The associated emissions calculations and expected time delivery of cargo for the combined intermodal route is calculated and displayed for each specific route from the continent of origin. The effects of emissions are done comparatively for each subsection maritime route. As such it is divided into the three routes of South America, South Africa, and North America. The chapter continues to display the results of emissions of SO_2, NOx, VOC, FC, PM, and CO_2 for both the maritime and rail sections of the transportation of freight.

Chapter 4 continues to display the combined results of current routes and projected intermodal routes of transportation of freight from maritime origins and along the rail to the hinterland market in Germany.

Chapter 5-Conclusions, presents the conclusion and summary of the results of the model when applied to a specific maritime trade routes from the South American East Coast, South Africa and the East Coast of the United States to Northern Europe.

2. LITERATURE REVIEW

2.1 Intermodal Freight Transportation

The movement of goods between locations by freight transport often involves the combination of different modes of transportation. These intermodal movements may apply multiple different modes of transportation, linked end-to-end, to move freight from a point of origin to a point of destination. Freight supply chains also incorporate the need for door to door supply which means that the entire systems can organize the transportation of goods from the point of origin to the final customer. Freight transportation is carried out on a global intermodal network composed of various actors that demand and provide transportation services (Pfeifer, 2013). The freight movement includes services by means of airplane, truck, train, or ship, as well as the transfers for moving cargo between the modes. There are also a variety of stakeholders that include customers, service providers, and governments each will have their own different interests that cause impacts on freight transportation networks and services. Complex relations also exist between the actors and the stakeholders involved. Therefore, it is important to consider freight transportation as an integrated system (Crainic, 2007).

Maritime transportation refers to freight transportation from an inland origin to an inland destination that includes the use of ocean shipping. Ocean shipping is the most utilized and efficient way to transport large volumes of cargo between continents and represents between 65% and 80% (Christiansen, 2012) of total international trade. This takes advantage of economies of scale aimed to the size of the vessel allowing for a large reduction in unit cost per item transported. A generalized description of the type of goods to be shipped in conjunction with the type of packaging that the goods will be shipped in affects the maritime shipping demand, this, in turn, determines the size and frequency of the shipments.

Seaports are increasingly functioning as the hubs from which the hinterland is supplied with imported goods, and where goods that need to be shipped to the hinterland market are grouped together and loaded from ships that come from other hubs or feeder ports from an origin that maybe a hinterland with associated market. As the capacity of hinterland transportation rarely corresponds, with the volume of goods to be transported to and from its port, from the moment of loading and unloading a vessel does not always correspond to the moment of loading of the hinterland mode, the distribution function of the port inevitably involves the storage of goods. A port itself can also be considered as a chain consisting of consecutive links (e.g. ship unloading, storage transport, storage, loading transport, hinterland loading). The ports as such can be in competition with it each other to be a link within these global logistic chains. However, the competition is more closely linked to the terminal of these ports which deal with the specific type of cargo that is aimed to be transported to a specific hinterland market, (e.g. the port of Sines and port of Algeciras aiming at the Madrid hinterland). The level of competition between ports in the North-West European port range differs strongly by cargo type.

The important elements for a port in the supply chain are:

- Availability of hinterland connections;
- Attainability of consumers;
- Maximum depth of port approaching route;
- Port ship turnaround time productivity;
- Reliability (absence of labor disputes);
- Reasonable tariffs;
- Degree of congestion.

The hinterland connections, attainability of consumers, port productivity and reasonable tariffs were most frequently mentioned as important criteria by the container carriers.

2.1.1 Port and hinterland infrastructure planning

The European Union and the Ports themselves respond to the expected growth of the market with large investments. These investments focus on the components of the transport chain, maritime access, port capacity and efficiency and hinterland transport. Developments in the maritime industry with increases in ship dimensions and hence the advantages of scale lead to the fact that many ports in Portugal, need to deepen their maritime access to improve their accessibility for ships of over 8,000 TEU and recently of 13,500 TEU (ship Emma Maersk). The same occurs in the Le Havre-Hamburg range but, the container handling capacity is growing fast in the Le Havre - Hamburg range, because of private investments in terminal capacity. Rotterdam, Antwerp, Bremen and Hamburg terminal capacity in these ports is planned to double, from 37 million TEU in 2005 towards 70-80 million TEU in 2020. (Hamburgsüd, 2015); (Zondag, 2008).

Port flows, and the utilization of the new infrastructure are not only dependent on trade developments but also on the developments in the market shares of the ports. Such port competition modeling framework should integrate developments in a trade by origin, destination and cargo type, in ship sizes, maritime access, port capacity and efficiency, and hinterland transport. It is necessary to encompass the parameters in order to evaluate the investments under different economic and maritime scenarios while including the effects of developments in competitive ports (Zondag, 2008).

2.1.2 Route/logistic chain components

A port is a link in a logistic chain. Future freight flows by the port are a factor in the choices towards the forecasting and modeling of logistic chain. The modeling does not need to cover the full logistic chain between origin and destination of the goods. The logistic chain in the modeling focuses on the part for which the competitive position for import and export of the port alternatives in the modeling differs. A full chain can consist of hinterland – port – sea – port – hinterland or more complex chains if for example sea-sea transshipment is also included. The thesis investigates maritime costs resulting from sea-sea transshipment and intermodal transport costs of container transport to the hinterland market terminals. The three core components of the logistic chain in the modeling are therefore sea transport and access, port handling and hinterland transport. The maritime component consists of sea transport costs and times between port of origin and destination. This can be further increased from additional sailing costs to ports (e.g. sailing Scheldt river to Antwerp), as sailing windows are dependent on the tidal cycles and draft of the respective ship (Zondag, 2008).

2.2 Maritime Transportation

2.2.1Supply of Maritime Transportation

In the models in question, a specific instance of a maritime transport supply consists of two legs or a three legs segment when transporting freight from a port of origin to an inland destination. The first leg is the movement of the cargo from maritime ports of origin, transported along a maritime route to the destination port terminal. The second leg of the operation is the freight movement from the destination port terminal to the inland destination. The second option is a case of transshipment where there are two maritime legs from 2 ports and the final leg being the inland leg to the hinterland terminal. The inland legs of the transport operation are often referred to as the hinterland legs of the operation. Each of these segments requires the supply of a transportation service to accomplish the demanded cargo movement (Pfeifer, 2013).

2.2.2 Demand for Maritime Transportation

The demand is based on the supply to ports in accordance with the port schedules and time to offload the respective ships that call at the respective ports. The cargo physical description is related to the containerized cargo of twenty-foot equivalent units, the origin and the destination of the cargo, the service level required by the party that demanded the shipment, and the time span of the shipment it to be completed in. For reasons of simplification, the demand is defined by the capacities of the hinterland terminals.

2.2.3 Planning Levels in Freight Transportation

In freight transportation systems, the planning makes a general association of three levels Strategic, Tactical and operational. The transportation system also needs to consider the temporal aspects of the model (Pfeifer, 2013).

2.2.3.1 Strategic Planning

The concerns of the design of a freight transportation network and the related long-term planning (longer than a year), which determines general planning, and from the long-term perspective focuses on the trends of the transportation system is strategic planning. Decisions of strategic planning relate to transport capacity expansions and changes to tariff policies, involving the allocation of physical terminals, transshipment hubs, and other infrastructures that facilitate freight transportation. The many levels where strategic planning can take place can be either regional, national, or international. A firm’s objectives and scope in performance and planning give rise to the transportation system geographical range, which determines the geographical scope of strategic planning. Demands on strategic planning require tactical or even operational information creating overlaps between strategic and tactical and/or operational decisions (Christiansen, 2012).

2.2.3.2 Strategic Planning in Maritime Transportation

Strategic planning in maritime transportation covers wide range issues from the design of a transportation service to the selection of contracts. The nature of maritime transportation leads to often a volatile and competitive environment which provokes complications to the strategic decisions which often need to be based on market forecasts. Most strategic shipping decisions are on the supply side and include, according with (Christiansen, 2012):

- Market selection;
- Fleet size and mix;
- Transportation system/service network design;
- Maritime supply chain/maritime logistic system design;
- Ship design.

2.2.3.3 Tactical Planning

Tactical planning is medium-term planning, where freight transportation system has the resource allocation determined. Medium-term planning is responsible for determining the entities that operate on the physical transportation network. Increased effectiveness and efficiency, through the application of carrier specifications and service type specifications, are measures of medium-term planning. Depending on the type of service under consideration and the scope of the company performing the planning, results in tactical planning occurring either across multiple modes of transportation and transshipment facilities or for a single mode of transportation.

2.2.3.4 Tactical Planning in Maritime Transportation

Maritime Transportation's tactical planning focuses on routing and scheduling of ships meeting transport demands (Christiansen, 2012). Problems associated with tactical planning include:

- Adjustments to fleet size and mix;
- Fleet deployment (assigning ships to trades);
- Ships routing and scheduling;
- Inventory ship routing;
- Berth scheduling;
- Crane scheduling;
- Container yard management;
- Container stowage planning;
- Ship management;
- Distribution of empty containers;

2.2.3.5 Operational Planning

Local and operational management perform short-term planning by means of Operational Planning. Operational planning includes scheduling and implementing carriers, freight services, crews, and maintenance activities. Operational planning must effectively and efficiently plan the routing and allocation of the carrier to fulfill a demanded transport service. Operational planning may also include the selection of transportation services to provide to return the most profit. Operational Planning problems in maritime transportation include:

- Vessel speed selection;
- Environmental routing concerning individual voyage legs;
- Ship loading.

2.3 Rail network considerations

The railway industry is of vital importance for many countries. All railway companies aim to achieve regular and more reliable train services, to satisfy their customers both in terms of passenger and cargo delivery times. Logistics of train schedule is a methodology for optimization of these services for quality and organizational improvement. Railway operators plan train services in detailed timetables, for example, defining the train order and timing, at junctions and platforms.

With reference to freight coordination between the transfer of containerized cargo and the correlation between the entire scheduled time for deliveries is to be achieved. Timetables should consider minor delays occurring in real-time. However, there are always risks which occur from unexpected events such as technical failures, track incidents, etc., that can cause primary delays, which affects the running times, dwelling and departing events.

Regarding the entire supply chain, the interaction between trains, these delays are propagated as secondary delays to other trains, and so, disturbing the entire network. Therefore, train dispatching is very important. Not only do dispatching orders keep the railway safe from collisions but also have the objective of minimizing secondary delays throughout the network. Train dispatching currently relies on human operators that use elementary Decision Support Systems (DSS).

2.3.1 European Rail

2.3.1.1 Common Transport Policy

After the second world war, Europe was weak economically and politically requiring a rebirth. The objective was to make a collective effort and in new unison create common infrastructure in a multitude of sectors and industries one being the transport network. The common transport policy is a starting point for the success of the free movement of people and goods. In 1957, it signed the Treaty of Rome that aims to abolish customs barriers and support the flow of trade with a view to further objective achieving a single market.

In the late eighties member states focused their transport level concerns on the underdeveloped states and neglected this sector of the economy in Europe. The EC White Paper (1985) on the - completing the internal market sets the timetable and program for carrying out the guidelines expressed in the treaty, proposing a free internal market and the elimination of factors that distort competition.

2.3.1.2 Railway reduction of market share

This sector, from the '70s, has had serious challenges towards revitalization, leading to the intervention of the European Union through the railway reform. The segments of passenger service and goods were both negatively affected by the decline of the sector. In relation to transport of goods, the number of kilometers traveled by train decreases 22.3% from 1970 to 1994, while the number of kilometers for passenger transport increased 36.6% at the same time. However, the increase in the volume of passenger traffic cannot be considered a success as it grew timidly for thirty years and is a minimal increase when compared with in other modes of transport: road (121.9%) and air (490.7%), (EC White Paper, 1996).

The European Commission also addresses the causes of the sector's decline in the White Paper of 1996. The road sector is more competitive as it is flexible and less costly, mainly because the price does not include the costs of externalities that are higher in this sector than in others. The evidence of decline and clarity of the causes of it, imply that Member States are forced to rethink and step up legislation to the railways, which occurred in the early nineties.

2.3.2 TEN-T Atlantic Corridor Ports under focus

Railways have a competitive advantage compared to the roads for freight transport, on two conditions: The first is on greater transport distances, which is more favorable for railways. The longer distances on rail transport result in a lower variable cost for running a freight wagon in each train compared to high costs for auxiliary operations such as intermodal transfer, loading and unloading, empty wagon provision, and hunting. The second condition that benefits railways for carrying commodities are the larger shipment quantities. This advantage results from economies of scale in traction, wagon handling, and consolidation activities.

The central region highlighted by a blue contour is the so-called “Blue Banana”. Altogether some 148 Million people live in the Blue Banana. This corresponds to 28 % of the population of the European regions the Blue Banana produces some 36 % of the BIP of all these regions. The adjacent region at the left-hand-side will be called “Western Adjacency of the Blue Banana” (region 4). It encompasses the three largest metropolitan areas of France (Paris, Lyon, and Marseille) and has about 31 Million inhabitants, corresponding to 6 % of the population of all these regions, and produces 9 % of the GDP.

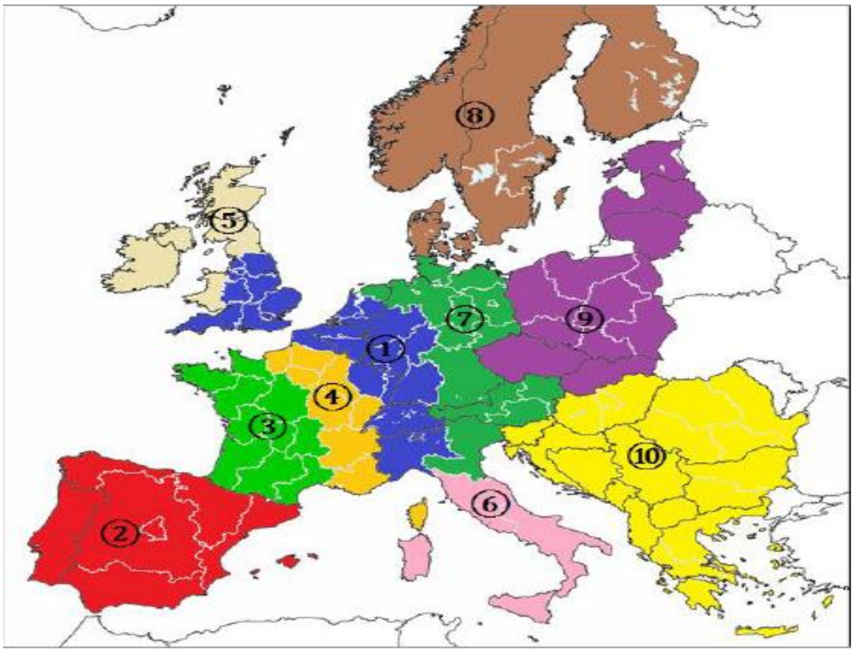


Figure 1 European Economic Regions

The Atlantic Arc runs through the economic regions of Iberia number 2, Western France number 3 Eastern France number 4 and finally into economic region number 1 “the Blue Banana” where, the hinterland terminals of Germany are found, likewise rail corridor 2 is found within the Blue banana region.

The population in the Atlantic Arc can be estimated at more than 80 million inhabitants (25% of the population of Eurozone) and is distributed around twelve urban agglomerations of more than one million inhabitants. The corridor is the shortest itinerary to get to Paris, London, Berlin, Northern and Eastern Europe or Russia. From an economic perspective, the Atlantic Arc accounts for 30-40% of the GDP in the Eurozone: more than 2 trillion Euros' worth of GDP.

Currently there is considerable modal imbalance, which should lead to an equal share of transport modes (to the benefit of sustainable ones, particularly railway and maritime transport) As an example, we could say that approximately 50% of freight traffic between the Iberian Peninsula and the rest of Europe takes place along the Atlantic corridor. Only 1% of this traffic takes place by rail and 16% by sea, the remaining 83% by road. This has led to saturation in the road infrastructure and to the standstill and unsustainability of the system. The goal of the Rail Corridor is to foster intermodal transportation through:

- Coordinate the planning and implementation of the different actions in the corridor;
- Improve the quality, competitiveness, and efficiency of the rail services;
- Promote rail as an alternative mode of road transport;
- Ensure interoperability in the rail transport of rolling stock, services and operators;
- Boosting the development and coordination of intermodal logistics centers and terminals.

2.3.2.1 Northern European Ports

The Netherlands has a dense railway network with a heavy basis charge from local, regional and inter-city trains. The national government and the regions are eager to promote the leading role of Rotterdam as major European port (but also of Amsterdam) by providing hinterland transport capacities at high quality for all modes, including railways. The Betuwe-route, a pure rail freight line, connects Rotterdam to the German border, thus constituting the Northern part of the central corridor (EU corridor No. 1, Rotterdam-Milano). The Betuwe-line should bundle practically all noisy and dangerous goods transports between Rotterdam and Germany.

The port of Rotterdam has recently improved by expansion of its hinterland options with the construction of a rail connection between Maasvlakte 1 and Germany (the so-called Betuwe-line; investment cost €4.7 billion). The port of Antwerp has similar ambitions by revitalizing the Iron Rhine railway connection to Germany. The Hamburg Senate will be investing €2.9 billion in all the above aspects to make the port fit for the future. The package includes deepening of the Elbe to enable even future generations of container ships to call at the port. Other investments are in new port facilities and container terminals, renewal of the port railway tracks and expansion of flood protection. (Zondag, 2008)

Germany can be called the “country of the corridors” as it hosts the longest parts of many international first tier railway corridors: (i) the central corridor from the borders of the Netherlands to those of Switzerland, (ii) the parallel North-South Corridor No. 3 with its main parts running from Hamburg to Munich and to the Austrian border (heading for the Brenner to reach the Eastern part of Northern Italy), and (iii) the East-West corridor No. 8 from the Belgian border at Aachen to Cologne and Duisburg, and further to Berlin and the Polish border.

2.3.3.2 Portuguese Ports

Lisbon port has a strong demand from its location inside the capital area with facilities along both banks of Tagus river. It centralized many logistic chains for the entire country. Results of 2013, indicated that 11,9 million tons of cargo have been shipped of which 45% were containerized. The port of Lisbon has three container terminals with different characteristics and utilization levels: Alcântara terminal, deep sea and already with utilization above 70%, Santa Apolonia Terminal, short sea, with 50% and Poço do Bispo (mainly insular traffic) around 80% utilization rate. Although here is still available capacity in global terms (overall utilization is 60%), a bottleneck can be identified at Alcântara terminal. Strikes of stevedores also had influenced in the container terminals previous years´ throughput. On the other hand, rail connection to the Spanish border has a considerable detour (of more than 135km)

Sines port is in the southern part of the Portuguese Atlantic coast, presently holds a relevant position in the world's shipping market, with direct lines to/from major production /consumption centers in the world (many of which use large vessels of over 14,000 TEU of cargo capacity), namely to/from two of the most dynamic markets worldwide: Asia and South America. The port has seen recently (2013) an impressive increase in traffic due to its hub & spoke (transshipment for large transatlantic vessels) positioning.

2.4 Atlantic Corridor

Totaling around 6200 km of existing lines, it includes heterogeneous characteristics of rail infrastructure from which we can describe the following key points:

- Tracks with standard gauge in France and Germany (1435 mm), Iberian gauge in Spain and Portugal (1668 mm);
- Itinerary with double track between Le Havre, Mannheim, Strasbourg, Metz, Paris and the south of Madrid (Santa Cruz de Mudela), the connection to Zaragoza and between Lisbon and Oporto;
- Itinerary with single track between the south of Madrid (Santa Cruz de Mudela) and Algeciras, in the 2 branches connecting Spain to Portugal (Medina del Campo-Pampilhosa & Manzanares-Entroncamento);
- Electrified itineraries by tri-tension (25000V~, 3000VCC, 1500VCC) between Le Havre, Metz, La Rochelle, Paris, Strasbourg Port du Rhine and the south of Cordoba (Bobadilla), 15000V~ from the French border to Mannheim and in Portugal between Sines, Lisbon, Leixões, Abrantes and Vilar Formoso (25000V~);
- Partially electrified itinerary (25000V~) on the 2 branches connecting Spain to Portugal (Medina del Campo Pampilhosa & Manzanares-Entroncamento);
- Non-electrified itinerary between the south of Cordoba (Antequera) and the port of Algeciras;
- Different signalization systems between Germany, France, Spain, and Portugal;
- Very variable maximum gross load charge per geographical areas connected to the topography of the existing network, with a load of 22,5 ton by axle on the totality of the route.

The rail network is still not attractive but with the projected developments will become a much more attractive proposition. In the Portuguese perspective, the rail networks attractiveness requires developments in Spain to reach regulation standards. The main criteria are the same train lengths. In addition, the need to have the network electrified in Spain. Portugal Itself is also required the standardization of train lines particularly for Corridor 04 which currently has specifically different train lengths to the standard.

Table 1 Ten-T Standardization Parameters of a unified rail network across the European Union (right) Percentage division of rail traffic usage in Atlantic corridor (corridor 04) (left)

TEN-T RNE Standardization Measures		
Atlantic Corridor		
Electrification		
Axle Load	22.5	t
Line Speed Freight	100	km/h
Train length	740	m
Management system	ERTMS	
Track Gauge	1435	mm

Percentage of the total rail network		
Passenger lines	31	[%]
Mixed traffic	70	[%]
Freight only	1.5	[%]

Table 1 provides the defining parameters for rail network project that has the objective of being connected by the year 2030. This allows the ability to have a unified standardized rail transport network across Europe. This eliminates the need to have changes of trucks, trains and container transfer between sections where there are disruptions in connectivity. Currently, the desire to transport containerized cargo to the European hinterland market is an unattractive prospect in this case due to the necessity to have to have many cargo transfers, along the desired routes. One of the largest difficulties facing Spain and Portugal is a large investment in changing the track gauge. Currently, Portugal and Spain have Iberian Gauge which is 1668mm limiting the size of wagons and containers that can be conveyed.

There are major problems that affect the possibility of rail transport. The Portuguese projects have deadlines from 2017 to 2020 which means in five years Portugal is in a position to exploit the rail network from within its own borders to the rest of Europe. The Spanish time frame has its deadline to end in 2030. The Portuguese complexity lies in that Portugal may require delays to the rail gauge related infrastructure since it requires the need to exploit the Spanish market. In this regard, Portugal would require the rail implementation to occur when the Spanish authorities begin the application on the connecting sections.

The maximum practical or permissible train length is limited directly by braking performance, longitudinal in-train forces and safety against derailment, and infrastructure constraints. These are the available length of terminals, yards, and passing sidings. The practical train length is also limited indirectly, by the maximum trailing mass.

As shown in Table 2 implementation of the TEN-T Atlantic corridor UIC track gauge, the following were found across the region;

- PTb+ in Portugal;
- Type A in Spanish freight lines;
- Three different load gauge types (A, B, B+) along the corridor freight lines in France;
- An in the corridor regions of Germany.

Permissible axle load is presently 22.5 tons or 25 tons in the entire German–Scandinavian corridor. In Germany, 22.5-ton axle load is generally permitted on mainlines

Table 2 Gauge differences along Atlantic corridor (right) Rail truck axle loading (left)

Track Gauge	Gauge differences along the Atlantic corridor		
Global required	58% completed	1435	[mm]
Compliance	France and Germany	1436	[mm]
Spain Madrid-Valladolid HS lines	Madrid-Antequera HS lines	1437	[mm]
Spain Madrid-Antequera HS lines	Madrid-Antequera HS lines	1438	[mm]
Portugal	None (Iberian gauge)	1668	[mm]
Rest Spain and Portugal	Iberian Gauge (Iberian gauge)	1688	[mm]

Axle load 22.5t	
All core sections good	
Abrantes-Puerto Allono	>22.5 axle trucks require up grading
Tours-Woipy	> 22.5 axle trucks on secondary route

2.4.1 Atlantic Corridor Status

The Atlantic Corridor, Shown in Figure 2 as defined in alignment by EU Regulation 1316/2013 (European Economic interest group. 2015), connects Europe's South-Western regions towards the center of the EU, linking the Iberian Peninsula ports of Algeciras, Sines, Lisbon, Leixões (Porto) and Bilbao through Western France to Paris and Normandy (up to the port of Le Havre) and further east to Strasbourg and Mannheim. It covers rail, road, airports, ports, railroad terminals (RRTs) and the River Seine inland waterway seen in Figure 2.

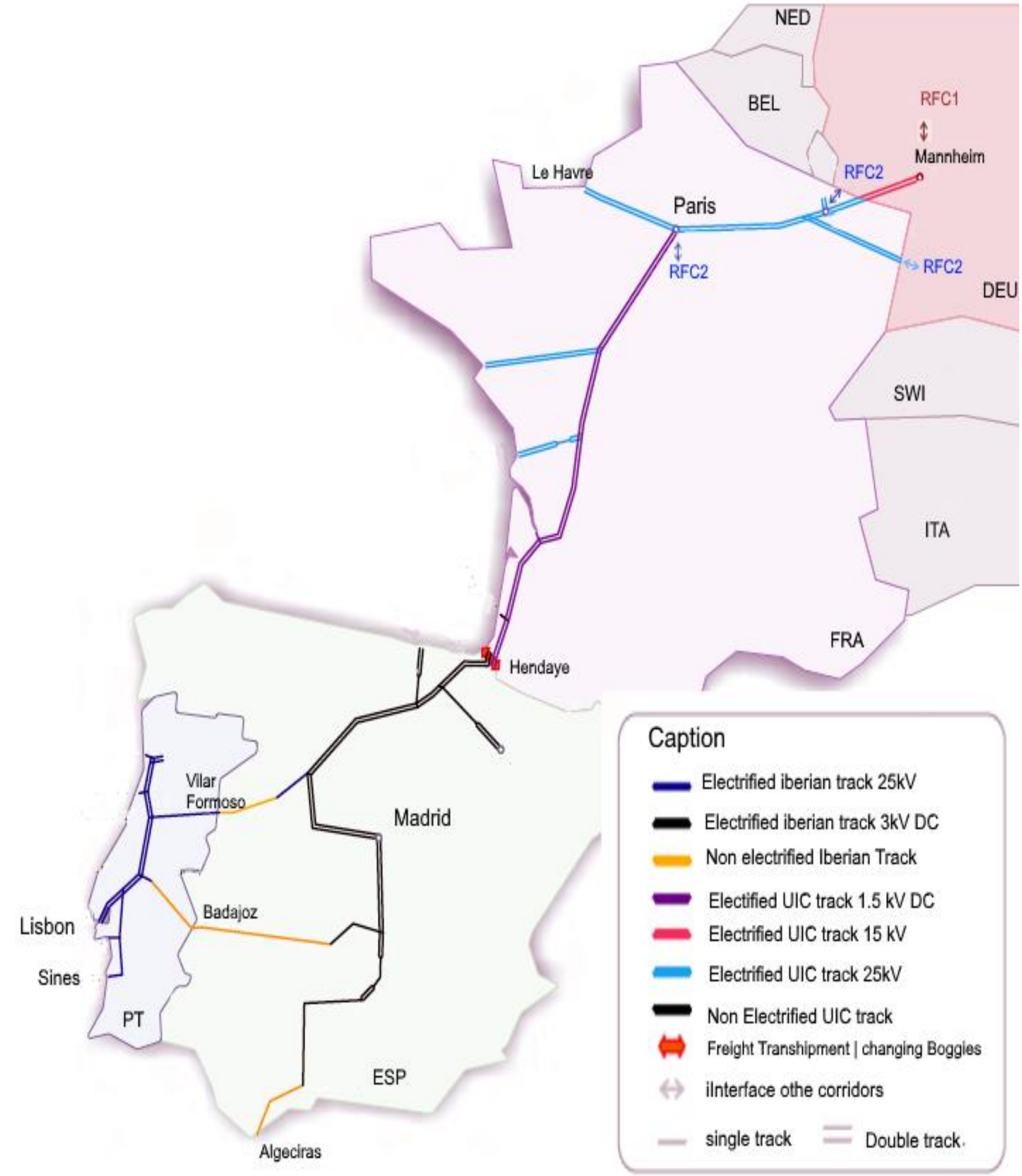


Figure 2 Corridor 04 rail network diagram and current project status illustration of the Electrical supply per respective route

The Atlantic Corridor is characterized by an outstanding dimension which is not yet fully exploited. Critical factors hindering interoperability and the seamless connection of modal networks lead to a situation of an unbalanced hinterland modal split, hindering the growth of the most efficient modes of long-distance transport. Important critical issues were identified at corridor level, largely related to the rail infrastructure:

- The missing link between Évora and Caia in the border Portugal-Spain;
- Different track gauges;
- Limited train lengths.

Moreover, improvements in landside access and last mile connections to ports are needed, with most of the existing bottlenecks being related to rail. The interconnecting nodes are also affected by limitations, thus artificially broadening the role and market share of roads. Airport connectivity with TEN-T rail is also limited. LNG availability at ports might limit the role of some Atlantic corridor ports in the future, if a proper plan is not rolled out, exploiting the potential of the existing LNG terminals along the Atlantic coastline. It is worth noting that Member States are already envisaging efforts in this domain (i.e. Portugal and Spain are working together on a project which is developing the LNG plan). (Secchi, 2016).

Table 3 shows the quantity of rail in kilometers achieving the standards required by the European commission. Table 3 shows the rail in kilometers for both freight and passenger rail for each country that the Atlantic corridor crosses. In addition, the total quantity in kilometers of rail links that meet the TEN-T requirements.

Table 3 Parameters per nation achieving TEN-T requirements

Atlantic corridor rail compliance						
	(km of links reaching standard)					
	DE	FR	ES	PT	Corridor	
Length of all sections	149	3017	2551	804	6520	[km]
Length of freight lines	149	1661	1917	804	4532	[km]
Length of passenger lines only	0	1355	633	10	1999	[km]
Electrification requirement	100%	98%	68%	100%	87%	[Electrified]
Track gauge	100%	100%	25%	0%	58%	1735 [mm]
Line speed (core freight lines)	100%	93%	99%	96%	96%	>=100km/h
Axle load (core freight lines)	100%	100%	100%	100%	100%	22.5t
Train length core freight lines	100%	100%	0%	72%	57%	min 740 m
ERTMS/ signaling system	0%	6%	11%	0%	7%	in operation

Table 4 Transport system specific Congestion problems in the network provoking bottlenecks

Bottlenecks	
France Spain	
Irùn-Hendaya	Axle change and load transfer
	GPSO line improvement expected to create direct line to Bordeaux
Spain-Portugal	No electrification
	Planned no implementation
Vilar Formoso - Fuentes de Oñoro	
Caia-Badajoz	
Southern section	
Evora- Caia	MSC possible actual construction
Evora -Merida	Missing links works done

Table 4 shows that the bottlenecks occurring are concentrated around connections from border section to Spain and the main lines from Portugal leading into Spain. There are additional problems on the Atlantic corridor route to be addressed at the French-Spanish border sections regarding the Axle changes. The different track gauges can be seen in Table 2, highlighting the differences from Iberia to the remainder of the Atlantic corridor.

The main missing link is the cross-border connection between Lisbon and Madrid. The section Porto – Valladolid is affected by the lack of electrification on the Spanish side. Additionally, problems of interoperability (difference in gauge, electrification, signaling systems and train length) affect the existing San Sebastian – Bordeaux section, where the new line has not reached the development consent. Still unclear is also the question of the optimal path for an interoperable route for freight across Madrid and from there to Burgos, and the subsequent needs for infrastructure development. With regards to roads, the electronic tolling systems are not interoperable yet, although Portugal and Spain are starting interoperable systems along the Atlantic coast.

Table 5 highlights sections particularly from the Portuguese-Spanish border connections that still have electrification requirements to be in line with Ten-T requirements. The connections between Portugal and Spain still require electrification

Table 5 Major electrification differences in the Atlantic corridor (left) Electrical parameter difference in the different sections of the Atlantic corridor (right)

Electrification	
France	definition
Gisors-Serqueux	bottleneck Rouen Le Havre
Spain	
Medina del Campo-Fuentes de Oñoro	Cross border Spain Portugal upgrading
Bobadilla-Algeciras	Conventional non-electrified
Madrid Badajoz	Conventional railway non-electrified cross border Portugal Spain

Voltage Differences		
Portugal	25	KV/AC
HS lines Spain	25	KV/AC
Northern France	25	KV/AC
Conventional lines Spain	3	KV/DC
Southern France	1.5	KV/DC
Germany	15	KV/AC 16.67HZ

Portugal has a major problem in requiring access to the Spanish hinterland market of Madrid. However, from the Portuguese perspective the main issue is the missing connectivity due to non-electrified sections of Vilar Formoso to Medina del Campo. The other section with problems is

Abrantes, Elvas-Badajoz-Puertollano. This affects the Portuguese ability not only to access the Spanish market but the European Hinterlands negatively as well. Portugal´s main port Sines main competitor Algeciras is also affected by the non-electrified route to Madrid from section Algeciras-Bobadilla.

Table 6 Portuguese investment cost related to previous studies (European Economic interest group, 2015)

Rail Project	Investment [m€]
Atlantic Seaboard corridor	734
North Line conclusion plan of modernization	400
Minho line	145
Western line	135
South line (ports of Setubal and Sado)	20
Leixões line	20
South line (tremitrena terminal)	14
North International Corridor	980
Aveiro corridor (Leixões Vilar Formoso)	900
Beira baixa line (Covilha-Guarda)	80
South International Corridor	800
Corridor Sines/Setubal/Lisbon	800
Algarve corridor	55
Algarve line	55
Interior development	1850
Douro Line (caide-Marco de Canevazes)	20
Douro Line (Marco - Regua)	20
Douro Line (Regua-Pocinho)	16
Vouga line	3
South line (Ramal de Neves Corvo)	11
Aveiro corridor (Leixoes Vilar formoso)	900
Beira baixa line (Covilha-Guarda)	80
Corridor Sines/Setubal/Lisbon	800
total	4419

Table 6 displays the resulting expected investment costs in Portugal based on previous studies on the rail corridor network that will be integrated as part of the Atlantic Corridor. The investment was found from reviews on the studies done with regards to infrastructure installation, upgrades to conform with the European directives and associated costs of similar projects from annual reports of the Atlantic corridor.

2.4.2 Cost of non-completion Ten-T route by 2030

The effects of non-completion of rail corridor would have direct and indirect effects upon the job market. Directly for the construction and infrastructure related jobs of implementation and operation of the new infrastructure. Indirectly from the new jobs created from the transportation opportunities from the newly connected network. The implementation of the core TEN-T network by 2030 would provide a substantial stimulus to the European economy, fostering both GDP and employment. They also suggest that the generated employment would benefit over-proportionally vulnerable groups, i.e. lower skilled workers. The highest economic multipliers were found for implementing the major cross-border projects along the nine CRNC and for deploying innovative technologies. Implementing the core TEN-T network including the cross-border projects and the innovative technologies can thus be recommended as a suitable policy to combat the weak economic situation in Europe. (Schade, 2015)

Induced employment: jobs generated due to an increase in the demand for all goods and services, when construction and other supplying sector employees spend their (new) income. Then, it is needed to estimate a consumption multiplier, that is, the percentage of new income that is spent rather than saved by employees. (Schade, 2015)

3. METHODS USED FOR COST, TRANSIT TIME AND EMISSION CALCULATIONS

3.1. Port costs calculation

3.1.1 South African to Europe Route Analysis

The maritime route chosen is the southern African route one which the shipping operator Maersk uses. The Route 1 consists of a northward leg that starts from Durban in South Africa to Rotterdam in the Netherlands. The northward leg has the following port calls Durban-Port Elisabeth-Cape Town, completing the African section. The ship continues to sail northwards up the Atlantic to make a port call at Rotterdam. The return voyage on the South leg which calls at Cape Town, Port Elizabeth, and Durban. Route 1 requires a fleet of 7 vessels, for a weekly call rate. The total round trip journey is expected to be 47 days. Route 1 rotation is Durban-Port Elizabeth-Cape Town-Rotterdam-Cape Town-Port Elizabeth-Durban.

The route follows a timetabled schedule from Maersk Africa 1 service, in which the time in port and voyage time between ports is adhered to. Route 2 makes use of the vessels leaving South Africa from Durban and traveling from the same scheduled ports of South Africa. When traveling north along the Atlantic they head to the Portuguese Port of Sines, and then on to Lisbon. The vessels return on the South-bound journey making port calls at Sines before returning towards South Africa. The vessel cargo quantities over the whole route are maintained to effect constant comparisons. The cargo heading northwards is 3,344 TEU and southbound 2,006 TEU. This gives a northbound cargo load ratio of 0.8 and southbound load ratio of 0.48. Route 2 rotation is Durban-Port Elizabeth-Cape Sines-Lisbon-Sines-Cape Town-Port Elizabeth-Durban.

Table 7 South African Route characteristics

Route 1			Route 2		
Rotterdam-Cape Town	7234	[nm]	Lisbon-Sines	73	[nm]
Cape Town-Port Elisabeth	422	[nm]	Sines-Cape Town	6032	[nm]
Port Elizabeth-Durban	391	[nm]	Cape Town-Port Elisabeth	422	[nm]
			Port Elizabeth-Durban	391	[nm]
South Bound	8137	[nm]	Southbound	6918	[nm]
Durban-Port Elizabeth	391	[nm]	Durban-Port Elizabeth	391	[nm]
Port Elisabeth-Cape Town	422	[nm]	Port Elisabeth-Cape Town	422	[nm]
Cape Town-Rotterdam	7234	[nm]	Cape Town-Sines	6032	[nm]
			Sines-Lisbon	73	[nm]
North bound	8047	[nm]	North bound	6918	[nm]

Key route points		Key route points	
Frequency	Weekly	Frequency	Weekly
Vessel Fleet	7	Vessel Fleet	6
Ports of Call	4	Ports of Call	5
Duration	49 Days	Duration	40 Days

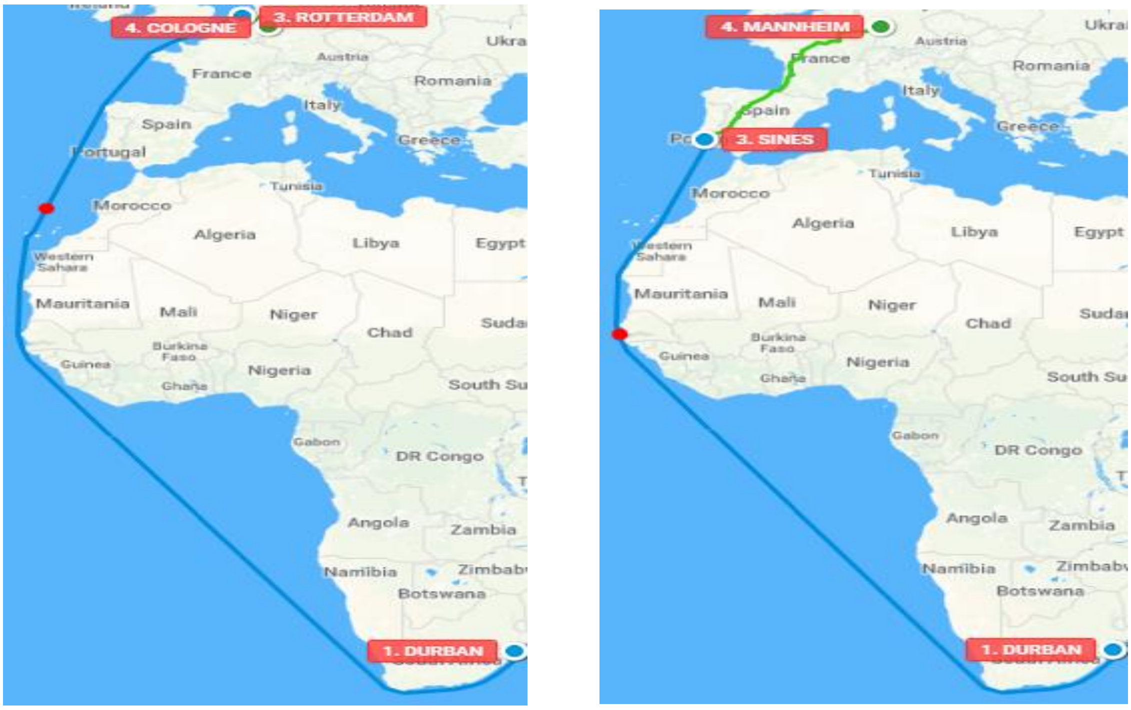


Figure 3 Route 1 Section illustration (left) of South African route, Route2 (right)

The objective is to demonstrate the difference between the cumulative costs of transportation of containerized cargo to the European hinterland of Germany. The comparison is for Route 1 which considers the status of ships traveling from South Africa to the Northern European port of Rotterdam. The quantity of cargo is then offloaded at these ports and is transported by freight rail to the hinterland. The cumulative value is compared to an alternative maritime route in which a rail transport of goods coming to the Portuguese port of Sines and then northbound to Rotterdam and returning to Sines for a second stop before heading to South American east coast ports again. This route implies a shorter duration of 9 days and one less ship is reducing in the ship load.

3.1.1.1 Maneuvering time

The time in ports was related to the time of a vessel´s entry into port, to the time the vessel leaves port. The time taken for a vessel from the port entrance, to making berth was estimated considering speed variation due to incoming traffic and related regulations stipulated by ports regarding pilotage. This is the time reduced from port unloading and loading activities. The port time for effecting maneuvers is the time to approach the terminal docking bay. The first reduction in time spent in port is time taken to cover the distance where approach speed is required from port entry from the pilot boarding regulations of the respective ports. Where speed restrictions are imposed, these values are used, where there is no set speed restriction, then the average speed in ports to the terminal bay is used. The second element of the time consumed in port is for maneuvering this estimation goes in hand with the general distance associated with respective terminals for engaging in maneuvering activities.

3.1.1.2 Loading and unloading container volume calculation

The analysis of the container quantities transferred to/from port on the liner service was done by analysis of the scheduled service time since no volumes are available in the literature. The daily time was recorded per route section and time in port. The number of quay cranes required to service the container moving activities was thus calculated. The method employed was to first determine the number of ship to shore cranes available. The number of ship to shore cranes enabled the calculation of the ratio of cranes per terminal quay length. The crane per meter ratio permitted the determination of the number of cranes servicing the vessel.

The loading and unloading of the vessel is determined by the move rate of the ship to shore cranes available at each respective port. A move constitutes the complete movement of hoisting, trolling, gantry and idle positions. The number of cranes that can service a vessel depends the number of quay cranes available at each respective port, that would be available to serve the vessel when berthed.

The number of containers moved in relation to international shipping is based on assumptions on the cargo load coming from South Africa. The vessel cargo quantities over the whole route are maintained to effect constant comparisons. The cargo heading northwards is 3344 TEU and southbound 2006 TEU.

The analysis of port productivity was based on values from a white paper by JOC (JOC Group, 2014) on Port productivity in regional areas and information provided by the South African port regulator. This enabled the quantity of cargo offloaded in relation to the Maersk scheduled time to be within the scheduled time., (Ports regulator South Africa, 2016)

3.1.1.3 Ports of South Africa

The charging rates are similar for each of the South African ports and follow the charging fee principle from Transnet. The Port dues are associated with the costs per the first 24 hours related to a fee per gross tonnage and subsequent 24-hour berthing stay. Light dues are charged in accordance with the overall length of the vessel. There is also a further vehicle tracking system fee which is charged according to the vessel gross tonnage. Pilotage is charged at a base rate and a subsequent fee per gross tonnage. Tugs are required for these ports and 3 tugs per vessel are attributed in accordance with the vessels size. There is a fixed fee per tug and an additional charge per gross ton. (Transnet Port Authority, 2017)

3.1.1.4 Handling Fees

Handling fees are charged in relation to the terminal handling fee charges from Hamburg Süd per respective port with relation to imported or exported containers and likewise reefers.

3.1.2 South American East Coast to Europe route analysis

The objective is to demonstrate the difference between the cumulative costs of transportation of containerized cargo to the European hinterland of Germany. The comparison is for Route 1 which considers the status of ships traveling from South American East Coast to the northern European ports with the first port of call at Antwerp and continuing north until Hamburg. The quantity of cargo is then offloaded at these ports and is transported by freight rail to the hinterland. The cumulative value is compared to an alternative maritime route that makes a greater emphasis on rail transport of goods coming to the Portuguese port of Sines and then northbound to Rotterdam and returning to Sines for a second stop before heading to South American east coast ports again.

Table 8 Ship main characteristics South America-South African routes for both legs

Vessel' Name	**MSC KRYSTAL**	
Main Particulars	277.30	[m]
LPP	263	[m]
Breadth Over all	40	[m]
Depth (D)	24.3	[m]
Draught (T)	14.50	[m]
Net Tonnage	37740	
Gross Tonnage	66399	
Engine power		[kw]
max speed	24,9	[kn]
Power	54900	[kw]
Main Engine Make	Man B&W Doosan	
Reefer plugs	632	[TEU]
Container capacity (2Oft)	5762	[TEU]
Container capacity (14T)	4180	[TEU]

Figure 4 Maritime Route 1 Section Illustration-South America Route

The study investigates the costs related to maritime container ship service, from the east coast of South America. The study investigates a comparison between sending container cargo from The South American East Coast leaving Salvador and heading first to Northern European ports and subsequently onwards to Portuguese ports. Where the goods are to be transferred from these ports to and from the German Hinterland. The secondary route is to have the vessel head first to the Portuguese port of Sines and then onwards to the German hinterland. The vessel will make a round European section voyage by making a port of call at Rotterdam and return through Sines.

Route 1 First port call in Europe is Antwerp, the vessel makes ports of call at Rotterdam-Bremerhaven-Hamburg, returning on the South leg by calling at Bremerhaven-Le Havre-Lisbon-Sines, Rio de Janeiro, Santos, Paranagua, Navengantes. The vessel then travels Northwards traveling to Santos, Rio de Janeiro and Salvador before heading across the Atlantic to Antwerp. The total route length is 14,930 nautical miles and the expected to have a fleet of 7 vessels, with a weekly call rate. The total round trip journey is expected to be 47 days. Route 1 follows the timetabled schedule in which the time in port and voyage time between ports is adhered to.

Route 2 under investigation makes use of the vessels leaving South America from Salvador and traveling directly to the Portuguese Port of Sines. The vessels then head north to Rotterdam. The vessels return on the South-bound journey making port calls at Sines before returning towards South America.

The vessel Cargo quantities over the whole route are maintained to effect constant comparisons. The port of call of Sines acquires the cargo originally intended for Antwerp. Whilst the cargo that heads to Rotterdam is for the equivalent quantity that would have headed to northern European ports respectively which maintains the international quantity of cargo from South America that is delivered. The cargo on the southward journey to Sines is the cargo quantity originally intended to go to Sines and Lisbon. This route is to be compared to a route that alternates this port of calls by sailing from the Port of Salvador to Sines-Rotterdam.

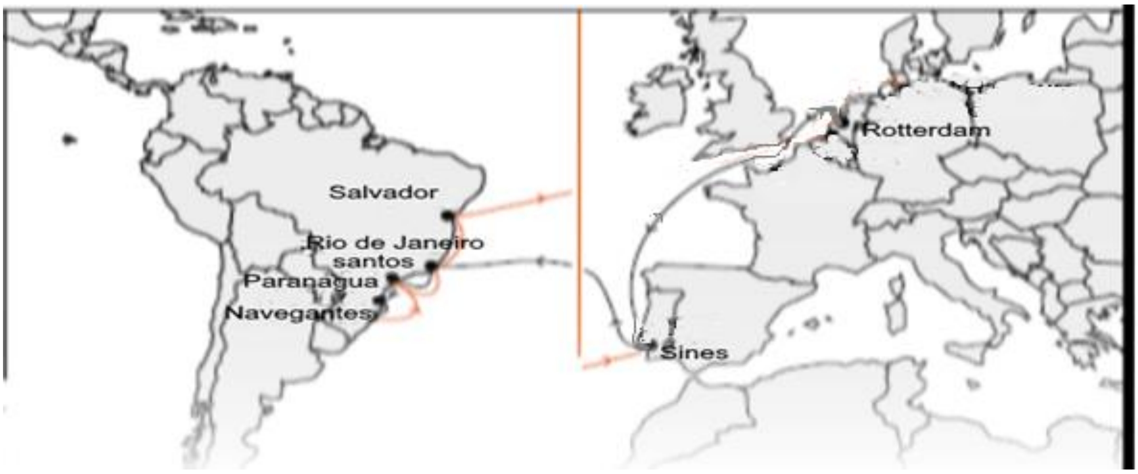


Figure 5 Maritime Route B Section illustration

Route 1 port rotation is Antwerp-Rotterdam-Hamburg-Bremerhaven-Le Havre-Lisbon-Sines-Rio de Janeiro-Santos-Paranagua-Navegantes-Santos-Rio-de Janeiro-Salvador-Antwerp. Route 2 port rotation is Salvador-Sines-Rotterdam-Sines-Rio de Janeiro-Santos-Rio-de Janeiro-Salvador.

Table 9 South American maritime route characteristics

Route 1			Route 2		
Antwerp-Rotterdam	144	[nm]	Salvador-Sines	4470	[nm]
Rotterdam-Hamburg	341	[nm]	Sines- Rotterdam	1370	[nm]
Hamburg-Bremerhaven	36	[nm]	Rotterdam-Sines	1370	[nm]
Bremerhaven-Le-Havre	580	[nm]	Sines-Rio de Janeiro	5207	[nm]
Le-Havre-Lisbon	1042	[nm]	Rio de Janeiro-Santos	249	[nm]
Lisbon-Sines	73	[nm]	Santos -Paranagua	202	[nm]
Sines-Rio de Janeiro	5207	[nm]	Paranagua-Navegantes	66	[nm]
Rio de Janeiro-Santos	249	[nm]	Navegantes-Santos	262	[nm]
Santos -Paranagua	202	[nm]	Santos -Rio de Janeiro	249	[nm]
Paranagua-Navegantes	66	[nm]	Rio de Janeiro-Salvador	809	[nm]
Navegantes-Santos	262	[nm]			
Santos -Rio de Janeiro	249	[nm]			
Rio de Janeiro-Salvador	809	[nm]			
Salvador-Antwerp	5670	[nm]			
North Bound Total	7541	[nm]	North Bound Total	7226	[nm]
South Bound Total	7389	[nm]	South Bound Total	7028	[nm]
Frequency	Weekly		Frequency	Weekly	
Vessel Fleet	7		Vessel Fleet	7	
Ports of Call	14		Ports of Call	10	
Duration	49 Days		Duration	47 Days	

Table 10 Train distances from respective ports

Route 1 Terrestrial Paths			Route 2 Terrestrial Paths		
Antwerp-Köln	223.54	[km]	Rotterdam-Köln	257.45	[km]
Rotterdam-Oberhausen-Köln	267.36	[km]	Rotterdam-Duisberg-Köln	262.36	[km]
Rotterdam-Venlo-Köln	257.45	[km]	Mannheim-Sines	2581.41	[km]
Rotterdam-Duisberg-Köln	262.36	[km]	Sines-Mannheim	2581.41	[km]
Hamburg-Köln	374.51	[km]	Sines-Badajoz-Mannheim	2861.7	[km]
Bremerhaven-Köln	374.51	[km]	Lisbon-Mannheim	2430.40	[km]
Le Havre Mannheim	198.00	[km]			
Sines-Mannheim	2587.37	[km]			
Lisbon-Mannheim	2430.40	[km]			

Route 1 port rotation is Antwerp-Rotterdam-Hamburg-Bremerhaven-Le Havre-Lisbon-Sines-Rio de Janeiro-Santos-Paranagua-Navegantes-Santos-Rio-de Janeiro-Salvador-Antwerp. Route 2 port rotation is Salvador-Sines-Rotterdam-Sines-Rio de Janeiro-Santos-Rio-de Janeiro-Salvador.

3.1.2.1 Loading and unloading container volume calculation

The analysis of the container quantities delivered and required at each port on the liner service was done by analysis of the Hamburg Süd schedule. The daily time was recorded per route section and time in port. The scheduled time in port less the maneuvering time is the loading/unloading time required. The number of quay cranes required to service the container moving activities was thus calculated.

The move constitutes the complete movement of hoisting, trolling, gantry and idle positions of the crane movement the rate is based on the specified hourly movement rate of the respective cranes. The number of containers moved in relation to international shipping is based on assumptions on the cargo load coming from South America. The containers entering the Northern European ports are assumed as ports of predominately incoming cargo and as such have a 75% cargo offload to on load ratio. The vessel initially coming from South America is assumed at 100% full. The calculation of the cargo offloaded is done in an iterative fashion where each subsequent port of call on the northward journey. The international cargo delivered reduces to zero at Hamburg which is accounted by having a 45% offload at Rotterdam and 50% offload at Hamburg. This is a reasonable expectation as these ports are international recipient ports and Hamburg is the last port on the northward leg and would be expecting cargo to return Southbound.

It is assumed that the international cargo loaded begins once more at Le Havre with 50% of the loading attributed to International cargo. The iteration of cargo loaded from the European ports is Iterative with 75% attribution to Lisbon and 50% to Sines. This will also imply a reduced cargo load heading to South America than that which came to Europe. The remaining containers on board are part of the rotational stock that must return and are empty.

In a similar fashion, the vessel that arrives at the South American Ports has their offload percentage done in an iterative form offloading at 80% at each port of call with Navegantes having an offload percentage of 79%. The result is all the remaining international containers are offloaded at the port of call at the southernmost point. The return journey northwards assumes a 75% loading rate at the ports of call in South America for the return Journey to Europe.

3.1.2.2 Port costs description per port

The costs associated with each port are divided into categories of port associated dues, tugs, and pilotage, in port fuel costs and handling costs. The description of the component costs of each category for each port of call will be described that produced the total for the previously stated categories.

Port of Antwerp Cost Description

The port of Antwerp the category of port associated dues was broken down into costs related to a fixed charge fee for electronic communication from the ship to the Port Authority, the next charge was for the gross tonnage which was denominated as tonnage dues upon guarantee fee. The next fee is in for the ship being a liner service charge. A container ship incurs a berthing charge at Antwerp per tonnage. The fee for electrical consumption was calculated by a fixed fee for three day's usage. Antwerp Fee for waste removal is based on the gross tonnage of the ship.

The tugs and pilotage fees for the port of Antwerp constitute of charges for a VBS Flemish port vessel control fee in accordance with Flemish block size which determines the associated charge. The pilotage and tug charges further comprise of the Helicopter approach charge and the helicopter departure charge and the pilot fees themselves.

The handling charges are the cost per ton of containers moved on the port. In addition, charges are incurred at Antwerp for inspection fees related to incoming international cargo. The inspection fees are food inspection charge for reefer containers and border incoming inspection charge for dry containers. (Port of Antwerp, 2017; Flemish Maritime and Coastal Services Agency, 2011)

Port of Rotterdam cost description

The port of Rotterdam charges a port tariff based on the gross tonnage of the vessel. The port tariff permits two discounts the First for the quantity of service by the port calls the vessel makes per annum yielding a 10% discount. The second discount is the section of the route that the vessel is coming in from being short sea as it arrives from another European port of 18%. There is a further charge for port due based on the dead weight of the vessel. The port of Rotterdam charges for the length of quay occupied by the vessel. Charges for the waste fee has a fixed charge plus additional BT rate in accordance with the vessel size and type.

Rotterdam is one of the principal ports for oil bunkering having refineries and all types of marine fuels required for bunkering was chosen as the location for oil bunkering and as such a charge was incurred at this port. The time taken for bunkering is in line with the time in port. The bunkering makes use of on side Barge transferring of two pumps of 400m^3/hour which yields 11199 tons which imply a 50-day autonomy for the consumption rate of 223.99 tons/day.

In this analysis, the mooring charges are part of the associated port dues, the electric charges are based on the Industrial base rate by the CREG European comparison of electricity and gas prices for large industrial consumers 21 April 2015. The boilers also require feea-water and a charge for the delivery of the quantity required occurs at the port of Rotterdam.

The pilotage charges for Rotterdam are in accordance with the tabulated pilot tariff structure comprising of two components a start tariff and column tariff. The resulting price is the combination of factors that a route through the port of Rotterdam incurs. This cost is from the point of the pilots embark on performing navigation and the related navigable section charge. The towage cost is associated with the cost per tug it is recommended two tugs are required for this vessel and the rate per vessel is taken from the calculation per maneuvering time described in the maneuvering time section. (Port of Rotterdam, 2017)

Handling charges are charged per ton discharged, the containers have a 14ton equivalence per TEU in this analysis to be in line with the maritime load maximum stipulation of the number of containers loaded on the vessel based on 14-ton equivalence.

Port of Hamburg cost description

The Hamburg Port Authority charges a fixed fee of per vessel making a port of call, charges a Port due per gross tonnage of the vessel, an additional charge associated with the weight of cargo offloaded. The cost for electrical energy consumption is based on and CREG European comparison of electricity and gas prices for large industrial consumers 21 April 2015.

The pilotage charges that the port stipulates a charge for the pilot fee and for port manager fee for pilotage. No reference had been found to tug charges at this port or terminal. There are fixed fees for electronic documentation transfer and a charge for the processing of port fee declaration.

Eurogate Terminal of Hamburg, the berthing rate is fees for documentation required is done by Electronic data transfer fee. The terminal then charges for a standard visiting fee per vessel of 50€. The terminal further has a berthing fee which is time sensitive with a cost per gross tonnage for the first 24 hours and an additional charge per gross tonnage for each subsequent 12 hours spent in port. The terminal also charged for the weight of goods entering the terminal This rate is defined by whether the goods are from European or overseas shipping.

Eurogate’s price structure for 2017, handling charges are attributed to ISO 20’ containers. The containers handling costs incur charges for lashing on board, charged per container on board. Reefer unit inspection and maintenance costs are charged for the first 24-hour period and for every subsequent 24-hour period, the cost is calculated per the time in the port of the vessel and all reefers transferred onto and off the vessel. Included in the cost to this port is the cost fee for the transfer of containers to rail car charged per container. The handling charges include the costs for a stevedore gang whose composition that comprises of a gang boss, forklift driver, 2 Hookmen, crane operator and tender, truck driver and eight holdmen. (Hamburg Port Authority, 2016) , (Eurogate, Prices and Conditions Eurogate terminal port of Hamburg, 2016)

Port of Bremerhaven cost description

The charge rate for port dues per the Bremerhaven Port Authority has a tonnage and berthing due both based on a rate per gross tonnage. The Eurogate terminal of Bremerhaven has charges for quay dues. These quay dues are calculated at a rate per tonnage of the amount of the goods offloaded at the quay. The vessel is also charged a berthing due at a rate related to the gross tonnage of the vessel. The berthing charge has a rate for the first 24 hours and a reduced rate for each subsequent hour

Waste dues were charged in relation to a fixed charge per gross tonnage where a maximum charge of 600€ is to be incurred. The handling charges at the Bremerhaven Terminal charges are for the handling of the containers transferred. The charge is per container transferred Additional charges are charged for the lashing of onboard containers, the flashing rate is per container on board. The reefers a charged a maintenance charge per 24-hour period per reefer. There is a further additional cost for waterside security per container charge. The electric power that was charged was based on the CREG –European comparison of electricity and gas prices for large industrial consumers 21 April 2015.

The pilotage fees are rated per vessel gross tonnage the subsequent fees are charged for Berthing and unberthing of the vessel. Here is a charge for pilot waiting. Charges for the tugs are for the assumption of 4 tugs used. Each tug is charged annual harbor use rate and the charge is thus the annual portion per vessel call at the terminal. (Bremen ports, 2017**;** Eurogate, Prices and Conditions MSC gate Bremerhaven, 2016)

Port of Le-Havre cost description

The port of Le-Havre charges per the volume of the ship making a port of call this value is then adjusted depending on the quantity of tonnage transferred by the ship making a call by the Tonnage per ship volume ship due multiplier 0.7384 α + 0.4867. where α is the ratio between tonnage volume and tonnage. There is a rebate of 10% for regularity at which the vessel will make berth as a regular line. The Port of Le Havre charges weight dues in accordance with the type of product loaded and unloaded from the vessel with a differing charge upon whether containers are loaded or unloaded. The rates are charged in Euro per metric ton. Included in the port dues

are charges for fresh water taken on board the charge for electrical power usage based on industrial European rate and the port administration fee.

Handling costs comprise of costs related to dues per container unit loaded on board and the cost the charges for the gross weight of goods loaded and loaded are with respect to the type of goods. The goods in question a frozen goods where a standard product of frozen European Hens being loaded are considered for reefer container cargo and electronic goods being laptops for goods transported in 20’ dry containers.

Port of Lisbon cost description

The port dues attributed to the port of Lisbon in this dissertation are for the fixed administration fee per vessel making a port of call. The port dues per gross tonnage and the variable time required by the vessel to be in port. The costs are determined by a charge for the first 24 hours in port and the subsequent post 24 hours in port. Due to the frequency of the vessel, there is a 25% discount on the gross tonnage tariff.

The pilotage fee is for the calculated for the requirement for a vessel to be moored alongside the quay this charged by the pilot rate multiplied by the square root of the gross tonnage. The summation of rate fee and the hourly pilot rate give the total pilot fee. The pilotage fee also incurs an additional charge for the time spent by the motor boat having dislocated to bring the pilot to the vessel and return to the point of departure.

Waste is subject to a fixed fee charged up to the gross tonnage of the ship to a maximum set value. The is charged per gross tonnage up to a stipulated maximum which the vessel exceeds this fee is obligatory whether the use of the waste facilities is accounted for.

The electric power is due to the charges for supply of single and three phase supply systems from the port and a charge per use rate stipulated by the port. The power consumption of the vessel is an estimation of the electric power from a formula from Gienalcyck estimation of ship power. This value is based on a hundredth of the power when in full operation of the vessel.

The Handling charges are attributed to the Port labor required for a stevedore gang and the equipment required for offloading of the vessel. The assumption is made that the containers can be loaded directly onto trailers that can be moved by transferred directly to and from the rail terminal for departure. As such it is the rate of all the trucks available at the terminal and the time required to transfer all the containers which are attributed to the cost of equipment at Lisbon. The stevedore's gang is for the costs associated with successive gangs to be utilized for the entire time the vessel is in port since the labor charge is hourly. (Port of Lisbon, 2016)

Port of Sines cost description

The charge rate for Sines has a charge which is based on the gross tonnage but is adjusted in relation to the loaded and unloaded cargo. The ratio of unloaded to loaded cargo determines the rate charge factor for the type of ship which is charged in relation to the type of ship. This is the charge for the ship harbor due which in this case will be subject to a discount for the regularity of the liner service of 10%. There are another two reductions one for coming from a short sea route Pilotage charges are based on the gross tonnage and the related pilot usage value the product of these factors is multiplied by the coefficients of piloting activities required for the docking, mooring and unmooring of the vessel.

The power consumption of the vessel is an estimation of the electric power from a formula from Gienalcyck which makes an estimation of electrical power requirement for ship based on the Ships Maximum continuous rating power. This value is based on a hundredth of the power when in full operation of the vessel. The charge is based on the price of heavy fuel oil.

Handling costs that have been stipulated are attributed to Stevedore operator fees. The gang rate is the cumulative cost of time the vessel operates in port for discharging and loading of cargo. Since operator charges are distinguished by the hourly rate. No mention of other costs has been found. (Authority Port of Sines, 2016; Gienalczyk, 2010)

Port of Rio de Janeiro cost description

The port of Rio de Janeiro has a Port due to charge per gross tonnage of the vessel and a standard docking fee. The port of Rio de Janeiro charges a mooring rate per length of ship and time spent docking at the port. There are associated fees required to be presented to the Port Authorities in Brazil when a vessel makes berth in Brazil, there are 22 in total. Each of these documents is subject to a fee per document for issuing a certificate of the declaration. These are elaborated as follows.

Documents required on arrival, crew list, store list, crew personal effects list, ballast declaration, Manifest, Bill of Lading, crew and passenger vaccination documents, ship documents, fuel, diesel and water quantities on arrival, derat or exemption certificate, Notice of Readiness, Cargo receipt, Statement of facts, Draft survey result, Cargo Manifest

At the Multi-Rio terminal, the container handling charges are comprised of a cover charge per containers transferred. The next associated charge is for weighing of containers to be loaded. Cargo to be imported are subject to import and administration customs charges. Further, there is a scanning charge applied to these containers. Containers loaded with other South American ports will be charged a transit charge. There is a charge for the supply of reefer plugs to the vessels. The containers are subject to a handling fee per container in the port. The fuel consumption in port is for electrical power that the vessel may need in port this is done in the same manner as for the Port of Sines.

Pilot dues charges was an area of concern that this dissertation could not address as no official documentation has been readily available for analysis. However, this cost is of substantial consideration considering articles written about the monopoly of the state Maritime pilot service. (MultiRio, 2016; Superintendência de Gerência de Regulação Portuária; Tarifas de Porto de Rio de Janeiro).

Port of Santos cost description

The port of Santos port dues is associated with the following charges; the first being the cost per containers offloaded at the Port of Santos, the second is the costs associated with the issuing of Certificates of declaration and reports of emissions Once more the documentation required are as those described for the port of Rio de Janeiro. There is a fixed docking fee. The mooring rate is charged per length of the ship.

The electricity charge is related to the supply of high and low voltage. The power consumption rate is determined by the state of São Paulo Port Authority. In this case, it considered that the ship electrical requirements at this port of call will require low voltage needs by the same power consumption formula which was used at the port of Sines.

The handling charge is the charged per containers imported containers weighed to be loaded on to the vessel and for the inspection and maintenance of Reefer cargo. Further, there is the overall handling charge for the transfer of reefer cargo at the port. (Brasil terminal portuario, 2017)

Port of Paranagua cost description

The Port of Paranagua charges per the rate of gross tonnage arriving at the port of supply of certificates for documentation required by the Port Authority as previously explained at the port of Rio de Janeiro. The ship is charged a mooring charge per length of the ship. The dues also include the charge for electrical consumption the ship incurs whilst in port the electrical consumption estimation is the same procedure as described at the port of Sines multiplied by the rate charged by the port authority of Paranagua.

The handling charges incurred comprise of charges for specialized personnel. The categories that the personnel charges cover is for weighing of containers to be loaded, for operators of specialized equipment, the shipping agent general services, for the coordination and mooring of the vessel. The handling costs further incur costs attributed to the weighing of containers to be loaded. The charges for the monitoring of reefer containers and the cost of per transfer of containers to and from the vessel. (Estado de Paranã secretaria de estado de Infrastutura e logistica administraçao de portos paranagua, 2015; TCP, 2016).

Port of Navegantes cost description

The port dues associated with the port of Navegantes are for the containers moved at the port and for the mooring charges for the length of the ship in the port. Fuel consumption is for the electrical power estimated to be used whilst the vessel is in port. The power consumption is related to the power of the ship through a formula proposed by Gienalcyck for the estimation of the electrical ship power requirement whilst at sea. Reefers at the port are charged for access to energy per reefer**.** The handling cost is attributed to the costs of weighing containers to be loaded, the movement charge for the transfer of containers to and from the vessel and further the costs for the inspection and monitoring of Reefers. (PortoNave, 2016; Tarifa Porturaria do porto de Navegantes, Itajaí, 2015)

Port of Salvador cost description

The port of Salvador the port dues is attributed to the charge for containers transferred at the port of Salvador. Port dues are also incurred for an inclusive charge for the gross tonnage of the vessel and mooring which is calculated as a rate per gross tonnage of the vessel. There is an electrical charge per connection at a fixed rate of 18.62 R$. Handling costs are attributed to the cost of weighing the containers to be loaded, the use of the ship to shore crane which the charge per crane usage is attributed to the charge per container moved. Further, there is a cost required for certificates for each container loaded. (Portuaria, 2015)

3.1.3 North America to Europe Route Analysis

The study investigates the costs related to maritime container ship service traveling from the North American port of New York the shipping operator of Maersk uses, to the western European ports. The first route is direct to Rotterdam and the second is to the Portuguese ports of Sines and Lisbon. The route consists of a Westward leg that starts from New York in the United States of America to Rotterdam Netherlands. The Eastward leg, returns to New York, United States. The total route length is 6,766 nautical miles and is expected to have a fleet of 3 vessels, with a weekly call rate. The total round trip journey is expected to be 22 days. Route 1 port rotation is New York-Rotterdam-New York.

Table 11 Ship Main characteristics

Vessel's Name	**MSC Brussels**		 © Hannes van Rijn MarineTraffic.com
Main Particulars			
LPP	336.7	[m]	
Breadth Over all	46.5	[m]	
Depth (D)	25.2	[m]	
Draught (T)	14	[m]	
Gross Tonnage	107849		
Engine power	68520	[kw]	
max speed	25.2	[kn]	
Power	68520	[kw]	
Main Engine Make	Man B&W Doosan		
Reefer plugs	700		
Container capacity (2Oft)	9712		
Container capacity (14T)	6500		

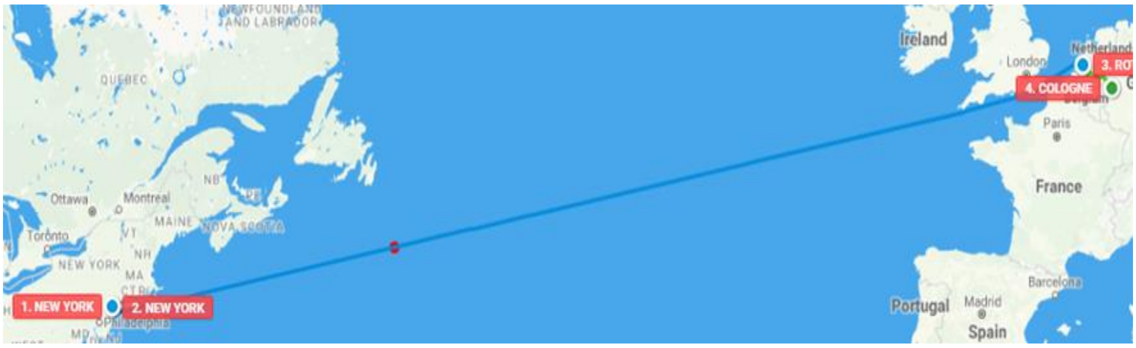


Figure 6 North American Route 2 Section illustration

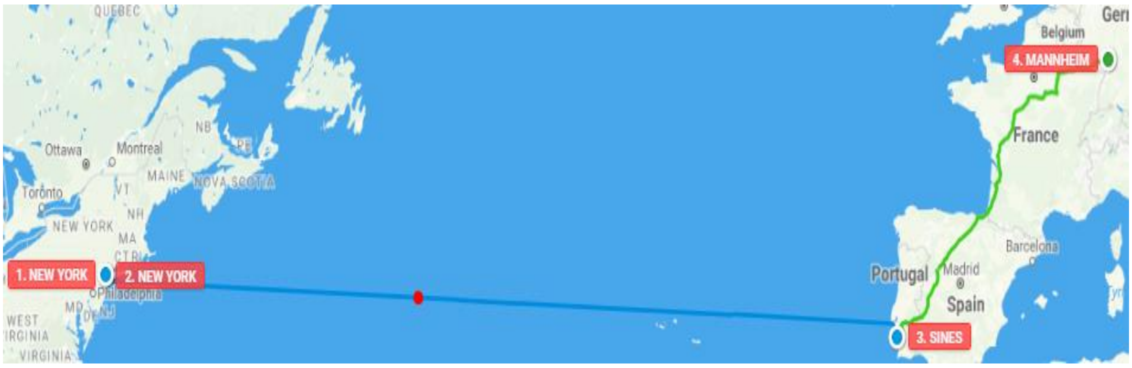


Figure 7 Maritime Route 2 Section illustration

The route adheres to the timetabled schedule in which the time in port and voyage time between ports is adhered to. The second route under investigation makes use of the vessels leaving the United States port of New York to Portuguese ports of Lisbon and Sines. The return journey Westward to New York from the Portuguese Port of Sines. The vessel cargo quantities over the whole route are maintained. The East and West routes maintain a cargo transport of 3315 TEU. Route 2 port rotation is New York-Lisbon-Sines-New York.

Table 12 Route voyage details for North American transportation

Route 1 Terrestrial Paths			Route 2 Terrestrial Paths		
Rotterdam-Oberhausen-Köln	267.36	[km]	Mannheim-Sines	2581.41	[km]
Rotterdam-Venlo-Köln	257.45	[km]	Sines-Mannheim	2581.41	[km]
Rotterdam-Duisberg-Köln	262.36	[km]	Sines-Badajoz-Mannheim	2861.7	[km]
Maritime Route 1			Maritime Route 2		
New York-Rotterdam	3383	[nm]	New York-Lisbon	2980	[nm]
Rotterdam-New York	3383	[nm]	Lisbon-Sines	73	[nm]
West Bound	3383	[nm]	Sines-New York	2986	[nm]
East Bound Total	3383	[nm]	West Bound	2986	[nm]
			East Bound Total	2980	[nm]
Key route points			Key route points		
Frequency	Weekly		Frequency	Weekly	
Vessel Fleet	3		Vessel Fleet	3	
Ports of Call	2		Ports of Call	3	
Duration	22.35 Days		Duration	21.56 Days	

The objective is to calculate the cumulative cost difference of containerized cargo transportation methods to the European hinterland of Germany. Route 1 comparison considers the status of ships traveling from North American East Coast from the port of Newark, New York to the northern European port of Rotterdam. In Route 1 Containerized cargo is then offloaded at the port of Rotterdam and then is transported by rail to the German inland terminal of Köln. In Route 1 an analysis is made between the effects of utilizing the regular Dutch line and the Betuweline. The cumulative value is compared to an alternative maritime route that likewise leaves from the port of Newark, New York. In Route 2 the vessel makes ports of call at Portuguese ports of Sines and Lisbon. In Route 2 the terrestrial path options of rail transportation is by either going through Vilar Formoso or Badajoz to the German inland terminal of Mannheim.

3.1.3.1Loading and unloading container volume calculation

The analysis of the container quantities delivered and required at each port on the liner service was done by choosing 3315 TEU to be transported this maintains a 51% load of the vessels that are traveling on the Maersk routes schedule the reason was to maintain the same offload quantities as the vessel for the South African routes. This was to see the effect of A larger vessel whilst maintaining the same cargo quantity. The daily time was recorded per route section and time in port. The scheduled time in port less the maneuvering time is the loading/unloading time required. The number of quay cranes required to service the container moving activities was thus calculated. The method employed was to first determine the available number of ship to shore cranes. The average move rate relates to the average move time per ship according to the source material which determines the offload time for the number containers to be off loaded, which is within the bounds of the scheduled time. (Ports Regulator of South Africa, 2016; D. Smith, 2012).

3.1.3.2 Handling charges

The handling charges utilized the charging system of the rates from Hamburg Süd for the respective ports. The handling charges take it into account that the charges for import and export containers and the difference for the reefer and the standard 20-foot containerized cargo. The handling charges are based on the rates for Hambürg Süd for each port.

Port of Newark Cost Description

The port of New York has a berthing assignment charge. The vessel is charged for light dues based on the length of the vessel. The port of Newark is also charged for container facility charges based on the quantity of cargo off loaded. In addition, the wharfage charge is related to the tonnage of cargo offloaded. There is a further charge of security. The fresh water is charged per tonnage required by the vessel pilotage is charged in relation to the cubic number of the vessel which determines the predetermined charge for pilotage and the tug service, in addition, there is a specified towage charge for the size of the vessel.

3.2 Maritime Costs

The maritime costs associated with a vessel and subsequently the fleet that is to operate along the routes between Europe, South Africa, South America and North America are now explained. The vessel cost structure relationships can be illustrated as seen below with input components of Fuel Costs, Port Costs, Operating Costs and Capital costs which in this case is the new building purchase price. Figure 8 displays how the relationship between voyage and time in port being related to the terminals, and how the cost per unit, can be acquired.

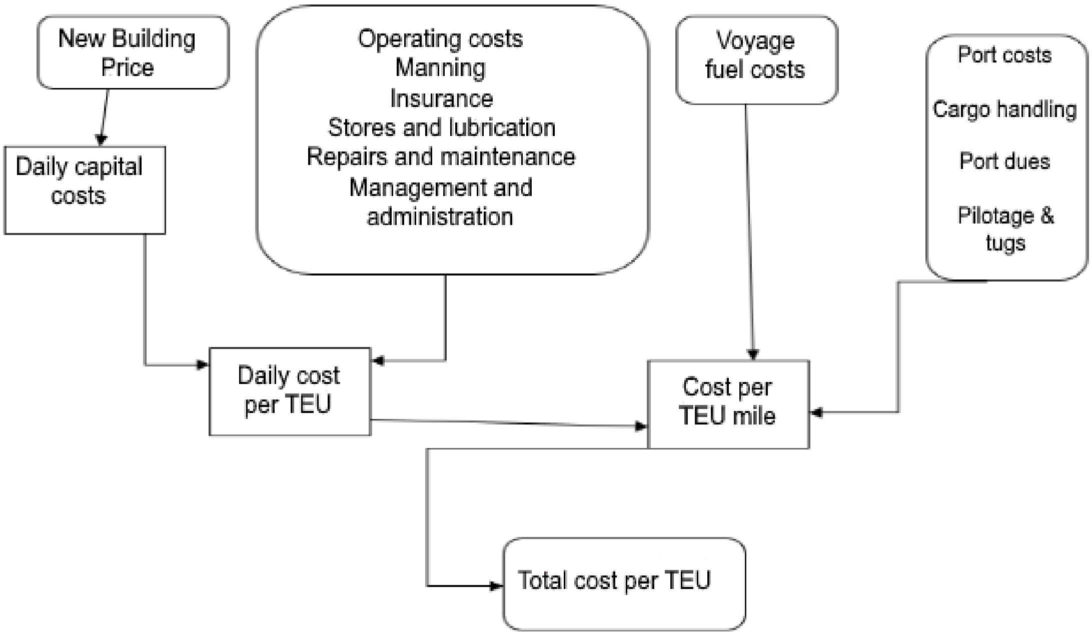


Figure 8 Maritime container transportation components affecting unitary cost.

Voyage costs depend on the factors such as duration, distance, area, and ports They can be broken down;

- FC =Fuel costs
- PD=Port dues
- TP=Tugs and pilotage
- CH=Cargo handling
- CD= Canal dues

$$VC = FC + \mathrm{PD} + \mathrm{TP} + \mathrm{CH} + \mathrm{CD} \tag{1}$$

3.2 Fuel costs

3.2.1 Propulsion fuel costs

Fuel consumption is dependent on two factors costs are related to the time at sea traveling between the origin and destination nodes. The second factor is fuel consumption required for various equipment on board the vessel. The fuel consumption is further directly related to the specific engine used on the route which the fleet in question have all similar engine types in terms of engine specifications of marine diesel fuel type power and stroke type. Relating the fuel consumption in relation to the speed that the vessel travels is determined by the following formula:

$$\sum_{j}^{N} F_j = F^* \left(\frac{S_j}{S^*}\right)^a \tag{2}$$

- F = Fuel consumption
- F*= Design consumption of engine also designated as the specific fuel oil consumption (SFOC) of the engine is
- S=The course speed that the vessel undertakes per section of the voyage
- S*= Service design speed of the vessel
- a=3 - Specific engine type factor
- N=Number of ports
- j= Specific route between ports (Santos, 2015)

3.2.2 Auxiliary maritime fuel consumption components

Auxiliary fuel consumption was also attributed to the associated number of auxiliary engines utilized during the voyage. The power of each auxiliary engine is 1176kW. There was additional 5.2kW attributed to each reefer with a Consumption rate of 0.23[kg/kWh] for frozen products per TEU**.** In port fuel consumption were associated with a standard hoteling rate of 4 tons per day (Cheaitou, 2012)

Auxiliary fuel costs were calculated by from the fuel consumption rates of specific equipment specifications from the ship´s description for the South American route analysis. These included the electrical power of generators. The power consumption from the electrical generators was estimated by simultaneous usage factors outlined for surface ships from the United States Navy (United Sates Navy,2012). Consideration of scenarios for waste incineration during the voyage allowed the calculation on the energy required by an incinerator per each section of the leg. Subsequent equivalent electrical energy consumption total was added to other energy consumption this would. Fuel consumption for electrical generation considers the ECA region where ULSFO fuel must be used in compliance with the sulphur reduction regulations imposed. The estimation of electrical consumption can be viewed in Appendix 2.

The calculation of consumption rates of different boiler types on board the vessel, was carried out according to the time the vessel was at sea and the time at port with an estimated approximation of the percentage of this time that the boilers would have to function per each section of the voyage. The consumption values would provide the quantity in tons for both gas oil and Marine diesel oil boilers fuel consumption per leg section and the overall journey consumption. The results of these calculations can be seen in Appendix 2 for the specific fuel consumption from the auxiliary entities of the MSc Krystal used on the South American voyage.

3.3 Operating costs

The daily operating component costs are overhead costs associated with the daily operation of maritime vessels. The comparative values from calculations of the source material are displayed below in conjunction with the formulae estimations of the respective operating cost components.

Table 13 Comparison of dissertation values in relation to reported values

Comparison operating costs 8000-9000 TEU					
	Euro commission	Drewry 2013	Calculated		
	8000-9000	8000-9000	8000-9000		
	[$/day]	[$/day]	[$/day]	Average	Ʊ
Manning	2 628	3 164	2 021	2 605	572
Insurance	1 327	1 519	2 864	1 903	837
Stores, Spares & Lubricating Oils	3 166	3 323	1 944	2 811	755
Repairs and Maintenance	2 099	1 559	1 407	1 688	364
Management & Administration	1 093	723	372	730	360
Total Daily Operating Costs	10 314	10 288	8 608	9 737	977

Table 14 Comparison of dissertation values in relation to reported values

Comparison of Operating Costs 5000-6000 TEU						
	Drewry 2013 [$/day]	USMN [$/day]	[Calculated] [$/day]	Euro-commission [$/day]	Mean [$/day]	Ʊ [$/day]
Manning	2984	2000	2 022	2176	2320	505
Insurance	767	500	2122	931	945	801
Stores and Lubrification	3203	2500	1915	2603	2119	991
Repairs and Maintenance	1433	4500	1003	1557	1862	1749
Management & Administration	592	500	372	931	487	90
Total Daily Operating Cost	8979	10000	5 235	7434	7643	4186

(Delhaye, 2010) (Brevik, 2014) (Murray., 2017)

The table above shows the comparative operating costs from various sources related to a vessel of similar size. Tables 13 and 14 display the comparison of costs related to the calculation methodology for operating costs described below in comparison to reviewed source material, from the United States Merchant Navy (Murray 2017) European Commission reports, Drewry Shipping Consultant data and similar thesis material. This was in order to confirm the reliability of the calculations related to operating costs the difference in costs in the overall aspects show that deviations occur that are important and can be considerable. However, the average operating cost is feasible as the costs are not going to affect substantially the overall result. The difference for the smaller vessel of 5000-6000 TEU for the South American and South African Routes, is more substantial than for the larger vessel of 8000-9000 TEU.

The daily operational and periodic maintenance components are as follows:

- Ct – crewing (Manning);
- Cal – Stores and consumables;

- Cmr – maintenance and repairs,
- Cs – insurance;
- Cad – administration;
- Cd – periodic maintenance costs.

The maintenance and repair costs are estimated with the following formula:

$$C_{mr} = K_{1m} * P + K_{2m} * HP^{0.66} \tag{3}$$

- K_{1m} is a constant of 0.0035;

  K_{2m} value is 105 for a two-stroke motor diesel (Santos, 2015).

Maintenance and repair costs are for scheduled routine maintenance to prevent breakdowns and mechanical failure which include onboard spares. Additionally, comply with the classification society and charters requirements this will be incorporated with the owner standard policy

$$C_d = K_{1pm} * P \tag{4}$$

- K1pm is 0.006 is for liner service;
- P is the purchase price of the vessel.

Periodic maintenance costs are for maintenance requirements that follow a scheduled routine such as every 5year classification society surveys which require the vessel to be in dry dock. The surveys may be for structure or vessel age dependent in relation to the machinery. Further painting and hull maintenance are carried out during these down times

Stores and consumables are calculated by the following equation

$$C_{al} = K_{1sc} * N + K_{2sc} * CN^{0.25} + K_{3sc}HP^{0.7} \tag{5}$$

- N-is the crew number;
- K_{2sc}- is has a value associated with dry good vessels of 4000;
- CN- is the vessels Cubic number;
- K_{3sc}-has the value of 200 associated with 2 stroke diesel engines;
- HP is the vessel propulsion power (Santos, 2015).

Consumables include oil and lubricants required by the engine and rotative equipment.

Table 15 Ship Crew salaries of a container ship crew (Ct) (Santos, 2015)

crew break down	QTY [no.]	salary [$] [$]
Master	1	8750
Chief Officer	1	6432
2nd officer	1	3174
3rd officer	1	2773
Chief engineer	1	8097
2nd engineer	1	5880
3rd engineer	1	3086
4th engineer	1	3030
Electrician	1	3829
Bosun	1	1586

Able Seaman	2	1227
Ordinary Seaman	2	899
Oiler	2	1263
Wiper	1	850
Fitter	1	1549
Cook	1	1596
Messman	1	711
Total	20	54732

Table 15 above displays the salary for each member of a ship crew on board a container vessel. Hence the associated crew cost (Ct)

$$N = K1_c + ((K2_c * CN)/1000) + K3_c * HP^{0.5}) \tag{6}$$

$$Ct = K * N^{0.95} \tag{7}$$

- N is a reference guide to the number of crew required by the vessel in this study from current operational perspective 20 crew members is a standard common operation on container vessels. The model is associated with Model A European crew members;
- $K1_c$ for Model A European crew is 12;
- The values for the constants for the container vessels are $K2_c$ is 0.07 and $K3_c$ is 0.0018;
- HP is the vessels Horsepower and CN is the vessels Cubic Number;
- K is 3000 for container vessels.

Equation 7 gives the Annual crew cost estimation for the purposes of the dissertation. The monthly costs were calculated from Table 16 hence the annual cost for the crew was found for the vessel.

The administration costs (CAD) are associated with the registration to the flag state which will be Singapore. Included in the port costs summation which takes shore based administrative and management costs, Communications costs, Owners ports charges, agent's charges, miscellaneous costs.

The insurance cost estimation was done through the following formula:

$$C_s = K_1 * V + K_2 * GT \tag{8}$$

- V is the purchase price of the vessel
- GT is the gross tonnage of the vessel
- Dry cargo 20000< DWT <80000; K1=0.008; K2 = 5

Dry cargo DWT >80000; K1=0.006; K2 = 2.5 (Santos, 2015)

Insurance covers against loss from physical damage or loss to the hull and machinery about two-thirds of the cost and one third is usually attributed to third party liabilities which can be attributed to the cargo damage, collision of a vessel, pollution or injuries to the crew. Third party insurance covers P&I (Protection & Indemnity) for financial responsibility and legal cover. A generic formula was used as no information to the owners claim record is known.

3.4 Capital costs

The monthly installment is found with the following formula:

$$P_i = s_o \left[\frac{\frac{j}{12}}{1 - \left(1 + \frac{j}{12}\right)^{-12n}} \right] \tag{9}$$

- P_i is the monthly installment;
- j is the annual interest rate which is taken as 8% in this study;
- J_i Is the interest parcel (The amount payable related to the specific time when a capital repayment is required).

$$J_i = \frac{j}{12} S_{i-1} \tag{10}$$

- S_o is the initial loan value which is assumed as the initial cost less down payment;
- n is the number of years on loan (Ventura, 2014);
- The number of years on loan 30 years at 8% interest.

The depreciation of the vessel was calculated by straight line depreciation and the annual cost is associated with the first year´s value of depreciation for a new vessel. The useful life of the vessel is 35 Years.

The calculations from the previous formulas 9 and 10 utilized to determine capital costs related to insurance, capital repayment value related to interest and the vessels depreciation. The capital repayment costs as will be elaborated below are calculated on the initial year of operation, which will relate to new vessel investment review of the capital costs.

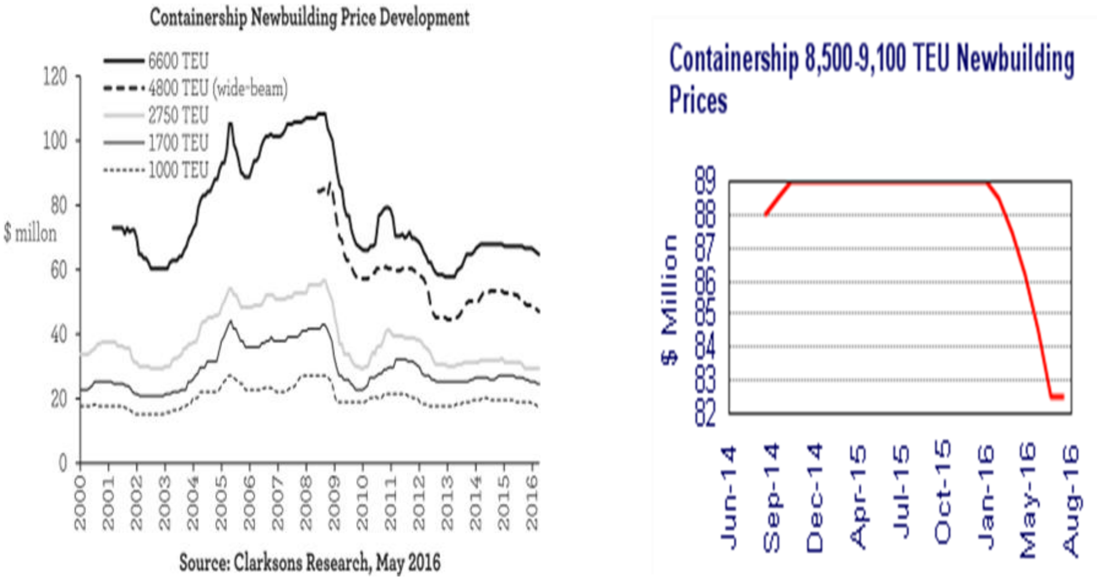


Figure 9 Containership Newbuilding Prices ($ Million) Clarkson Research (Clarkson, www.clarkson.net/sin2010/markets/Market.asp?nes_id=32742, 2017)

Figure 9 (left) shows the annual change in the purchase price of vessels since 2000 to 2016. The interpolation of the graph for values from 2016 was used for the vessels traveling on the South

American and South African maritime routes. Figure 9 (right) was used to determine the price of the vessel traveling along the North American Route.

Hull weight:

$$W_H = k1 * L^{k2} * B^{K3} * D^{k4} \tag{11}$$

K1=0.0293, K2=1.76, K3=0.712, K4=0.374.

Where L is the vessels length B is the breadth of the vessel and D is the vessel depth.
Superstructure = 10% of Hull weight and weight of equipment is:

$$W_E = K1 * (L * B * D)^\wedge K2 \tag{12}$$

K1=0.1156, K2=0.85.

The weight of machinery:

$$\mathrm{Wm} = \mathrm{K1} * \mathrm{P_{MCR}}^{k2} \tag{13}$$

K1=2.41, K2=0.62
P_{MCR} Is maximum continuous ratio of the vessel´s main engine

The salvageable value is the price related to the recuperated value of the vessel if the vessel is sold for scrap metal. The estimated weight of the hull super structure and machinery was estimated to determine a scrappage steel weight value. The scrap value is based on the steel scrap value based on the United States for HMS steel the lightweight of the vessel was calculated to 35100 ton. The scrapping return value per year is obtained from a division of the estimated number of payback years of 15. The market price 213$/ton as of 1 March 2017.

3.5 Container quantities moved at ports

In port movement of containers is as follows:

- Ship ←→ crane←→Hostler←→Stack←→Crane/pick←→Truck/rail

The movement through container terminals depends upon the equipment that each port has the vessel once being moored and if not geared, will make use of the ship to shore cranes available to handle its respective length. Each port will have, a different set of terminal equipment such as hostler trucks, straddle carriers, forklifts, rubber tire gantries and rail mounted gantries.

Each container will be subject to average moving time that required to move the container from the offloading platform along the specific aisle to the container storage yard. Then subsequently the containers will be moved and loaded onto rail transportation. Where terminals have multiple Rubber tire gantries and straddle carries the transport system known as a straddle carrier system. The scenario for the containers removed from the vessel and then from straddle carriers or RTG to the storage yard and then from the storage stack and onto the rail locomotive flatcars. There is another system layout making use of the hostler trucks which is similar. In this case, the hostler truck receives the goods from the ship to shore cranes and then onto the SC´s and RTG´s which in turn stack containers at the respective container storage sites. Simultaneously again other

RTG´s and straddle carriers are moving the stored containers to the rail locomotives. This is known as a straddle carrier relay system.

The results of the time vessel spent in port and quantity of containers offloaded can be seen in Appendix 3. Additionally, below the productivity rate of the servicing of the vessels was determined following the formulae from 14 to 17 described below.

The number of quay cranes at the respective terminals was obtained to determine the number of moves that can be applied to the respective vessels at the port. The terminal quay lengths were obtained to ascertain the number of cranes per meter:

$$Number\ of\ Cranes\ Quay\ length = Crane/meter \tag{14}$$

Therefore, in accordance with the vessel length, it is possible to know how many cranes will service the loading and unloading operations of the vessel:

$$\frac{Crane}{meter} * ship\ length = Number\ crane\ servicing\ vessel \tag{15}$$

The total moves per hour can then be found by multiplication of the number of cranes per vessel and the crane's respective move rate:

$$Number\ cranes\ serving\ vessel * Cane\ moves\ per\ hour = moves\ per\ hour \tag{16}$$

Analysis of the container quantities delivered and required at each port on the liner service was done by analysis of the Hamburg Süd schedule. The daily time was recorded per route section and time in the port of for the South American route. The container quantities for the South African and North American route delivered and required at each port on the liner service was done by analysis of the Maersk schedule. This was adjusted for the time spent at the ports of call for routes on the Maersk route. The daily time was recorded per route section and time in port.

Therefore, from the scheduled time to be in the port of the vessel multiplied by the move rate per hour give the number of moves which is associated with the twenty-foot equivalent containers removed. Assumptions are that the administration activities are done simultaneously while the on-loading and offloading processes take place. This is particularly possible with the ports on this route having adopted electronic data entry systems to facilitate greater expediency.

$$Moves\ per\ hour * time\ in\ port = moves\ per\ vessel \tag{17}$$

The container quantity to be delivered at the respective port is assumed to be the difference quantity unloaded with respect to the moves made and the respective vessel capacity. The division of the number of reefers and dry containers is done with respect to the vessel´s stipulated dimensions, which indicate the reefer and Total TEU capacity. The TEU capacity is done considering that 14 tons = 1TEU. The number of reefers and dry containers is found by the proportion of the vessels total allocated TEU and reefer capacity and that which was offloaded at port.

3.6 Rail costs

The cost component calculations of the costs of rail transport comprised of the following:

a) Fixed costs which include capital costs of the rolling stock and locomotive, depreciation of the rolling stock and locomotive personnel costs associated with rail employee salaries

b) Variable costs are the consider the estimated maintenance costs found by expert estimations, (Baumgartner, 2001; Delhaye, 2010) as a percentage of the purchase price. The driver's salary is also a variable cost, which is accounted for by separate charge rates that are associated with each country´s salary remuneration stipulation. The values are dependent on the permitted working hours of the driver in relation to the section of the route. Another variable cost is for the energy consumption, for the transportation of goods associated with each type of product in the containers. The products that are transported are laptops and shoes which are considered manufactured items which is attributed a fixed fee per ton-km

c) Tariff charges for the respective rail routes are costs in relation to the tariff structures. A comparison of values is displayed with relation to CIS Software, Rail operator charge system calculations and charge associated with RNE timetable schedules. These costs are associated with direct costs for infrastructure use.

3.6.1 Rail Cost structures

Direct costs are those in which the train incurs directly by its exploitation. These costs can be subdivided into the following categories.

In costs of access to infrastructure and operating costs of the service, one can include:

- Infrastructure use costs: all the fees that must be paid for the use of the infrastructure.
- Service exploitation charges: all costs related to traction and rolling stock.

Fixed costs are those that occur independently of the activity carried out by the train. They are "Periodic or hourly costs". These costs include:

- Depreciation of locomotive and rolling stock;
- Financing of the locomotive and rolling stock;
- Driving staff (salaries, social security);
- Insurance and taxes;
- Other costs.

Variable costs that vary proportionally to the activity of the train. The costs are related to the kilometers traveled by the locomotive and rolling

- Fuel or energy consumption;
- Maintenance costs
- Drivers' and other assigned staff's allowances;

Indirect costs are those not directly attributable to the operation of each train but occur by the normal operation of companies. The following costs are components of indirect costs:

- Infrastructure costs: depreciation and financial expenses, or rental/leasing of facilities of the company, maintenance expenses and insurance of said infrastructure;

- Administrative &management costs: staff, office, communications and computer equipment;
- Commercial costs: personnel and commercial expenses;
- Other indirect costs. (ANFAC, 2009)

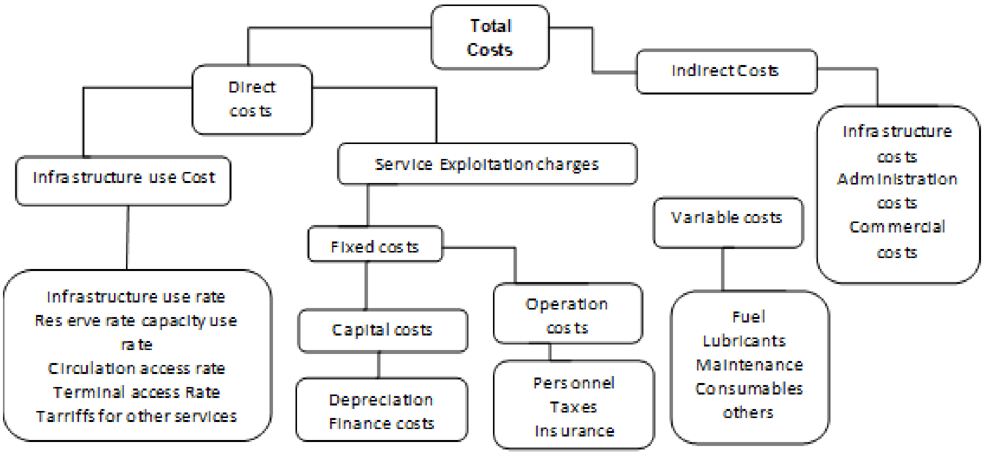


Figure 10 General Rail cost structure

3.6.2 Rail variable and fixed costs results

Fixed and variable resulting costs were based on findings from the European Commission the average fixed costs were based on the following criteria (Delhaye, 2010). Table 16 summarizes components to the costs associated with the calculation of the cost per intermodal unit to be transported by rail by means of electric rail locomotive and flatcar carrier.

In the analysis of the respective rail transportation of containers from either maritime route 1 or 2 from the African and North American continents, personnel costs we considered the cost of the locomotive conductors. The variable personnel costs are related to supporting personnel in the communications and train schedules, also including the shunting costs. These costs and an additional 20% overhead charge of the personnel costs whose sum of these costs leads us to the average fixed operator cost as denoted in Table 16. Variable costs change considerably per each country and the line type used, path, train type and loads and cargo type. As such to obtain a general calculation for €/trainkm was based on source material from the European Commission report on rail transportation. The shunting costs assumed a cost of 411.65 €/train for diesel and electric trains, including the personnel costs. The average international trip is1000 km in length. The values described above provided the basis for the results displayed in Table 17.

Table 16 Electric Locomotive and flat car rolling stock assumptions used for fixed cost component calculations

Purchase Price per piece [€]	3252011	Flat car number per train	28	[No.]
Number of Locomotives	1	loading capacity per wagon	2	[TEU]
Depreciation (years)	20	Rental price per day	21.4	[€]
Maintenance costs [%]	6.25	Operator working hours per day	6.5	[Hour/Day]
insurance cost [%]	1.5			
rest value [%]	10			

Operator number working days	300	Fixed Operator costs	179.82	[€/hour]
Operator working hours/day	6.5			

Table 17 Electric traction costs per product type carried in relation for energy and fixed costs and variable costs

Electric Traction Transportation			
	Average fixed costs	Average Variable Costs	Average Energy
	(€/tonKm)	(€/trainkm)	(€/trainkm)
Agricultural Products and live animals	0.0066	3.71	4.84
Manufactured Articles	0.0081	3.71	3.81

(Delhaye. 2010)

In Table 17 The electric locomotive and rolling stock values for capital-related costs and operating costs are shown. These costs a part of the costs involved and are expressed as cost per kilometer-tonnage seen in Table 17. Table 17 above was used to calculate the costs of transportation of goods by means of electric traction which has the general average cost in Europe for fixed costs, variable costs and energy consumption to transport the specific containerized cargo. These values were used for the analysis for the South African and North American route analysis. The Analysis for the South American route utilized fixed and variable resulting cost which was compared to the reports by ANFAC (2010) to compare the results of the overall traffic by rail that the dissertation intends to apply in comparison to the existing infrastructure results per country. Depreciation in ANFAC method was based on the purchase price of the diesel-electric locomotive. The value is based on the purchase price of the vehicle which was 3200000 € and the value total depreciation is adjusted for the cumulative depreciation price of inflation of 1.12. The Atlantic Corridor TEN-T unification of railway lines for freight transportation purposes implies. The locomotives and the flat car residual value was 20% useful life 30 years and 10 years with an annual interest of 6.4%. The rolling stock flat car container purchase price was 85 000€. (ANFAC, 2010)

Table 18 Electrical train and flatcar price financing characteristics South American route rail section

Type	Electrical	Structure costs Rolling stock platform		
Purchase Price per piece [€]	320000	platform price	85000	[€]
Residual value	20	Residual Value	20	[%]
Useful life (years)	30	Useful life	25	[years]
Finance period [years]	10	Quantity to Finance	100	[%]
Annual interest [%]	6.4	Financing Period	10	[years]
Euribor [%]	1	Type of Annual interest [TAE]	6.4	[%]
Differential [%]	1	Euribor 1 year	5.396	[%]
		differential	1	[%]

The dissertation assumed the investment value of the purchase of a new locomotive to be in line with the TEN-T Corridor 4 Requisites. The locomotive purchased was a Bombardier TRAXX F140 MS with a weight of 86 tons that can carry the 1600-ton load and train length of 740m with 5.6 MW of traction power. The locomotive main dimensions were 18.9m long 2.98m wide. The trains operating power is 2.5MW for the current routes from Portugal to Germany which the locomotive model was a Renfe Class 33 of 120-ton weight length 20.7m breadth 3.48m and height 4.28m. The flat cars used to carry the containers connected to this are Greenbrier's all-purpose double flat car, stacker.

The number of flat cars and the length of the train is restricted by the characteristics, of Atlantic, Rhine-Alpine and North Sea-Baltic routes. As such it is found that in the projected routes a train length of 700m and weight of 1600 tons is permitted. This meant for the length of the train and weight restrictions 56 TEU could be carried on the projected journeys and those for Northern Europe to Germany. This means double stacked on 28 wagons. This also was in accordance with axle weight and maximum load per flat car which could take up to 3 containers at maritime container weight of 14 tons, Where, the maximum load is 60 tons. The current route has a restriction which only permits 17 wagons due to the restrictions on tonnage that can be carried at certain sections of not more than, 1000 tons and current lengths. of 600m (Pulfer, 2014)

3.6.3 The route analysis Rail Routes

The following routes have been considered:
Route 1 option 1 Rotterdam-Venlo-Köln
Route 2 option 1 Rotterdam-Duisburg Oberhausen-Koln
Route 2 option1 Portugal: Lisbon/Sines-Vilar Formoso-Irun-Paris-Metz-Mannheim
Route 2 option 2 From Portugal: Lisbon/ Sines-Elvas-Badajoz-Madrid-Irun-Paris-Metz-Mannheim

The Tarif costs per each country sectional route were calculated for each respective country along RFC 4 Atlantic Corridor. The countries involved being Portugal, Spain, France, and Germany. In a similar fashion, RFC 2 also calculated each respective tariff charge for the countries along this route to Germany and Holland.

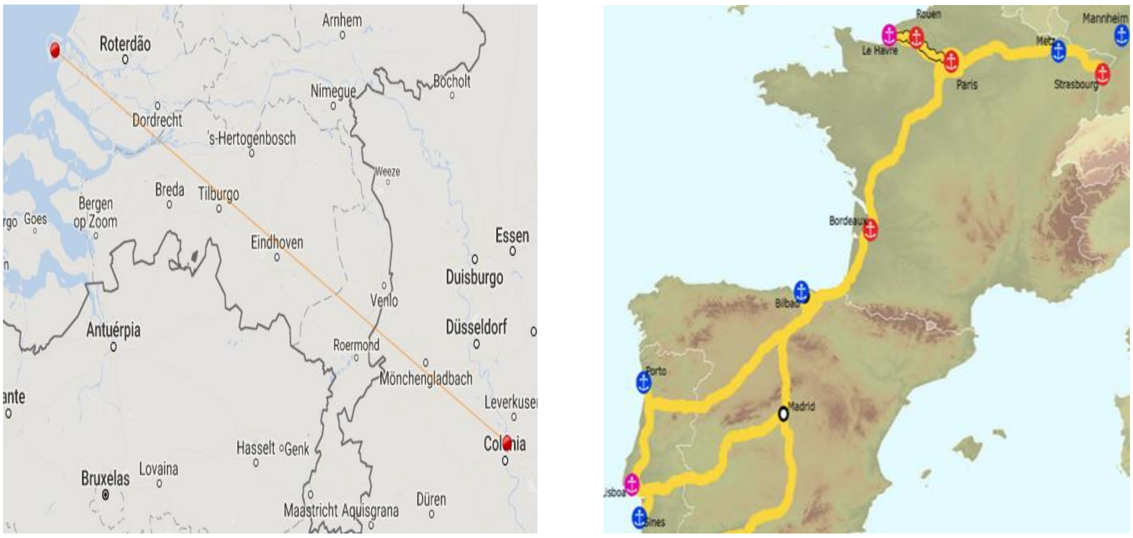


Figure 11 Rotterdam Köln rail route (left) Rail Routes Portugal to Mannheim Germany (right)

The tariff charges were calculated and the specific criterion and procedures to follow are laid out in Appendix 1 for each respective country through which the train path follows. The trains path is from each respective port of call to the rail terminal in either Köln or Manheim. In Table 19 the reviewed charges for each respective rail section of the overall route are determined and scheduled European rail network time table and path schedule, The European Network Rail charging information system (EICIS) and calculated values based on the tariffs of the respective countries rail operator maybe seen in Appendix 1 reference tariffs.

3.6.4 Tarif costs

Belgium: The Tariff calculation for Belgium requires first determining the rate of use charge. This is constituted by the charges for the price of the line, the price of the station and shunting charges. To obtain the line price is the summation of the product of all components see Appendix1 Belgium tariff. all the distances traveled multiplied by the section importance coefficient, which is multiplied by the speed the trains travel multiplies by the peak time coefficient multiplied by the train mass coefficient and by the environmental impact coefficient of the respective train.

The station that is used as a coefficient in Belgium being Antwerp for the South American route analysis it is determined again by a summation of two product equations seen in Appendix 1. The station base price multiplied by the station usage and the station importance coefficients which is added to the second product of the station base price in relation to the time spent and the relative importance of the station.

Belgium tariff has charges for the administrative activities asked capacity on a line and conflict management. The other components of Belgian tariff are the reserve capacity and the energy. The energy charge is broken into two components the charge for energy distribution and the supply of traction energy.

France: France charges by a base rate dependant on the train type in this case freight. Then there is an added access rate and a reserve rate and other taxes. The reserve rate depends on the distance section type and speed. The charge for the energy in France has two components a charge for the Electrical installation use and secondly the charge for distribution and transmission charges. Le Havre has a special rate for its access use see appendix1

Germany: Germany tariff is constituted by the rate of use charge which is a product of the base price and the product factor, this factor relates to the speed of the train. There is then an added competent weight charge which is related to the train weight overall being hauled. The second component of the tariff is Performance regime which is dependant on a variety of factors, in particular, the particular section to be used and how congested that section is likely to be. Appendix 1 elaborates on the sub categories of each components related charge for the infrastructure management. Each track section required review from the report for charges laid out by DB Shenker. The reserve rate was taken as the standard rate as well as the asking capacity. No cancellation charges were attributed. The Surcharges were charged in relation to the values in Appendix 1 The energy charge was related to the locomotive power required by the charge rate per megawatt hour

Holland: The Dutch tariff structure is a base rate that is multiplied by the distance the train travels. There is an additional charge for the excess capacity that the train has this is charged during peak times. It is interesting that under proRail both Betuwe and the conventional track follow the same procedures. In this study the performance measure was neglected as no data was available for analysis, this would have made changes to the overall tariff for Holland. The study was based on a neutral case that trains operated on schedule and no recompensation was delivered for early arrivals. There is a tabulated compensation charge for sections under maintenance by a set fee which can be seen in Appendix 1 Table 52. Energy Acces to the Catenary supply is charged per kWh

Portugal: The charges for Portugal are according to a base rate per each section of the line. This basic rate is charged in accordance with the product of various component coefficients which is detailed in appendix1. The charge for essential services for use of the track by the locomotive is calculated by the sum of two components the calculated base rate charge as per the network statement and the shared value related to investments. This summation multiplied by the distance the train travels gives the charge for essential services. The Portuguese charge has a specific rate in relation to the type of traction being electrical or diesel.
Investigations into the current route through Vilar Formoso took into consideration the sections between the Spanish border still to be electrified and as such a summation of the electrical and diesel traction was calculated. In the projected routes only electrical traction was calculated. The rate per train kilometer also considered the charges for the return journey of empty freight wagons.

No delay was considered and as such the performance regime penalty was not considered. That there would be a notice for schedules of greater than 30 days notice. There are three levels of administrative services depending on the kind of electric traction substation. The service type for the section under consideration is service type A for the line section north of Lisbon and for the South accounts for Service Type B.

Energy charges for Portugal are calculated for the zone through which the locomotive travels. The calculation method is described in appendix1 This provided a difficulty in assessment as to be exact a requirement for the entire month's electrical bill of all trains passing through. The charge for energy usage rate was taken from the charge stipulated by the Portuguese energy regulatory body for contracted global energy and its rate per kilowatt-hour.

Spain: The Spanish tariff structure composes of two principal cities the rate of use and the energy charges. The rate of use charges comprises of three components A summation of the three components. The first component is the rate of access which is charged for the number of kilometers traveled by the trains as an annual rate. The charge was taken in accordance with a number of freight trains traveling through Spain which was found from the European Commission reports on the Atlantic Corridor.

The rate of use second component is the rate of operation which charges in relation to the type of service rendered which in this case is M for freight services which travel along the C2 Rail type for the freight corridor service. The charges for reserve capacity is done per time and type of service. An average charge was done in this regard where the train is expected to be traveling in percentage to the charge per period . The case was done in view of the probability that the high and low traffic periods would constitute a percentage of to respective charge. Division of the time between normal, peak and low traffic period provided an additional coefficient to be multiplied by the respective reserve rate coefficient the summation provides the average reserve charge.

Spanish energy is charged per traction power required to haul the specific type of route section, distance to be traveled and type of freight haulage which was considered as conventional The Energy Cost associated with the locomotive Is related to the traction power of the section of rail requiring Diesel Fuel has a price of 1.26€/liter. When considering the consumption 0.14 gallon per mile and the expected time of the route section is 10 and a half hours as such the effective cost of resupply of the train is expected to be 109.91€ per trains.

EICIS: Is a Software system of the European rail freight network system which calculates the freight rate charge per route section selected it takes into account the train type electrical or diesel. Each section has a start and ending terminal to be selected on the respective freight corridor route which automatically determines the distance. The speed of the trains in service is chosen at 100km/h. The loaded on the axles, total train cargo load, locomotive load, and dimensions are also chosen for the program to apply its analysis.

RNE: The European Rail Network corridor schedules allowed for the calculation per section of existing routes the total charge for the respective country and the total for the routes selected for transporting the selected containerized cargo from the port of call to the German hinterland. The Review of corridors RNE, CO2, CO3, CO4,CO5, CO6 was done to determine all the possible links towards trains arriving at Mannheim or Köln. The Alpine Rhine corridor had at time combinations of CO2 CO3 and CO4 depending upon particular sections using either the Betuwe or conventional route towards arriving at Köln through respective nodes. RNEC06 had most of its route on the RFC-Atlantic corridor to Mannheim. These schedules also allowed verification of the time expected of arrival at the German rail terminals as each rail section had a time layout that would be coordinated with the prearranged paths along the route. These schedules also were the basis towards the initial and current route restrictions on weight and rail paths. These schedules highlighted where electrical train transfer is still not possible and diesel traction is used (the border crossing of Spain and Portugal) It also highlighted where train length and maximum loading were mainly restricted again for Portugal and Spanish sections principally. The use of each section had its respective charge rates.

Table 19 shows the route costs and distances as obtained from EICIS, RNE and dissertation calculations. The European charging EICIS system was used to check calculations from the network statements and tabulated charges per section on the timetabled RNE rail network corridors. The standard deviations were calculated to verify that the charging principle was correct according to the information available.

Table 19 Route comparison of rail cost results of the tariff charges calculated and from the European rail network and European charging system

Rail route tariff charge comparison								
Route	EICIS		RNE		Dissertation			
	[€]	[km]	[€]	[km]	[€]	[km]	Ʊ [€]	Ʊ [km]
Rotterdam-Oberhausen-Köln	924	267	735	317	933	238	91.64	32.60
Rotterdam-Venlo-Köln	819	257	395	245	948	257.	236.31	5.79
Rotterdam-Duisberg-Köln	914	262	735	313	1 081	204	141.28	44.54
Sines-Mannheim	6846	2587	3730	2607	6 842	2012	1468.30	275.69
Lisbon-Mannheim	6657	2430	3495	2427	6 575	1949	1471.75	226.12
Projected routes								
Route	EICIS		RNE		Dissertation			
	[€]	[Km]	[€]	[km]	[€]	[km]	Ʊ [€]	Ʊ [km]
Rotterdam-Köln	819	257	395	245	948	253	236.49	5.17
Mannheim-Sines	6712	2581	3730	2607	7080	2646	1500.08	26.82
Sines-Mannheim	6712	2581	3730	2607	7080	2646	1500.08	26.82
Sines-Madrid-Mannheim	6465	2861	2175	2786	6741	2996	2090.63	87.10

(Rail NET Euope, 2016), (Europe R. N., RNE Corridor CO5, 2016)

The RNE has a set value per section, while the calculated values and the charging system account for the specific charging principles for the type of cargo and line to be used. The sections with very high tariffs are through France, this is for lines where the larger deviation is seen for the rail routes from the Portuguese ports to Mannheim. RNE also had very low tariff rates for Spain where the calculated and EICIS values were of higher charges this accounts for the particularly large deviations for routes from Sines to Mannheim.

3.7 Maritime emissions

Emissions from ships comprise the following chemical compounds, as for reference**:**

- Particulate matter (PM) (10-micron, 2.5-micron);
- Diesel particulate matter (DPM);
- Oxides of nitrogen (NOx);
- Oxides of sulfur (SOx);
- Hydrocarbon - total (HC);
- Carbon monoxide (CO);
- Methane (CH_4)
- Carbon dioxide (CO_2);

Ocean going vessels emissions can be calculated by using energy-based emission factors together with activity profiles for each vessel. Emissions per ship call and voyage leg and mode can be determined using the equations below:

$$\mathrm{E} = \mathrm{P\ xSFOCx\ LF\ x\ A\ x\ EF} \tag{18}$$

where E = emissions [g]

P = maximum continuous rating power [kW]

SFOC = specific fuel oil consumption [g/kW/h]

LF = load factor (percent of vessel's total power)

A = activity [h]

EF = emission factor [g(emission)/g(fuel)]

Load factors are expressed as a percent of the vessel's total power. At service or cruise speed, the load factor is 83 percent. At lower speeds, the Propeller Law should be used to estimate ship propulsion loads, based on the theory that propulsion power varies by the cube of speed as shown in the equation below:

$$\mathrm{LF} = (\mathrm{AS}/\mathrm{MS})^3 \tag{19}$$

where LF = load factor (percent);
AS = actual speed (knots);
MS = maximum speed (knots),

The emissions of the vessel along both the projected route and the current timetable route were calculated with respect to each emission particulate type. The ocean-going vessels emission contributions were attributed in accordance with the load factor which had values associated with speed for speeds associated for voyages. The loading factor for maneuvering and hoteling of a container ship had set values of 0.5 and 0.17 respectively. (Browning, 2006).

The main engine and the auxiliary engine emission contributions are based on a medium speed operating vessel. The combination is the sum of the emissions produced by the main engine and the auxiliary engines.

$$\mathrm{E}_{aux} = P_{aux} * LF * A_{aux} * EF_{aux} \tag{20}$$

E_{aux} is the emissions in grams of the four auxiliary engines;
P_{aux} is the power combined auxiliary power of the four auxiliary engines;
EF_{aux} is the emission factor for auxiliary engines.
When the vessel is traveling and stationed in low emission zones, a compensatory factor of 0.17 for emissions of particulate matter to take into consideration the ultra low sulphur and higher-grade fuels used where lower emissions are to be produced. As such since the particulate matter and SO_2 are directly proportional. The Ultralow Sulphur fuel used in turn means a 0.004 reduction factor for the northern European ports where the and in general under Marpol emission control areas.

3.8 Rail emissions

Rail emissions can be found by emission factors, the emission factors were based on a European commission report that took in to account the average mix of rail and diesel traction. Furthermore, the method also would then consider the possibility of electrical energy coming from a fossil fuel energy supply. The emission particulate value of the pollutants value was defined by TREMOVE (Delhaye, 2010):

- Particulate matter (PM) 0.005g/tonkm;
- Oxides of nitrogen (NOx) 0.003g/tonkm;
- Oxides of sulfur (SO_2) 0.001g/tonkm;
- Flurocarbon - total (FC) 2.528g/tonkm);
- Volatile Organic substance (VOS) 0.011g/tonkm
- Carbon dioxide (CO_2) 7.932t/km;

Rail emissions are calculated by multiplying the train load weight by the distance travelled by the train. The rail emissions for the rail routes to Germany by the trains carrying the cargo from Portuguese ports by either the existing route through Vilar Formosa or by the projected route through Badajoz to Mannheim Germany. The number of trains required was determined by the quanty of cargo to be delivered at the repective ports. Therefore the journeys for the transport of goods to Germany and from Germany were determined and the number of trains is in relation to the new train loading of 56 TEU as previosly mention the total tonage of the locomotive is thus known. The summation of the maritime produced emissions and rail emisions was then applied where Route 1 maritime emmision production is added to the rail routes from Holland to German in land terminal, simmilarily Route 2 maritime route to Portuguese ports is added to the combined rail transport to and from German inland terminal.

The current rail transport scenario of requiring more trains to transport the containers delivered by ship. The reason is due to a load restriction of 1150 ton for tracks on the sections from Portugal and along Spain, this reduces the trains to only being able to transport 34 TEU per transported load. The future projected loads imply that with 740m trains able to handle 1600 ton loads, 56 TEU load will be uninhibited, therefore a great reduction in trains and hence emissions and congestion problems. The rail contribution to the rail is much reduced along the Dutch rail options and as such the emissions produced from transporting goods by rail to Germany.

4. RESULTS

4.1 South African route results

4.1.1 Fuel costs sensitivity in South African route

Route 1 travels from South African ports to Rotterdam and Route 2 travels from South African ports to Portuguese ports. Figure 12 below displays the sensitivity agglomeration of the price of the total fuel consumed between the two maritime routes. Route 2 maritime route is slightly more expensive than Route 1. The vessel on Route 1 must travel at a higher speed to meet the same weekly schedule as Route 2 whilst having to compensate for additional port time spent in Portugal. The sensitivity related to vessel speed shows that Route 2 is less expensive than Route 1. This is attributed to not requiring traveling a greater distance.

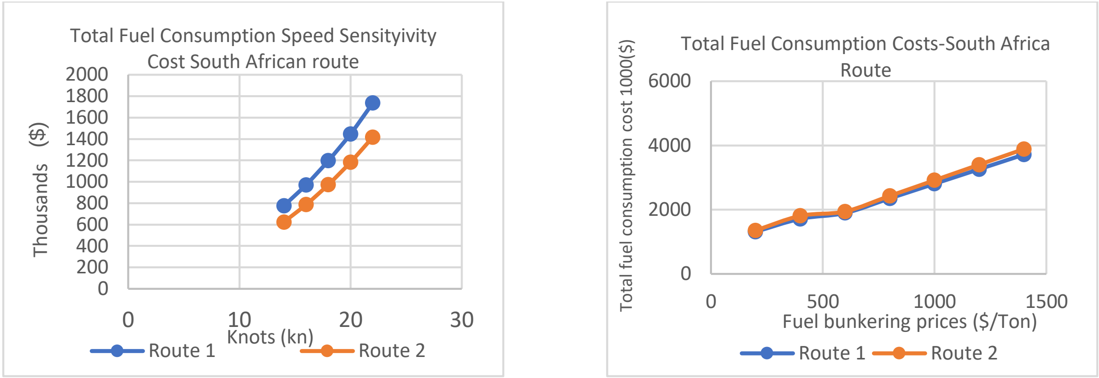


Figure 12 Fuel consumption comparison of two maritime route options (left) total fuel consumption comparison of routes related to speed (right) (South African Route)

A sensitivity analysis was done per fuel type in relation to the alterations in fuel bunkering prices for both routes. A sensitivity analysis was also done in relation to the alteration of the speed of the vessel. Fuel consumption considers the ECA region where ULSFO fuel must be used in compliance with the Sulphur reduction regulations imposed. The sensitivity on vessel speed shows that there is a steady steep rise with regards to heavy fuel oil as opposed to ultra-low Sulphur fuel oil. This arises from the fact that the largest part of the maritime journey is done in non-emission controlled areas.

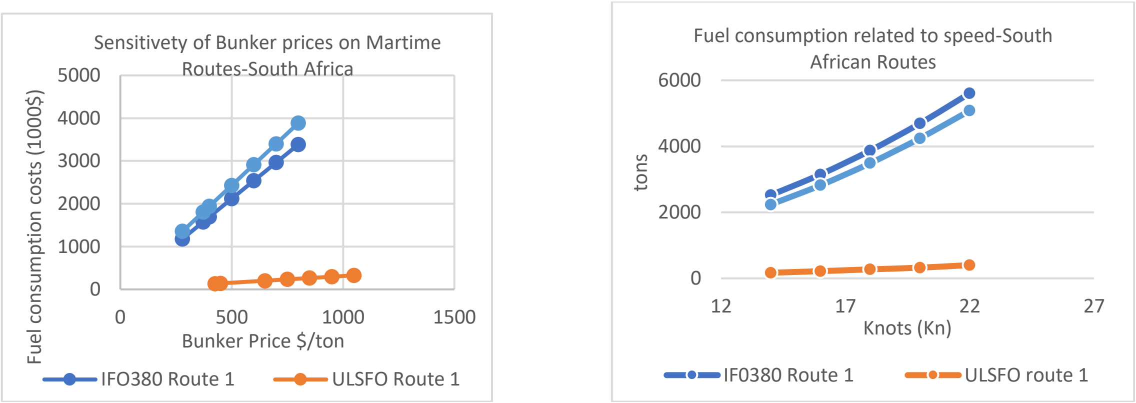


Figure 13 Fuel type and route consumption comparison related to fuel bunker price per maritime route (left) Fuel Consumption per vessel speed along maritime routes (right)-South Africa

4.1.2 Maritime Cost Structure South African Routes

The maritime cost structure of transportation of containerized cargo to either Rotterdam or through Portuguese ports of Sines and Lisbon, to Germany is shown in Table 20. In these routes containerized goods are transported from the South African ports of Cape Town, Port Elisabeth, and Durban.

The maritime cost of transporting goods to Portugal first is 88% of the cost of transporting goods to Northern Europe by MSC Krystal with an 80% cargo load and return journey with 48% load. The difference in maritime costs per vessel fleet delivery is 1.28 more expensive for Route 1 than route 2 operation.

Table 20 show the maritime annual costs structure for the two maritime routes. The transportation for one twenty-foot containerized unit by a vessel over the entire year will cost more on Route 1 by Rotterdam than by route 2 through the Portuguese ports.

Table 20 Maritime cost structure for the 2 maritime routes (South African Routes).

Maritime Single ship route 1			Maritime single ship route 2		
Ship Type	Container ship annual costs		Ship Type	Container ship annual costs	
Size (14t)	4180	[TEU]	Size (14t)	4180	[TEU]
Voyage days	46.59	[days]	Voyage days	38.96	[Days]
Design DWT	72900	[t]	Design DWT	72900	[t]
Manning costs	659435	[€]	Manning costs	623915	[€]
Insurance	692048	[€]	Insurance	654771	[€]
Stores & Lube	624539	[€]	Stores & Lube	590899	[€]
Administration	121321	[€]	Administration	114786	[€]
Capital repayments	3677442	[€]	Capital repayments	3479359	[€]
Interest	3022899	[€]	Interest	2860072	[€]
Gross profit margin	83.77	[%]	Gross profit margin	87.7	[%]
Port dues	630 691	[€]	Port dues	833726	[€]
Tugs and Pilots	374 288	[€]	Tugs and Pilots	452164	[€]
Total fuel cost	9 199 820	[€]	Total fuel cost	12205343	[€]
Handling	59990241	[€]	Handling	7598057	[€]
Vessel speed average knots	16.9	[Kn]	Vessel speed average knots	18.6	[Kn]
Total [€]	78 984 377	[€]	Total [€]	97 878 695	[€]
Total [€/TEU]	2109		Total [€/TEU]	2 033	

Route 2 the vessel is required to have a higher vessel speed which leads to higher fuel costs. The costs associated with and port dues the that are incurred by traveling to the Portuguese ports are slightly higher than those incurred by traveling on the route through Rotterdam. The handling fees and tugs and pilotage are more for Route 2 going through Portuguese ports than that of Route 1 traveling to Rotterdam. However, Route 2 allows for two more journeys and hence it has higher costs. Route 2 has a lower maritime cost per unit to be transported than that of Route 1 due to the additional journeys that can be achieved by traveling to Portugal. The additional goods transported on the additional journey reduce the overall cost per unit on this route. The revenues from the freight rate obtained from world freight rate comparison have higher freight rate charges for goods to Portugal from South Africa than those going to Rotterdam from South African ports.

The gross margin for Route 1 is less than Route 2 the gross margin is calculated from the revenue which is found from existing maritime average world maritime freight rate charges for twenty Foot containers containing frozen meat products for reefers and electronic products for the dry containers. Route 1 gains more profit per route from containers transferred than route 1.

$$Gross\ profit\ margin = \frac{Revenue - Cost\ of\ transporting\ containers}{Revenue} \tag{21}$$

$$Required\ Freight\ rate = \frac{annual\ cost}{cargo\ delivered} \tag{22}$$

The required freight rate is freight rate value that needs to be charged to break even. The gross profit percentage is the required freight rate divided by the gross profit margin.

4.1.3 Combined Costs Comparison South African Route Analysis

The alterations to both speed of the vessel and the maritime cost of fuel has the cost of transporting goods by rail directly through Holland as the cheaper form than by use of rail. Figure 14 left shows that even alteration of the vessel speed on routes from South Africa will have the cheapest routes of container transport through Rotterdam than go through Portugal.

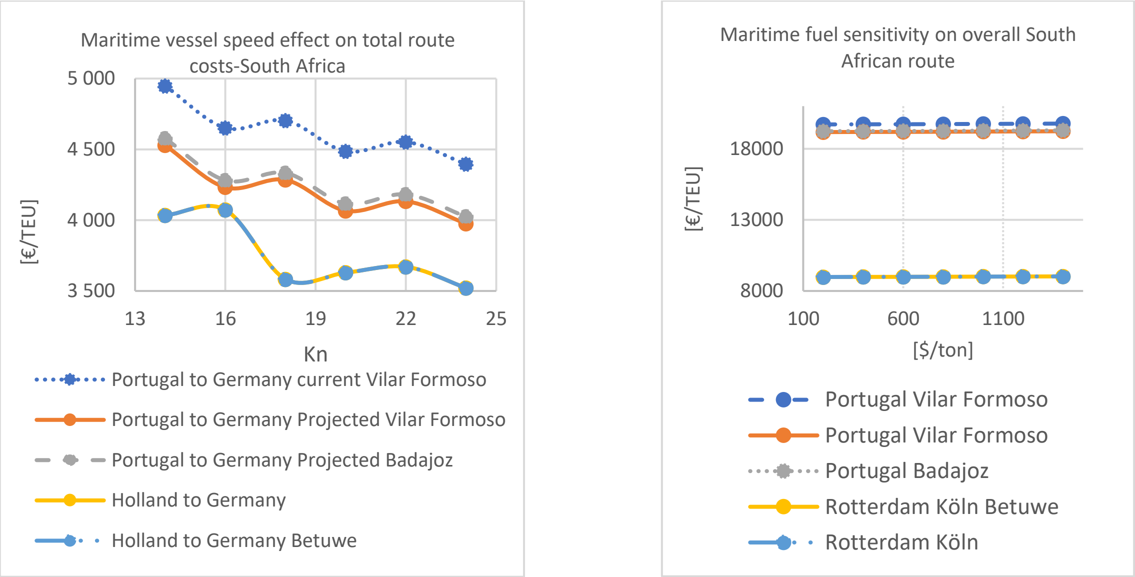
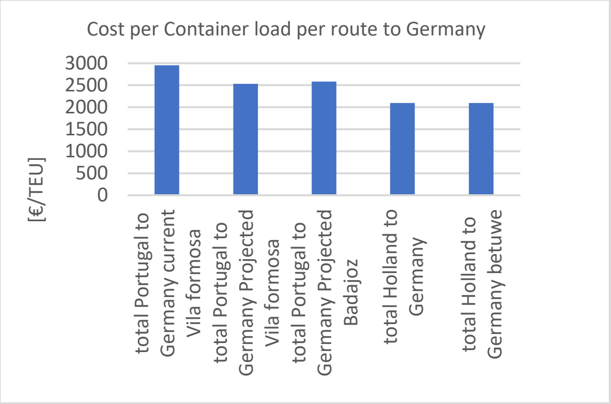


Figure 14 Combined costs associated with speed variation of the vessel to Rotterdam and Portuguese ports (left) Difference associated with alterations to fuel price- (South African routes)

There is nearly no difference in the cost of transportation by Betuweline or conventional rail line to Köln, this is due to the negligible difference in distance and that the tariff structures from Pro-rail are very similar. The distances traveled to the German border are also small and the difference in unit transport cost small to the connecting nodes to Köln. The most expensive tariff section on rail is through France which contributes additionally to the increased rail charge for routes from Portugal. Figure 14 right shows that the Rail costs are a significant part of the overall costs and that the maritime fuel price has no effect on which route is cheapest. The combined maritime and rail route options for intermodal transported units from South Africa transported through Portugal to Germany show the current rail route of traveling through Vilar Formoso being the most expensive. The reason is due to more trains required to transport goods along rail lines from Portugal through Spain, since the lines allows a lower quantity of containers than the projected routes with longer trains.

Table 21 Combined cost comparison for goods from South Africa to Germany through Rotterdam and Portuguese ports (right)- (South African routes).



Total cost comparison	[€/TEU]
Portugal to Germany current Vila Formosa	2951
Portugal to Germany Projected Vila Formosa	2532
Portugal to Germany Projected Badajoz	2581
Holland to Germany	2094
Holland to Germany Betuwe	2096

Table 21 above shows that the cost of transporting goods directly from South Africa through Rotterdam to Germany is cheaper by approximately a half of the cost of transporting goods through Portuguese ports. The difference in transportation costs by the Betuwe and conventional routes from Holland to Germany are negligible, in this case. The results also show that it is cheaper to travel through Badajoz than to travel by Vilar Formoso for goods from Portuguese ports. This is due to the lower tariff charges encountered in Spain.

The effect of being able to transport goods from Portuguese ports to Mannheim through Vilar Formoso will be cheaper by having the effect of the longer new train system that allows sections with a greater ton load than the current situation. The projected cost of transporting goods through Portugal from South Africa is expected to be cheapest by this route.

Table 22 shows that the combined travel time by route 1 direct to Rotterdam will take longer than a route through Portugal as well as the projected route which would be a day longer. For general manufactured cargo, this is not very important. For reefer cargo, this is very important as the shelf life for frozen vacuum packed beef of 45 to 60 days as can be seen if the reefer goes by sea and is the last to be loaded on the trains the product shelf life will be only 2 days (Delmore, 2009).

Table 22 Combined journey time projections for trains leaving rail terminals from respective ports to Germany regarding the first train and the last train to be loaded (South African routes)

Train expediency related to handling and		
	first single train total route [days]	last train total route [days]
Rotterdam-Oberhausen-Köln	22.75	26.09
Rotterdam-Venlo-Köln	22.79	26.13
Sines-Mannheim	19.98	21.65
Lisbon-Mannheim	19.84	21.52
Lisbon-Badajoz-Mannheim	20.46	22.13
Sines-Badajoz-Mannheim	20.54	22.22

Table 22 is used to demonstrate the time expectancy between having an expediated container and non-high priority container. The time is determined from the calculations of off load time from ship to shore cranes. The first container will be the time of offloading and will just incur an additional time delay for the transfer of the container to the rail service which is determined as the by the speed of the hostler truck or rubber tire gantry travel speed over the distance of the yard to the rail terminal. The first train is then the combination of the maritime distance travel time, The Terminal delay transfer time and the rail time traveling to the inland terminal directly. The rail time determined from the RNE service time schedule. This is to comply with pre-arranged path times. The difference with the last train is that there is the additional time required for the offload of the last container, which is the time taken to transfer the containers from the ship and the time taken to load all the containers on the train.

4.1.4 Emissions: South African maritime route analysis

Figure 15 shows the effect of emissions on the two maritime routes from the South African ports. The figure on the left shows the emission relationships according to the speed of the vessel and the right shows the relationship of the emissions. Route 2 is to the Portuguese ports and Route 1 to Rotterdam. interestingly Route 2 has a lower sulfur emission quantity, but higher NOx. The lower sulfur is attributed to the vessel and higher NOx is attributed to the vessel travelling a reduced distance but having to travel at a higher speed producing more NOx.

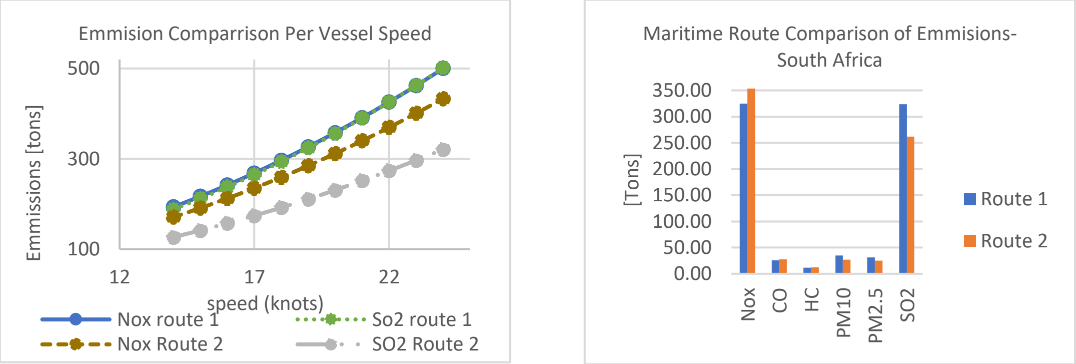


Figure 15 Emissions related to speed (left) and emission type (right) per maritime route - South Africa

Route 2 also does not benefit from the use of the cleaner fuels along the route using ultra low sulfur fuel oil which is to be used in the emission control area of the North Sea. However, the vessel does not enter this region at all and hence there is fuel consumption in this zone and during the hoteling and maneuvering at the port of Rotterdam. In Figure 18 the graph on the left shows that Route 2 has a greater carbon dioxide consumption.

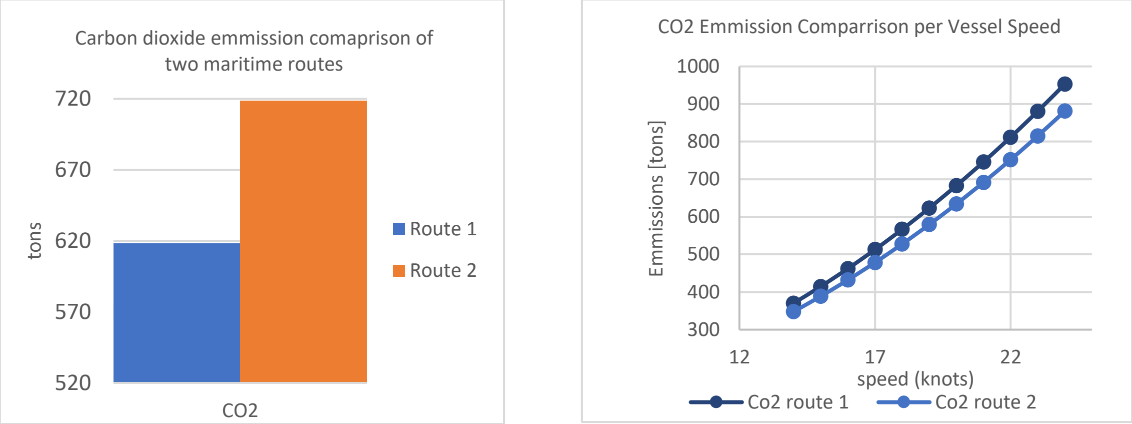


Figure 16 Maritime Carbon dioxide emissions route comparison (left) And route comparison to speed (right)

The effect of speed of the vessel has very little effect on either routes carbon dioxide emission this is due to Route 1 although having a greater distance has a significant section in Northern European Emission control areas. The reason Route 2 initially has a higher carbon dioxide emission is that of the different speeds of the vessels. Route 2 travel is with an average of 18.6 as opposed to Route 1 with 16.8 this is to compensate for the travel to the two Portuguese ports. Secondly, the transfer rate in Portuguese ports is less than that for Rotterdam.

4.1.5 Rail Emissions: South African Route Analysis

The rail emissions show the effect of emissions from the transportation of all the trains transporting the containerized cargo to the German hinterland terminals the emissions take into consideration to resulting emissions based on the average European Commission (Delhaye, 2010) values for containerized electric traction of container freight transportation.

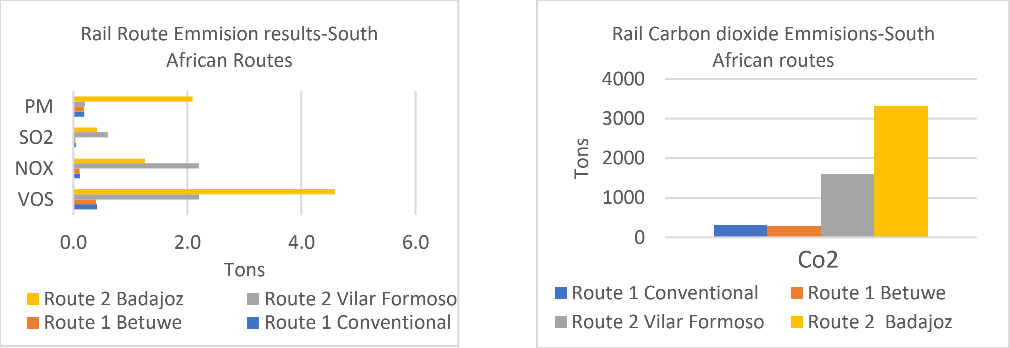


Figure 17 Rail route emissions to Germany (left) Rail route carbon dioxide emissions (right)-South Africa

There are two rail route options from Holland by Betuwe or conventional line. The aim of the European directive is to have a universal traction power system. At the time of writing the emissions were based on the average emission supply from the grid system. At this stage, Northern Europe and Holland do not have the supply exclusively connected to renewable power sources and hence as can be seen in Figure 18 the emission produced by rail travel for all trains is higher for the routes traveling from Portugal. The diesel locomotive component for the current route through Vilar Formoso between Spain and Portugal is a small section and has contributing factor but of a small percentage distance of the overall route. The combined emissions from South African routes to the German Hinterland show that emissions are not greatly affected by the speed of the vessel.

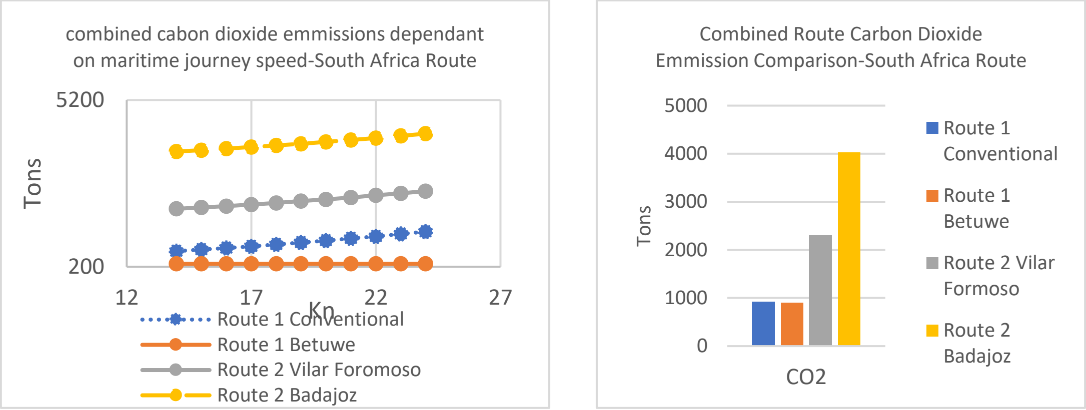


Figure 18 Combined Emissions per route with relation to vessel speed (right) Carbon dioxide emission per vessel route

The overall intermodal emissions show much greater carbon dioxide emission for either route traveled from Portugal to Manheim Germany and likewise, the pattern maintains for the various vessel speeds. This implies that the effect of rail electric travel does not display the tendency for greater reduced emissions than that of considered big polluters such as maritime vessels. The reason is due to the number of trains that must be used on the journey to deliver the quantity of cargo to the German hinterland.

The main contributing factors are the rail emissions as can be seen in table 23.

Table 23 Train route emissions related along various trajectories to Germany-South Africa

Rail Route Emission Quantities								
	EICIS	Trains	VOS	CO2	NOX	SO2	FC	PM
	[km]	[No]	[t]	[t]	[t]	[t]	[t]	[t]
Route 1								
Option 1 Rotterdam	267.36	96	0.4	299.3	0.1	0.0	95.4	0.2
Option 2 using Betuwe	257.45	96	0.4	288.2	0.1	0.0	91.8	0.2
Route 2								
Option 1 Portugal	2581	48	2.2	1588.9	0.6	0.2	506.4	1.0
Option 2 via Madrid	3050.7	48	4.6	3309.1	1.3	0.4	1054.6	2.1

The greater length of rail covered by traveling from Portuguese ports to Manheim (Germany) routes for option1 and option 2 that goes through Madrid account for the much higher quantity of emissions. The route through Badajoz has the carbon dioxide emission is 11 times greater than either route option through Holland, which indicates from a global warming carbon footprint stand point, that rail transportation is less favorable in this instance from Portuguese ports to German inland terminals.

Table 24 combined emission results

Combined Emissions South Africa to Germany			
	CO2	NOX	SO2
	[t]	[t]	[t]
Route 1			
Option 1 Rotterdam	15130.6	324.7	323.9
Option 2 using Betuwe	15119.5	353.4	261.7
Route 2			
Option 1	18834.9	1.02	324.0
Option 2 via Madrid	20555.1	2.08	262.1

The combined emissions of container transport from Africa to Germany that have rail routes going through Rotterdam to Germany produce the lower quantity of emissions. The second route that makes ports of call at Portuguese ports and then heads onward to the German hinterland. The second route produces a greater amount of emissions. Carbon emissions are greater for a route going through Portuguese ports and making use of projected Madrid route.

4.2 South American route results

4.2.1 Fuel Costs sensitivity in South American Route

The total consumption of fuel from the auxiliary and main engine was calculated with the additional estimation of maneuvering consumption from the entering of the port to leaving the port. The fuel consumption considers the effective consumption of electrical equipment and auxiliary engines. Appendix 2 shows the consumption for generators and boilers using marine diesel.

Route 1 is the route that travels from South America the Northern European ports of Antwerp, Rotterdam, Hamburg Bremerhaven and Le Havre before continuing south to Lisbon and Sines to part once more to the South American East Coast. Route 2 is the Route whose North Bound Journey travels directly to Sines and then A shortsea voyage with the same ship to Rotterdam which then returns to Sines. The ship then departs to The South American East coast.

Figure 19 shows a sensitivity analysis was done per fuel type in relation to the alterations in fuel bunkering prices for both routes. A sensitivity analysis was also done in relation to the alteration of the speed of the vessel. The port time remains constant but the journey times between each section differ, requiring a different scheduling and number of vessels per fleet to correspond with the requirements of the new schedule.

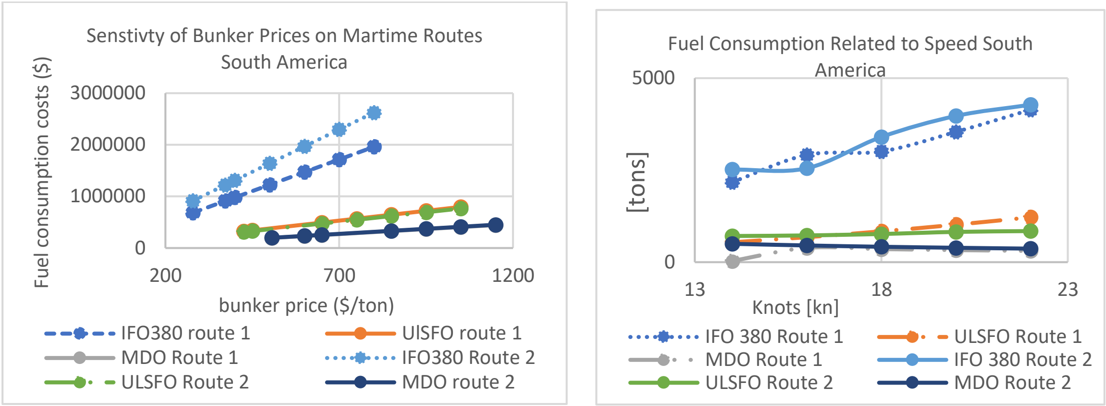


Figure 19 Fuel type and route consumption comparison related to fuel bunker price per maritime route (left) Fuel Consumption per maritime route and type of fuel in relation (Right)

Figure 20 displays the fuel consumption price sensitivity of the two maritime routes. Route 2 is more expensive than Route 1, due to the vessels higher speeds for the transatlantic and shortsea voyage routes, compensating for the slower in port turnaround times. The sensitivity related to vessel speed shows that there is a variance in which route is more expensive depending on the speed of the vessel where Route 1 is less expensive for slow and super slow steaming. For full steaming, Route 2 begins to be less expensive than Route 1.

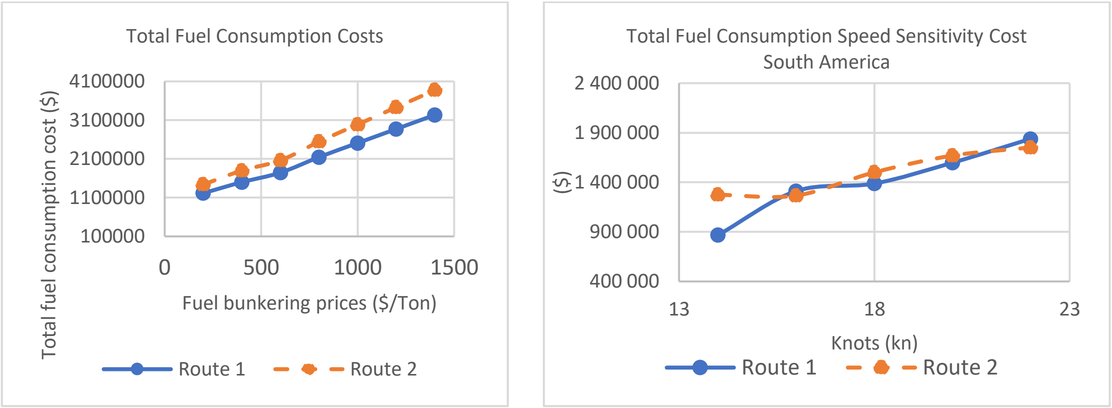


Figure 20 Fuel consumption comparison of two maritime route options (left) total maritime fuel consumption comparison of routes related to vessel speed (right)-South American routes

4.2.2 Maritime costs South American route

Table 25 below displays the South American routes voyage maritime cost structure. Table 25 displays the daily cost of the variable types of fuel cost. The gross profit percentage which calculated from the required freight rates, the revenue was calculated from the CMA freight rate charges for the maritime transportation for reefers and dry containerized cargo.

The gross profit percentage was calculated as stated in the previous section. The Revenue less the cost of transportation of the containers divide by the revenue. The revenue in this case was calculated from CMA freight charges which included the basic freight rate from Brazil, the bunker surcharge, the terminal handling rate of the port of Origin, an additional low Sulfur surcharge for cargo that is destined to Northern European ports, an ocean carrying international shipment charge for containers travelling between continents. and a sealing charge for containers entering Brazil. The respective total of these components multiplied by the containers going to the respective port defined the revenue.

Table 25 Maritime Costs Route A costs (left) and Maritime Costs Route B costs (right)

Maritime

Single ship Route 1

Ship Type	Container ship annual costs	
Size (14t)	4180	[TEU]
Design DWT	72900	[t]
Manning costs	697452	[$]
Insurance	671995	[$]
Stores & Lube	157654	[$]
Administration	128492	[$]
Capital repayments	3012470	[$]
Interest	228083	[$]
Depreciation	1000678	[$]
Maintenance	150542	[$]
Gross profit	62.34	[%]
Port dues	3173104	[$]
Handling	38223726	[$]
Tugs and Pilots	339932	[$]
IFO 380 ton per day	49.85	[t/day]
ULSFO ton per day	15.43	[t/day]
MDO ton per day	7.87	[t/day]
Total fuel cost	1 215 719	[$]
Vessel speed average knots	16	[Kn]
Total [$/day]	162 569	[$/day]
Total [€/day]	143061	[€/day]
Voyage days	49	[days]
Total cost route A	43 119 865 536	[€/year] €/TEU

Maritime

Single ship Route 2

Ship Type	Container ship annual costs	
Size (14t)	4180	[TEU]
Design DWT	72900	[t]
Manning costs	697452	[$]
Insurance	671995	[$]
Stores & Lube	157654	[$]
Administration	128492	[$]
Capital repayments	3012470	[$]
Interest	228083	[$]
Depreciation	1000678	[$]
Maintenance	150542	[$]
Gross margin	61.56	[%]
Port dues	1553767	[$]
Handling	25632108	[$]
Tugs and Pilots	104206	[$]
IFO 380 ton per day	69.92	[t/day]
ULSFO ton per day	15.55	[t/day]
MDO ton per day	8.36	[t/day]
Total fuel cost	1437802	[$]
Vessel speed average knots	16	[Kn]
Total [$/day]	126 613	[$/day]
Total [€/day]	111 419	[€/day]
Voyage days	47.00	[Days]
Total cost route B	30 602 218.6	[€]
	380	€/TEU

4.2.3 Rail Costs in South American Route

Variable and fixed costs source material records and calculations are shown below for the respective countries, along the rail route options for the of transportation of the containerized cargo to the German hinterland. The first scenario of the transportation of the containerized goods through the Northern European ports and return containerized cargo traveling to Portuguese ports of Lisbon and Sines. The alternate route is through the combination of cargo sent from Sines and the remaining short sea voyage to Rotterdam. The return journey to South America leaving Rotterdam making the last port of call at Sines.

Table 26 Comparison of ANFAC results with dissertation calculation.

Fixed costs	Portugal	Spain	France	Germany	Holland	Belgium
	[€/Year train]	[€/Year/ train]	[€/Year/ train]	[€/Year/ train]	[€/Year /train]	[€/Year /train]
ANFAC Locomotive Depreciation	95573	95573	95573	95573	95573	95573
Dissertation	87328	87328	180400	180400	180400	180400
ANFAC Locomotive Financing	45940	45940	45940	45940	45940	45940
Dissertation	43046	43046	80724	80724	80724	80724
Capital Repayments	9968	9968	20591	20591	20591	20591
Locomotive Insurance	33079	33079	60133	60133	60133	60133
Train Driving Personnel ANFAC	239542	239542	332371	326159	326159	326159
Dissertation Route 1	220950	296443	370238	228340	11722	58750
Dissertation Route 2	361223	391908	458640	273101	138433	-
Rolling Stock Depreciation ANFAC	60211	60211	60211	60211	60211	60211
Rolling Stock Depreciation	71683	71683	71683	118067	118067	118067
Rolling Stock Financing ANFAC	25841	25841	25841	25841	25841	25841
Dissertation	32076	32076	32076	52832	52832	52832
Rolling stock insurance	23894	23894	23894	39356	39356	39356
Rolling stock capital repayments	8182	8182	8182	13476	13476	13476
Traction expenses ANFAC	107520	107520	107520	107520	107520	107520
Other Rolling Stock Expenses ANFAC	56448	56448	56448	56448	56448	56448
Total Fixed Costs ANFAC	631076	631076	723905	717692	717692	717692
Total fixed Costs dissertation	619053	694545	899090	824331	607713	654741

(ANFAC, 2010) (Own calculations)

Table 26 above displays the comparative rail fixed costs, as opposed to those found by the dissertation train personnel, was based on the driver remuneration price per country. Depreciation is calculated according to the straight-line depreciation method.

Table 27 Variable cost comparison between dissertation and source material

Variable costs	Portugal	Spain	France	Germany	Holland	Belgium
	[€/Year/ train]	[€/Year/ train]	[€/Year/ train]	[€/Year/ train]	[€/Year/ train]	[€/Year/ train]
Energy ANFAC	154000	273961	60803	177610	177610	177610
Dissertation	114598	63337	268432	831601	11617	106710
Alternate route				831601	11507	
Alternate route					25838	
Personnel ANFAC	26880	26880	19066	12876	12876	12876
Locomotive maintenance ANFAC	145600	145600	145600	145600	145600	145600
Dissertation	250556	250556	250556	250556	250556	250556
Rolling stock Maintenance ANFAC	62955	62955	62955	62955	62955	62955
Dissertation	5856	5856	5856	5856	5856	5856
Total Variable ANFAC	389435	509396	288424	399040	399040	399040
Total Variable Dissertation	397890	346629	543910	1100888	280904	375997

(ANFAC, 2010) (Own calculations)

Table 27 displays the comparison between the calculated and reported costs associated to variable costs of each country. The energy costs are related as explained to the countries that the train travels through to Germany. The energy costs relate per each route section. In Appendix

1 the rail tariff charges show the charging structures related to energy supply charges and usage related for locomotives of use of the infrastructures of the respective countries. The dissertation maintenance was related to 6.25 percent of the purchase price of the locomotives annually. Similarly, the maintenance costs were dealt with in the same manner for the flat cars that account for the rolling stock.

Tables 28 and 29 show the results for South American rail sections of Route1 and Route 2 respectively. The tables compare the source material with dissertation calculation for respective routes. The comparative cost of the dissertation to the source material relates the variable costs related to the cost required for trains to transport the required cargo over the specific distance. The fixed charges were related to the charges associated with fixed costs for all the trains required to transport the containers to the hinterland and the return trains with empty containers over the distance that train travels.

Table 28 South American cost per train-km for respective countries for the variable and fixed costs Route 1

South American Analysis Route 1	Portugal	Spain	France	Germany	Holland	Belgium	Holland Betuwe	average
	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]
Total unitary variable cost ANFAC	2.0	4.1	2.3	3.2	3.2	3.2	3.2	3.0
Total unitary variable cost Dissertation	2.6	3.6	3.2	3.3	5.4	6.2	5.4	4.2
Total unitary Fixed cost ANFAC	5.1	5.1	5.8	5.8	5.8	5.8	5.8	5.6
Total unitary Fixed cost Dissertation	5.1	5.2	5.5	6.0	5.8	5.4	5.8	5.4

(own calculations)

In Table 29 and 30 there are differences particularly from the ANFAC results and dissertation results. The components affecting these results are the differences in results from the ANFAC and dissertation calculated values. This is a small contributing factor. The distances travelled by the trains from the dissertation analysis and the values the ANFAC reports calculate are the main point of discrepancy. The ANFAC results are found from company owned software package Enero which obtains the results for the entire annual distance travelled by the trains. The total variable costs and similarly the fixed costs are divided by the total travelled distance by the trains. As such the calculated method accounts for only a short section. Compared to how much the train would travel over the rest of the country when in use. which is how the cost per km is determined. When not considering the short sections just between countries boundaries, but larger distance of generic cost per five hundred km travelled the values are closer.

Table 29 South American cost per train-km for respective countries for the variable and fixed costs Route 2

South American Analysis Route 2	Portugal	Spain	France	Germany	Holland	Belgium	Holland Betuwe
	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]	[€/km/train]

Total unitary variable cost ANFAC	2.0	4.1	2.3	3.2	3.2	3.2	3.2
Total unitary variable cost Dissertation	2.6	3.6	2.3	2.1	9.6	18.4	12.8
Total unitary Fixed Cost ANFAC	5.1	5.1	5.8	5.8	5.8	5.8	5.8
Total unitary Fixed Cost Dissertation	5.1	5.2	6.0	4.9	5.2	5.9	4.7

(Own calculations)

Table 30 shows the comparative values of the calculated rail tariff charges as to those given by the European infrastructure charging system. The values are to verify the tariff charges by the system against the methods that are out lined from the respective rail freight transporting companies. The methodology and reference to each respective freight transport company according to the country of operation is found in appendix 1. The train cost per kilometer is found by the tariff charge per train

Table 30 Route 1 Tariff charges comparison per country compared to the European Charging system

Total access charge tariff								
Route 1	Portugal	Spain	France	Holland	Holland Betuwe	Belgium	Germany	Germany Betuwe
	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]
EICIS	2549	140	12046	941	709	562	6947	6602
Dissertation	2876	158	11986	1213	963	689	6486	4134
Distance	[km]	[km]	[km]	[km]	[km]	[km]	[km]	[km]
EICIS	2045	1262	2453	337	254	188	2106	1931
Dissertation	2461	1268	4725	337	254	188	1276	2260
	[€/train km]	[€/train km]	[€/train km]	[€/train km]	[€/train km]	[€/train km]	[€/train km]	[€/train km]
EICIS	1.25	0.11	4.91	2.79	2.79	2.98	3.3	3.42
Dissertation	1.17	0.12	2.54	3.6	3.79	3.66	5.08	1.83
train journeys	60	60	86	225	21	41	21	21
	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]
EICIS	152948	8412	1035963	211748	14898	23025	145883	138641
Dissertation	172555	9490	1030835	272822	20230	28255	136213	86812

Table 31 Tariff charges comparison per country compared to The European Charging system

Total access charge tariff							
Route 2	Portugal v Formosa	Portugal Badajoz	Spain	Spain-Madrid	France	Holland	Germany
	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]	[€/train]
EICIS	1463.74	869.56	140.2	239.98	10975.74	941.1	771.87
Dissertation	1765.262	1102	209.78	233.92	10934.38826	1212.54416	967.72
distance	[km]	[km]	[km]	[km]	[km]	[km]	[km]
EICIS	1179.52	842.08	1262	2160	2453.2	177.7	445.8
Dissertation	1294	842.08	1268	2524	2453.2	169.2	447.2
train journeys	78	78	78	78	78	124	124
	[€/train _km]	[€/train _km]	[€/train _km]	[€/train _km]	[€/train _km]	[€/train _km]	[€/train _km]

EICIS	1.24	1.03	0.11	0.11	4.47	5.30	1.73
Dissertation	1.36	1.31	0.17	0.09	4.46	7.17	2.16
	[€]	[€]	[€]	[€]	[€]	[€]	[€]
EICIS	114171	67825	10935	18718	856108	116696	95712
Dissertation	13769	85956	16362.84	18246	852882	150355.	119997

Table 31 above relates to the tariff charges of the dissertation in comparison to the charges by the European charging system for the rail sections through each specific country. The train journeys are related to the number of train journeys required for the transportation of the cargo delivered from each of the maritime ports of call for the first route1 and for the second route 2.

In Appendix 1 the description and methodology towards each respective country's´ tariff structure are outlined and the respective components that constitute how the tariff charge is obtained for the transportation of train through the countries respective territory along the specific route. Appendix 1 Table 38 shows the relationship of the predominant cost system where Holland, Portugal, France, and Spain have a marginal cost-based structure, whereas France is based on elasticity of use, while Belgium and Germany have a state based compensatory subsidy.

4.2.4 Combined Route Costs in South American Route

Table 32 shows a comparison of resulting costs per intermodal unit from the calculations done in the dissertation and by values obtained from reports from ANFAC. A comparison of the intermodal unit cost is also done in relation to each rail and maritime combination. On the left are the intermodal unit costs results from source material and the dissertation´s calculated values for Route1 maritime combination with above option using conventional routes and below options the change due using the Betuwe rail line. In a similar fashion on the right, the maritime values for intermodal unit costs is shown from the dissertation calculated results and source material results. The above result is for use on the rail route traveling through Vilar Formoso to the German inland terminals and the values below are for Rail routes traveling through Badajoz.

Table 32 Total combined cost combined cost comparison of transportation of goods from South America

Total Route 1 costs by source material value	753.7	[€/TEU]
Total Route1 costs dissertation	816.2	[€/TEU]
Total Route 1 costs by source material value with Betuwe	736.0	[€/TEU]
Total Route 1 costs dissertation with Betuwe	767.7	[€/TEU]

Total Route 2 charge tariff reports via (Vilar. Formoso)	560.7	[€/TEU]
Total Route 2 charge tariff dissertation (Vilar. Formoso)	582.1	[€/TEU]
Total Route 2 charge tariff reports via (Badajoz)	557	[€/TEU]
Total Route 2 charge tariff dissertation (Badajoz)	578.0	[€/TEU]

Table 32 shows that The Route 2 option of transporting goods from South America is the cheapest per intermodal unit travelling through either Badajoz or Vilar Formoso. Route1 shows that Then Betuwe Line is the slightly cheaper option

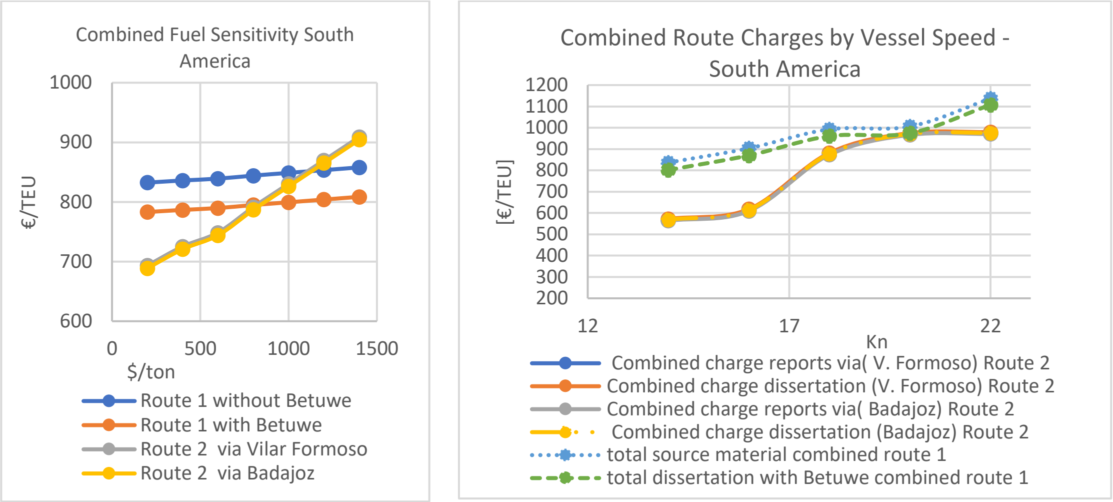


Figure 21 Combined Fuel sensitivity for four different rail alternatives from South American Maritime Routes (Left). vessel speed sensitivity alteration on the two maritime options affecting the combined routes from South America (right)

The costs of per unit cargo are more expensive to transport to all Northern European ports of Route 1 Maritime route. The second option of maritime Route 2 is to travel directly to Portugal and make use of the port of Sines and then to travel onward to Rotterdam and return to Sines, ending the European leg, before the return to South America. The second route is cheaper to have goods travel to fewer ports of call along the European route and make use of rail transport to Germany.

The difference in cost per intermodal unit by making use of goods traveling by Vilar Formoso or by the projected Badajoz overall for Route 2 has negligible effect. This is attributed to the low energy and tariff costs in Spain. Route 1 the sections traveling through Holland or by making use of Betuwe has a very little difference as the Dutch section is short and tariff structures are similar.

The total combined route sensitivity of the various combined intermodal options. The graph displaying combined fuel sensitivity shows that there is very little change for the maritime Route A on the combined route costs. There is a steeper gradient change in combined costs related to route 2 combined options with Route 2 maritime route. The combined Route 2 has the cost of transporting goods by fewer points of the call by traveling directly to Sines and then to Rotterdam and a return to the Sines. Route 2 is more expensive when the fuel price gets over a 1000 $/ton.

The speed sensitivity costs related to vessel speed displayed on the graph above right shows that the route 1 costs by the vessel traveling to multiple European ports at any vessel speed are more expensive under current market conditions. There is an exception at 20 Kn where either option results in the same costs per unit between Route 2 or Route 1 transporting goods to Germany. The two options of train routes traveling to Germany from the Port of Sines under the route 2 scenario has near negligible difference related to the speed of the vessel.

Figure 22 Time to German Hinterland first train offloaded (left). Time to German hinterland for last loaded cargo from port of calls coming from South America (right).

Figure 22 displays the time in days expected from a voyage from South America for products to arrive in the German Hinterland. The first train goods delivery time from the port of call shows that the fastest means is to send the products through lowland country ports of call which allows for 30 days of shelf life for frozen products such as beef. Transporting goods by Portuguese ports allow 20 days of shelf life and thus 2/3 reduction in shelf life time. The first train by Route 2 arrives more quickly by Sines rather than Rotterdam as the first port of call. This gives an extra 5 days shelf life. It also shows that there is little difference between goods delivered by the first trains from a vessel making a port of call at Sines or at a Benelux country. The Last train also shows that transporting goods by the Benelux European ports is the quickest means of transportation of goods. Along Route 1. Travel time for goods from Sines only allows 15 days shelf life if traveling by the last train traveling on Route 1 internal ports of call to the German Hinterland. In comparison to the options along Route 2 of direct travel to Sines and then to Rotterdam by the maritime vessel. The last goods traveling by train, from Rotterdam or by Sines is negligible, arriving on the same day. Route 2 allows for 25 shelf day life for frozen articles such as beef.

4.2.5 Maritime Emissions in South American route

Figure 23 shows the carbon dioxide emission is greater for Route 2 than Route1, from the reduction of port-related emissions, by port-related equipment for offloading of containers. Additionally, the reduction in speed that the vessel needs to travel from port to port in Route 1.

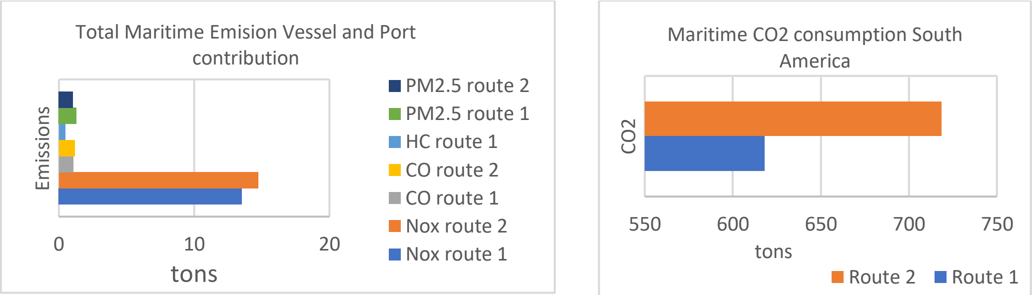


Figure 23 Carbon dioxide emissions related to the maritime vessel route (left the emissions on the current vessel speeds in relation to the two maritime routes (right)-South America

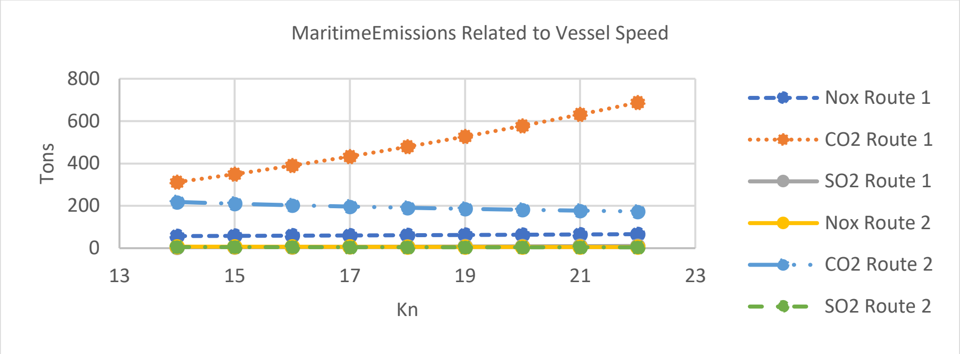


Figure 24 Emissions Related to vessel speed according to the maritime route. (South American route)

Figure 24 shows the emissions produced due to the speed of the vessel in relation to either maritime route. The carbon emissions are greater for Route 2 traveling to Northern European Ports of call first. Route 2 traveling to Sines first and then on to Rotterdam returning to Sines shows a decrease in carbon emissions as the speed increases. This is due to the reduction in time spent and auxiliary equipment use in ports. On Route 1 the additional Northern European ports of account for the increased auxiliary engine usage and its emission contributions.

In a similar manner to that of the ocean-going vessels, the harbor craft consumptions were calculated. The emission particulates emissions were based on harbor craft values from harbor vehicles found from an EPA report on average harbor vessel power of 903 KW and a load factor 0.45 from Port of Los Angeles Report on Air emissions survey by Louis Browning of 2008. The respective harbor emission factors were in accordance with the report, “Current Methodologies and Best Practices for Preparing Port Emission Inventories” with the respective quantity of g/kWh of emission particulate. The determination the time spent by each rubber tire gantry, straddle carrier, forklift and hostler truck in transporting containers from the docks through the storage areas and onto the rail terminal. The emission rate was based on findings of a similar report done on Dutch ports and relate the values to the average emission incurred from the handling of cargo. This resulted in finding the total number of emission particulates for each analyzed route. (Mahoney, 2016)

4.2.6 Rail Emissions in South America routes

Table 33 Train route emissions related along various trajectories to the Germany-South Africa

	Trains	VOS	CO2	NOX	SO2	FC	PM
	[no]	0.1	7.9	0.003	0.001	2.528	0.005
		[t]	[t]	[t]	[t]	[t]	[t]
Route 1 Option 1	224	22.1	1615.9	0.612	0.204	515.0	1.017
Route 1 Option 2 using betuwe	224	22.4	1617.1	0.612	0.204	515.4	1.02
Route 2 Option 1	201	37.3	2689.9	1.017	0.339	857.3	1.7
Route 2 Option 2 via Madrid	278	76.4	5510.8	2.084	0.695	1756.4	3.47

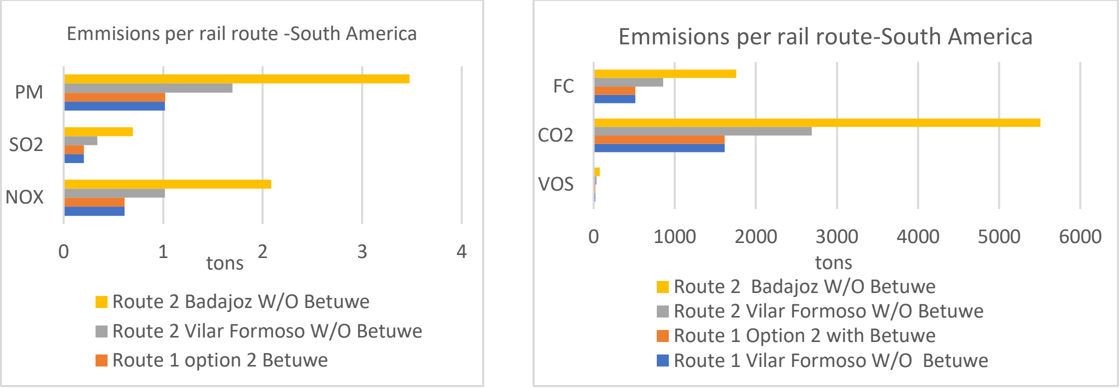


Figure 25 Emission per rail routes-South America.

The emissions per rail route are displayed in Figure 25 the largest carbon dioxide contributor and other emissions are along Route 2. Where the trains depart from Sines and travel by the projected route through Badajoz has the highest emissions. This is due to the longer distance required to be traveled by train. Route 1 has a much-reduced train emission contribution which in addition to the reduced maritime emissions and port contributions is displayed above. Emissions were found by multiplying the distance traveled by the by train the emission factor and the weight that the loaded goods train. (Delhaye, 2010)

Table 34 combined emission results-South America

	CO2	NOX	SO2
	[t]	[t]	[t]
route 1			
option 1	56543.7	251.3	1.1
option 2 using Betuwe	56544.9	229.5	0.2
route 2			
option 1	52864.6	229.9	1.8
option 2 via Madrid	55685.6	231.0	2.1

Table 34 displays that the combined intermodal effect of emissions for containerized transport to Northern European ports directly and then on to Köln. Compared to the alternative options by the combination of traveling to Sines and then a short sea route to Rotterdam where the train routes from Sines are either from Vilar Formoso or through Badajoz and then Madrid to Mannheim. Route 2 has less emission in both cases this is due to less return cargo having to travel to Portugal and the reduction in additional port emission contributors such as harbor vessels.

4.3 North American Route Results

4.3.1 Fuel Costs sensitivity in North American Route

A sensitivity Analysis was done per fuel type in relation to the alterations in fuel bunkering prices and in relation to the alteration of the speed of the vessel. As shown in Figure 26 The port time remains constant but the journey times between each section later, requiring a different scheduling and number of vessels per fleet to correspond with the requirements of the new schedule.

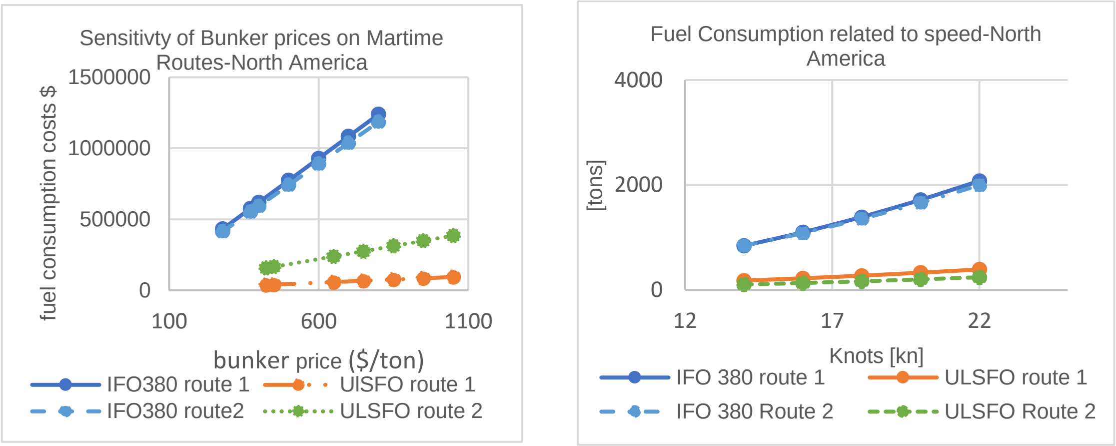


Figure 26 Fuel type consumption comparison per bunker price per maritime route (left) Vessel speed fuel consumption per maritime route and type of fuel in relation (Right) -North America

Figure 26 shows that Route 2 has the highest cost of heavy fuel oil with the Atlantic crossing as the main consumption section. The difference is small as both vessels travel relatively similar distance over this section with Route 1 having the requirement for the greater speed, thus the increased consumption. Route 2 has higher Ultra-low Sulphur consumption for time spent in port and the additional travel through the northern European Emission control area.

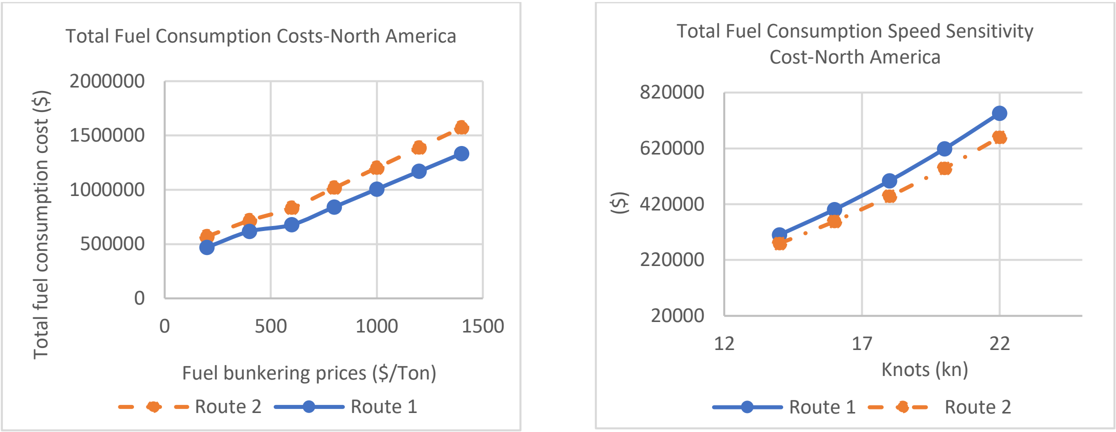


Figure 27 Fuel consumption comparison of two maritime route options (left) total maritime fuel consumption comparison of routes related to vessel speed (right)-North America

Figure 27 display´s the fuel price sensitivity for the total fuel consumption between the two maritime routes. Route 2´s maritime route is more expensive than Route1. This is attributed to the increased speed traveling to Lisbon and Sines and return compensating for longer in port times. The sensitivity related to vessel speed shows that there is a variance in which route is more expensive depending on the speed of the vessel where Route 1 is more expensive than Route 2. For the same speed Route 1 is more expensive due to longer distance and the need to use ULSFO in northern European ECA.

4.3.2 Maritime costs North American route

Table 35 shows the maritime cost structure for the North American routes between New York and Rotterdam and the alternative from New York to Portuguese ports of Lisbon and Sines. Either route has an operational fleet of 3 vessels providing a weekly service. The gross margin percentage is less for route 2 and this is attributed to the additional voyage made to deliver the containerized cargo. The gross profit margin is taken from the average world maritime freight rate price which is the average price for dry and reefer containers respectively to be transported from the port of origin to the destination port. as the revenue per container less the cost of transporting the containers divided by the previously mentioned revenue.

Table 35 route costs maritime Route A costs (left) route costs maritime Route A costs ((right)-North America

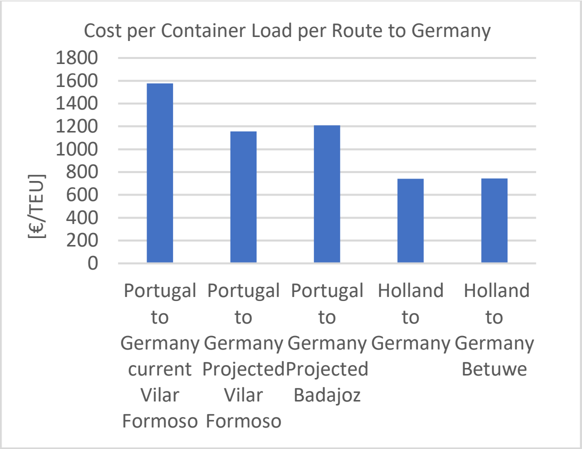
Single ship Route 1			Single ship Route 2		
Ship Type	Container ship annual costs		Ship Type	Container ship annual costs	
Size (14t)	6500	[TEU]	Size (14t)	6500	[TEU]
Voyage days	22.4	[days]	Voyage days	21.47	[Days]
Design DWT	109835	[t]	design DWT	109835	[t]
Manning costs	775433	[€]	Manning costs	794561	[€]
Insurance	391572	[€]	Insurance	401231	[€]
Stores & Lube	521984	[€]	Stores & Lube	534861	[€]
Administration	322511	[€]	Administration	957047	[€]
Capital repayments	5648292	[€]	Capital repayments	5787625	[€]
Interest	4643213	[€]	Interest	4757752	[€]
Gross Profit Margin	79.88	[%]	Gross Profit Margin	63.78	[%]
Port dues	3 634 365.98	[€]	Port dues	95 282	[€]
Tugs and Pilots	461 090.16	[€]	Tugs and Pilots	8 077	[€]
Total fuel cost	6 207 986	[€]	Total fuel cost	6 618 415.	[€]
Vessel speed (average)	19	[Kn]	Vessel speed (average)	19	[Kn]
Total [€]	22 764 581	[€]	Total [€]	20 116 887	[€]
Total [€/TEU]	229		Total [€/TEU]	189	
Total journey time	22.35	[days]	Total journey time	21.47	[days]
Ships	3		Ships	3	
Journeys	15		Journeys	16	

4.3.3 Combined Results for North American Route

The effects of speed and fuel price sensitivity of maritime costs related to the combined effect on containerized transport to the hinterland terminals are shown below. Further the comparative expected time of delivery for the transportation of containers the hinterland terminal considering both the maritime, voyage and port time is shown. Rail terminal loading time and the Rail journey time are also shown.

Table 36 displays the current combined route of transporting goods initially to Portuguese ports and then on to the German hinterland. The projected routes through Badajoz is only slightly more expensive than goods traveling through Vilar Formoso. This is due to the low cost of the tariffs and energy tariff through Spain, which is the region with greatest travel distance change for the routes from Portugal. The current cost of transportation through Vilar Formoso is more expensive than the other routes due to the lower loads that the trains can carry on current tracks, the new longer train systems allow for more containers and hence reduced cost. The much lower rail cost contribution for routes from Holland to Germany account for costs being lower than the combined costs from Portugal. The Betuwe Line and Conventional lines of Dutch rail have near similar cost calculation and little difference in distance traveled.

Table 36 The combined costs by rail and maritime to travel to Northern Europe-North America



Total cost comparison	[€/TEU]
Portugal to Germany current Vilar Formoso	1578
Portugal to Germany Projected Vilar Formoso	1158
Portugal to Germany Projected Badajoz	1209
Holland to Germany	743
Holland to Germany Betuwe	744

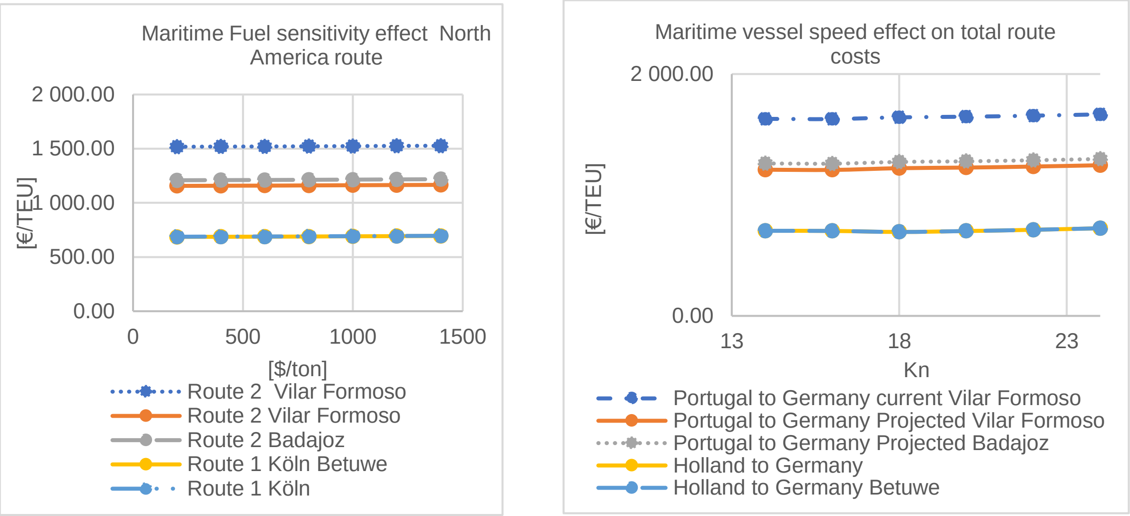


Figure 28 Comparative fuel cost sensitivity for Route 1 rail alternatives for Maritime Route A of vessels making port north European port calls and Route 2 direct rail from Portugal and Rotterdam (Left). The difference related to vessel speed alteration on the two maritime options affecting the combined routes (right)-North America

The maritime fuel sensitivity effect on the various combined intermodal options is shown in Figure 28 (left). There is a not relevant effect of the fuel price to the overall transport cost per unit for the various transport route options. The speed sensitivity costs related to vessel speed displayed on the graph above right shows that the Route 1. The cost of maritime fuel costs on the combined cost per intermodal unit has very little effect on both routes. Again, the combined cost of transporting goods through Holland is less than current and projected options from Portuguese ports. The main difference is attributed to the rail costs having much-reduced distance to travel reducing costs for personnel and energy consumption.

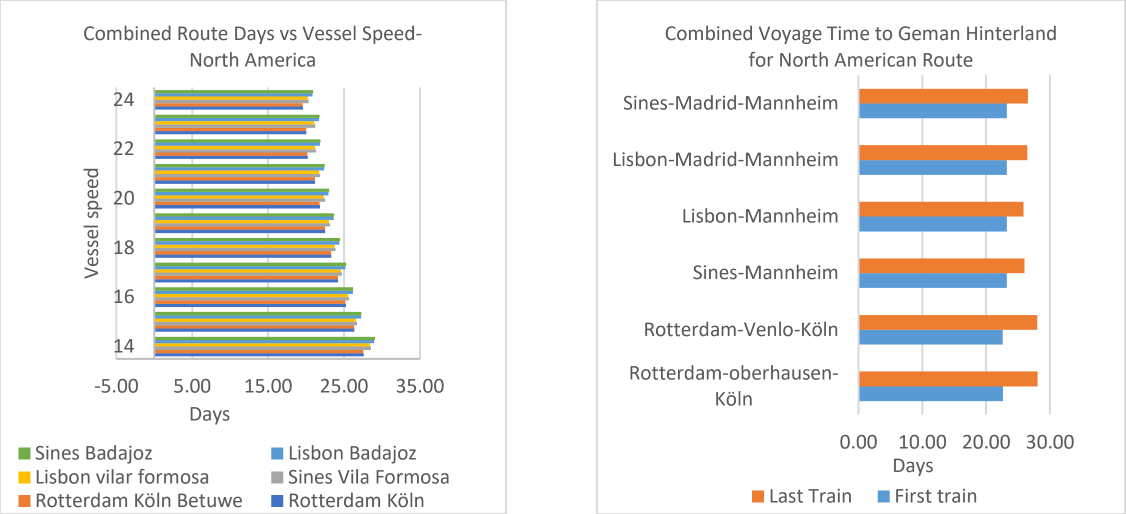


Figure 29 Time to German Hinterland Left first train offloaded in relation to changing vessel speed (left) Time to German hinterland for last loaded cargo from port of calls (right)- North America.

Figure 29 displays the time in days expected for a voyage from North America for products to arrive in the German Hinterland. The time for the first train to deliver goods from the port of call shows that the fastest means is to send the products through lowland country ports of call which allows for 23 days of shelf life for frozen products such as beef. Transporting goods by Portuguese ports allow 22 days of shelf life and thus 1 extra day. The results of the first train by Route 2 shows that it is quicker to send the goods by Rotterdam rather than Sines with the first port of call at Lisbon. This gives an extra day shelf life. The above left graph also shows that there is little difference between goods delivered by the first trains from a vessel making a port of call at Sines or at a Benelux country for any route either Badajoz or Vilar Formoso, likewise, the rail route options of the Netherlands Dutch standard and Betuwe has little difference on time.

The Last train also shows that transporting goods by the Portuguese ports is the quickest means of transportation of goods. Travel time for goods from Sines only allows 2 or 3 days less if the container is traveling by the last train traveling on Route 2 to the German Hinterland. Route 2 by the current loading scenario with the train traveling through Vilar-Formoso for the last train is slightly quicker by a day. In comparison to the options along Route 2 of direct travel to Sines and then to Rotterdam by the maritime vessel. The last goods traveling by train, from Rotterdam or by Sines is has a difference of three days. Route 1 traveling time for the last train containerized goods is 3 days more. This is due to the long waiting time expected for containerized queuing for the specific route.

4.3.4 Maritime emissions in North American route

The emissions types by the North American routes are displayed for containerized cargo transportation from New York to Rotterdam constituting Route1 and Route 2 being from New York to Portuguese ports. The subsequent section display how the Maritime emission production is compared to the various route options to and from the ports of call.

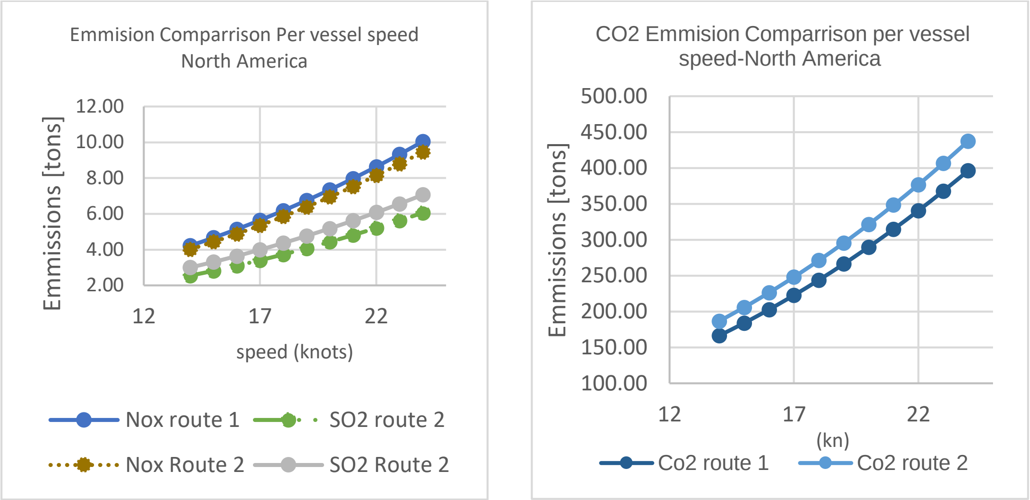


Figure 30 Emissions Related to vessel speed according to the maritime route- (Left) Emissions the difference in speed of the maritime vessel (right)- North America

Figure 30 right shows the emissions produced due to the speed of the vessel in relation to either maritime route. In Figure 31 left the carbon emissions are greater for Route 2 traveling to the Portuguese Ports of Lisbon and Sines than Route 1 making a port of call at Rotterdam. The whole journey maintains the same vessel speed. Route 2, even though has reduced the distance, the additional travel between ports not in an ECA zone affects the increase in emissions. There is an effect in route 2 of the time in ports in a no ECA zone.

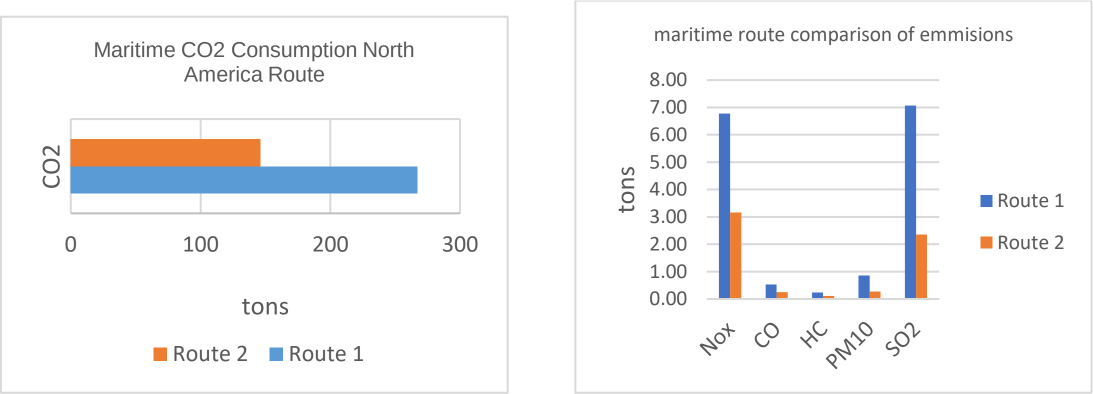


Figure 31 Carbon dioxide emissions related to the maritime vessel route (left the emissions on the current vessel speeds in relation to the two maritime routes (right)_north America

In Figure 31 the carbon emissions for the North America are greater because the distanced traveled is larger on as opposed to Route 2 this is also represented by the other emissions. The increase in speed on the vessel. MSC Brussels has a larger effect on the fuel consumption and hence emissions. The vessel travels further although in emission controlled area of Northern Europe. Carbon dioxide is emission is greater for route 1 than Route 2 for the same reason of distance travelled. Additionally, the reduction in harbor vehicles in support for docking and disembarking. The other emissions follow a similar trend for nitroxide carbon monoxide and particulate matter as is seen below in Figure 31 left.

4.3.5 Rail emissions in North American route

Rail Emissions-North America

			VOS	CO2	NOX	SO2	FC	PM
	EICIS	Trains	0.11	7.932	0.003	0.001	2.528	0.005
route 1	[Km]	[no]	[t]	[t]	[t]	[t]	[t]	[t]
option 1 Rotterdam	267.36	96	5.101	367.86	0.139	0.046	117	0.23
option 2 using Betuweline	257.45	96	4.912	354.22	0.134	0.044	113	0.22
Route 2								
option 1 Portugal	2581	96	49.26	3552	1.34	0.45	1132	2.24
option 2 via Madrid	3050.7	96	56.40	4067	1.54	0.51	1296	2.56

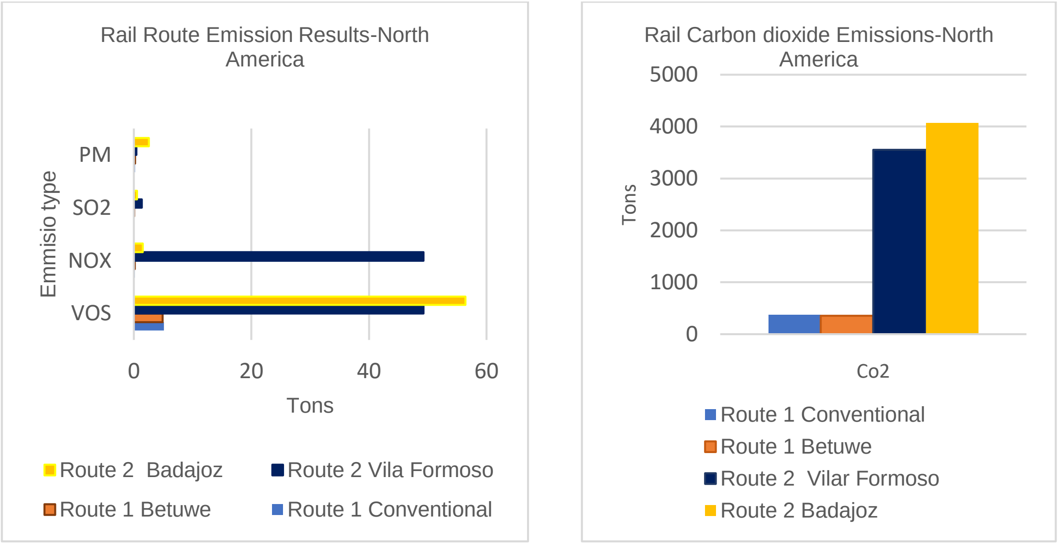


Figure 32 Emission per rail routes-North America

The emissions per rail route are displayed in Figure 32 the largest carbon dioxide contributor and other emissions are along Route 2. There is a greater amount of emissions if selecting the Badajoz route than Vilar Formoso due to the extra distance and hence energy requirements covering the additional distance as opposed to the route going through Vilar Formoso. Where the trains depart from Sines and travel by the projected route through Badajoz has the highest emissions. This is due to the longer distance required to be traveled by train. Route 1 has a much-reduced train emission contribution. This is due to the vastly reduced distance through Holland and the German border regions. The emissions were found by multiplying the distance traveled by the by train the emission factor and the weight that the train carried, with the emission factor coming from (Delhaye , 2010)

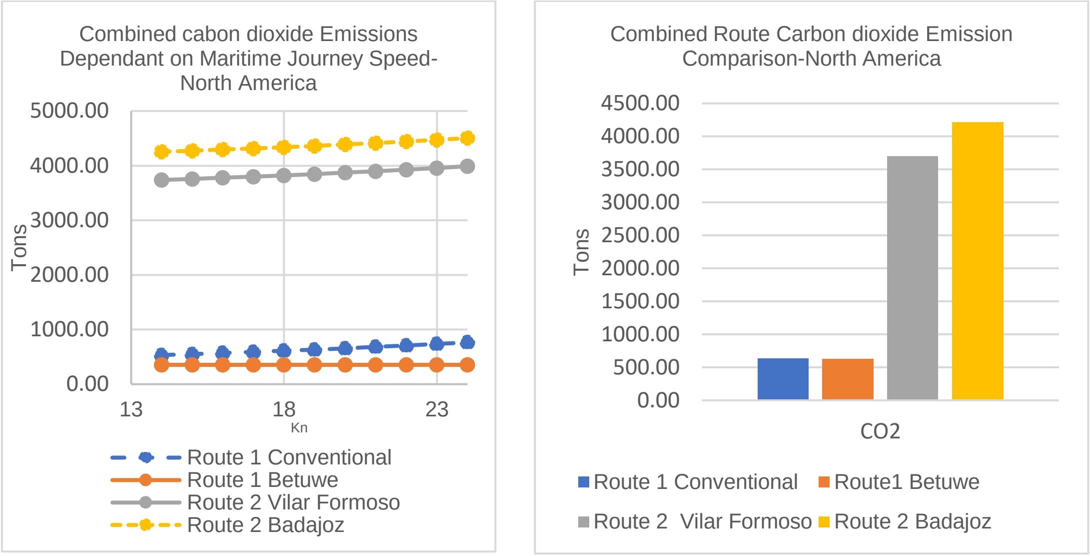


Figure 33 North American combined CO2 emissions (right) combined CO2 related to speed (left)

Figure 33 how the combination between maritime and rail emission production is compared to the various route options to transport all the containerized cargo to and from the ports of call to the German hinterland terminals. The combined emissions of container transport from North America to Germany that have rail routes going through Rotterdam to Germany, produce the lower quantity of emissions. The second route that makes ports of call at Portuguese ports and then heads onward to the German hinterland. The second route produces a greater amount of emissions. Carbon emissions are over six times greater for a route going through Portuguese ports and making use of projected Madrid route. The projected route going through Vilar Formoso has a reduced distance to travel and hence a 13% decrease in carbon emissions.

Table 37 shows the emission quantities produced for combined intermodal travel. The emissions displayed are for sulfur dioxide, carbon dioxide and NOx.

Table 37 Combined emission results in North America

Combined Emissions North American route.			
	CO2 [t]	NOX [t]	SO2 [t]
Route 1			
Option 1 Rotterdam	635.3	6.9	7.1
Option 2 using Betuwe	621.7	3.3	2.4
Route 2 projected			
Option 1 Vilar Formoso	3697.9	1.0	7.5
Option 2 via Madrid	4213.6	2.1	2.9

The rail contribution to the rail is much reduced along the Dutch rail options and as such the emissions produced from transporting goods by rail to Germany, from Portuguese ports is greater since the maritime influence between either distance does not have as great an influence, partly attributed to the ECA emission control. Table 37 shows that the conventional route produces slightly more emissions than Betuwe due to the slightly longer path. The increased rail path length for the projected alternative route from Portugal through Madrid produces more emissions.

5. CONCLUSIONS

In the analysis of routes from ports in South Africa and New York, United States through either Portuguese ports of Lisbon and Sines or the Port of Rotterdam and then by rail to German inland terminals. The intermodal transport unit cost was found to be higher traveling through the Portuguese ports, than the transportation of goods through the Port of Rotterdam. This is attributed to the greater distance travelled by rail from Portuguese ports to German inland terminals than from Northern European ports. This highlights the effectiveness of maritime transport that can make a large difference in the economies of scale. It requires many trains and nearly the entire weekly allowance of trains (using all allocated trains) to transport the quantities of cargo delivered by a vessel to a respective port.

The two case scenarios are the maritime routes from South African ports and from North America the Port of New York. In both cases the comparison found that either rail option from Rotterdam to the inland terminal of Köln, the conventional rail line or the Betuwe line, would have a lower intermodal unit cost than from Portuguese ports to Mannheim. The rail contribution costs per unit are equally is more expensive for projected routes from Portuguese ports, where the alternative rail route instead of traveling through Vilar Formoso is to travel through Badajoz.

In terms of the South African route scenario the current combined option for using intermodal travel to deliver goods to Germany from South African origin is the most expensive option. In the year 2030 the rail sections connection is expected for completion to be fully operational in terms of the TEN-T plans. The new rail system is cheaper in allowing greater quantity of cargo per train and hence less trains to transport a ship´s cargo load through the rail system. In the view of the South African Scenario using a 66000-gross ton vessel, the projected costs of either going through Vilar Formoso would produce a14% reduction in cost when the rail route is fully connected. Likewise, should the option be to go through Badajoz there is a 12% reduction compared to the current option. It will still be cheaper to travel directly to Rotterdam as both Betuwe and conventional routes from Holland give a 17% reduced cost in comparison to the projected connection through Vilar Formoso.

The intermodal transportation of containers coming from the United States East Coast encounters a similar situation to those from South Africa where the most expensive option in deciding to deliver goods by intermodal means is by sending the ship to the respective Portuguese ports and then by rail via Vilar Formoso to the German inland terminals. The option of sending the vessel to Rotterdam and then onto by rail to Germany provides a 47% reduction of cost per intermodal unit. The projected routes from Portugal give a 27% and 35% reduction compared to the current operating network through Vilar Formoso and Badajoz respectively.

The South American Route investigating the option of multiple stops at northern European ports offers a different view to transporting goods directly from South America and on to the Northern

European ports. The South American routes cheapest options for traveling directly to Sines and the traveling the remainder to Rotterdam provides a more economical alternative by dividing the overall transportation by rail and sea. The Route 1 Takes all its cargo to the Northern European ports from South America. The vessel collects its South American bound cargo from the ports of Le Havre and the Portuguese ports of Lisbon and Sines. This in turn means a lot of cargo travels by rail from the German inland terminals to the Portuguese ports. It also means in the forward leg of the journey much cargo heading to northern Europe goes by sea to one port with one set of handling, maneuvering and port related costs. Furthermore, the vessel does not have the additional south bound costs associated with stops at Lisbon. The resulting conclusion is that there is an intermodal unit cost that is 26% cheaper to transport goods through Route 2 by making stops at Sines before going to Rotterdam and returning to Sines for the current route going through Vilar Formoso as opposed to the conventional rail routes in Northern Europe. The Possibility of the projected route through Badajoz would provide a 23% reduction in cost as opposed to going through all northern European ports.

Regarding the containers of the South American East Coast route, goods transportation the sensitivity of the price of the total fuel consumed between the two maritime routes. Route 1 to the Northern European maritime route is more expensive than Route 2. The sensitivity related to vessel speed shows that there is a variation in which Route 1 is more expensive depending on the speed of the vessel. This occurs only for the vessel operating at maximum speed or at 15 kn. South American Route 1 is less expensive for slow and super slow steaming, than Route 2.

The combined cost of the rail and maritime travel shows that for either rail option Betuwe line or not Route1 is more expensive for any vessel speed except for 20 kn where the cost are approximately equal. The fuel sensitivity for the South American routes show that the Route 1 is more expensive for any fuel price than use of the current route but when fuel prices reach above 750$/t Route 2 begins to be more expensive and as the fuel price rises above 1000$/t the cost is cheaper to use Route 1.

The time in days expected from a voyage from South America for products to arrive in the German Hinterland is as follows. The time for the first train to deliver goods from the port of call shows that the fastest means is to send the products through Lowland country ports of call. Transporting goods by Portuguese ports for the delivery of the first train load is 6 days slower than by Holland and the last train will be 8 days faster through Holland by either conventional or Betuweline. This means that for expediated articles like meat products there is a 2/3 reduction in shelf life.

The emissions produced due to the speed of the vessel in relation to either South American maritime route. The carbon emissions are greater for Route 2 traveling to Sines and then Rotterdam than Route 1 traveling directly to Northern European ports of call first. Route 2 to Sines first shows an increase in carbon emissions as the speed increases. Route2 maritime carbon emissions are greater than route 1 due to the increased speed required to meet the journey time requirements of the schedule.

The transit time for containers from South Africa transported through Portuguese ports and then transferred to rail transport to the German inland terminal, is faster than transportation through Rotterdam and then by rail to the German inland terminal. This is important for courier services organizing shipping routes for items like electronic merchandise or automobile parts.

The rail emissions for the transportation of containers from the South American route are larger for Route 2 projected route that goes through Badjoz. In terms of the carbon foot print it is double that of route 2 traveling through Vilar Formoso. Route 1 option that use conventional or the Betuwe line are equal in emission by using the same standard infrastructure and very similar travel distances. The overall Route 2 emissions shows that the carbon dioxide emitted is greater for Route 2 than Route 1 options as well as NOx. and Sulfur dioxide. Route 2 making use of the rail network through Vilar Formoso produces 1.6 times more carbon emissions while the carbon footprint would be greater still travelling through Badajoz which produces double the carbon Emissions

Regarding the South Africa route, the cost of transporting goods directly from South Africa through Rotterdam to Germany is cheaper by than the cost of transporting goods through Portuguese ports. The difference in transportation costs by the Betuwe and conventional rail line through Holland by Venlo from Holland to Germany are negligible, in this case. In relation to the costs associated with using Portuguese ports. The results are found that it is cheaper to travel through Badajoz than to travel by Vilar Formoso.

The rail contribution to the emissions is much reduced along the Dutch rail options and as such the emissions produced from transporting goods by rail to Germany, from Portuguese ports is 5 times greater form the increase distance travelling along the Vilar Formoso train path to Germany.

The combined emissions of container transport from South Africa to Germany, that have rail routes going from Rotterdam to Köln Germany, produce the lower quantity of emissions. The second route that makes call at Portuguese ports and then heads onward to Mannheim Germany, produces a greater amount of emissions. The carbon emissions for rail routes from Holland to Germany are quarter less of that projected for Route 2 through Badajoz and a fifth less than Route2 going through Vilar Formoso. The current route going through Vilar Formoso has a 10% carbon emission reduction compared to the route travelled by Badajoz which as accounted for by the increased distance the train must travel by of rail.

Regarding the North American route of transporting goods initially to Portuguese ports and then on to the German hinterland. It is concluded that compared to the costs of transporting goods through Rotterdam is 2.1 times cheaper than transporting them from Portuguese ports with the current network through Vilar Formoso. The projected routes through Badajoz is three quarters of the price of the current route traveling through Vilar Formoso. However, the projected route through Vilar Formoso will be 5% cheaper than the option through Badajoz.

The time in days expected from a voyage from North America for products to arrive in the German Hinterland, by the first train to deliver goods from Rotterdam is 22.5 day. Transporting goods by Portuguese ports is 23 days. The time of delivery is negligible but for the last train delivered transporting goods directly to Portuguese ports results in 26-day time for delivery in Germany as opposed to 28 days when transporting goods through Rotterdam. The delay in waiting time for the trains to deliver from Rotterdam being attributed as the cause. The reason is that the Portuguese ports each have half the load that a single terminal at Rotterdam must handle as such there is a quicker ship turnaround time having less cargo enter port. Similarly, the converse is true of transporting the containers through the terminal to the trains awaiting loading.

The rail contribution to the emissions is much reduced along the Dutch rail options and as such the emissions produced from transporting goods by rail to Germany, emissions from Portuguese ports to Germany is much greater due to the much greater rail distance covered. Containers arriving at Portuguese ports and travelling through Vilar Formoso produces nearly ten times as more carbon than rail routes of Dutch origin. The carbon emissions for rail transportation through Badajoz is an increase of 14% on emission produced by rail travel through Vilar Formoso.

The combined emissions of container transport from North America to Germany that have rail routes going through Rotterdam to Germany produce the lower quantity of emissions. The second route that makes ports of call at Portuguese ports and then heads onward to the German hinterland produces a greater amount of emissions. Carbon emissions are over six times greater for a route going through Portuguese ports and making use of projected Madrid route.

Single port journey to Rotterdam is more economical per intermodal unit, when considering liner shipping quantities, than traveling to Portuguese ports. However, when a vessel has multiple European ports of call, utilization of rail form Portuguese ports with a call to Rotterdam brings cost benefits when the ship load is divided between forms of transport to inland terminals.

Emissions are greater as would be expected over the greater rail route distances, which explains why carbon emissions are greater for inland routes from Portugal where the number of trains contributing to emissions. The rate of delivery of goods depends on distance to first port of call, the quantity of cargo the vessel must unload, and the order of priority of the container.

Further work would be to investigate further the effects of each individual port and its various layout schematics, and also the cost effects of ship waiting times to the transport supply chain.

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Appendix 1 Tariff structures

Tariff structures:

References to tariffs:

Germany:

DB Netz AG Network Statement (NS 2012), valid from 12 April 2011, DB Netz Train Path Pricing System of DB Netz AG, valid from 11 December 2011 to 08 December 2012;

DB Netz AG Network Statement (NS 2013), valid as of 11 April 2012, DB Netz Train Path Pricing System of DB Netz AG, valid from 09 December 2012

Belgium:

Infrabel 2017 Network Statement, version of 11-12-2015, Valid from 11/12/2016 to 9/12/2017

Infrabel 2017 Network Statement, Version of 27/01/2017, Valid from 11/12/2016 to 09/12/2017

Spain:

Add Network Statement 2016

Adif tariff Network Statement 2017 (Ministro de Fomento)

France:

2017 National Rail Network Statement, Réseau Ferré de France version 9 December 2016

Netherlands:

Network Statement 2016 Betuwe Line Period of validity: 2016 timetable Sunday 13 December 2015 – Saturday 10 December 2016

Network Statement 2017, valid from 11 December 2016 to 9 December 2017, version 1.0, ProRail, 4 January 2016

Portugal:

Network Statement 2017, 10 December 2015;

Table 38 Tariff charging principal for various Countries along the rail routes defining the charging

Country	Charging Principle	% covering total cost	Maintenance	Modernization	Traffic Management	Congestion Creating Bottlenecks
Portugal	MC	20	x	x	X	
Spain	MC	20	x	x	X	
France	MC+	63	x	x	X	x
Belgium	FC-	20				x
Holland	MC	12	x		X	
Germany	FC-	60	x	x	X	

The Directive 2001/14 / EC indicates two different main economic philosophies, which may result in the definition of the infrastructure use rate: marginal cost (MC) and total cost recovery (CF), with each philosophy being able to undergo minor derivations. The marginal cost may be increased by a surcharge based on the operators' payment elasticity and thus reduce the state dependency (MC +). In turn, the principle of full cost recovery, i.e. the collection of all costs of maintenance and operation to the operator, can be changed to the principle of cost recovery fewer subsidies received through the pre-defined state contribution (FC-) .

The recognition of the respective charging philosophy becomes difficult to determine, since this is not announced by the infrastructure managers, and can be the object of different interpretations by each author.

Belgium Train tariff structure

The procedures and components for each tariff component can be summated as follows:

1.0 Rate of use: Price of the line (TR-L) +Price of the station (TR-I) +Shunting Charge

1.1 Line price: line base price (P) X Train Priority (Pt) *$\sum_{\text{all section}}$ (Distance (L) X the section importance coefficient (C1) x velocity coefficient of the section (C2) x the environmental coefficient (cu) x the train mass coefficient (C) x peak coefficient (H)x the deviation coefficient (T)

1.1.1 the base price of the line (P) 0.360814 [€/km]
1.1.2 train priority (Pt) [coefficient]
1.1.3 distance (L) (km)
1.1.4 Section importance coefficient
1.1.5 Coefficient of velocity
1.1.6 Ambient coefficient: 1 (Ce)
1.1.7 Coefficient of mass of the train (C)
1.1.8 Peak coefficient (H)
1.1.9 Deviation Coefficient

1.2 Station price: station base price(Pm) X coefficient of use (Cu)X importance of the station (C) + station base price (Pm) x0.01 coefficient of Importance of the station X $\text{time}^{1+0.01\text{xcoeficient of importance of the station}}$

1.2.1 Base price of station (Pm) 2.611345 [€ per utilization]
1.2.2 Coefficient of use
1.2.3 Coefficient of importance of the station
1.2.4 Time

1.3 Administrative price

1.3.1 Administrative costs for asked capacity (AK) 65.892531 [€/request]
1.3.2 Administrative costs for asked conflict management (AKC) 86.009603 [€/request]

1.4 Shunting charge: 1.524753 [€/unit]

2 reserve capacity

3 Rate of reserve capacity not used 0.2425 [GMN/ train km]

4 Energy: comprises of two components the charge for the supply of traction energy by Infrabel and the charge for the transport and distribution of the traction energy.

Table 39 Belgium Inferable section importance coefficient and Velocity coefficient

section importance coefficient category	C1	velocity coefficient		C2
1	2	1	Vref>220km/h	3.5
2	1.75	2	220<Vref<160	2.5
3	1.25	3	160>Vref>140	1.5
4	1	4	140<Vref<120	1.25
9	any purpose	5	120<Vref 1	

The related section importance coefficient is taken as category 4 and the velocity coefficient.

Table 40 Belgium Infrabel coefficient of mass of the train and peak coefficient categorization

mass of the train		C value
from	up to	
[ton]	[ton]	
0	400	1.2
401	800	1.55

peak coefficient		
Category	traffic density	H(i)

801	1200	1.9
1201	1600	2.55
1601	2000	2.6
400		0.35

1	important	4
2	average	3
3	normal	1

The train mass that travels through Belgium is 1600 tons and the corresponding coefficient was used. The trains travel in proportionality to the timetabled traffic density periods which follow the classification of important, average and normal. The distribution of the train flowing through the different congestion periods of important, average and normal is 1:4:5.

Table 41 coefficient of deviation

	deviation coefficient	
from including	to excluding	value T
0%	100%	1
100%	200%	1.2
200%	300%	1.4
100%		0.2

The value of coefficient T(i), deviation of train path compared to standard train path on the section of the line, is as described in Table three where the deviation range selected is from 0% to 100%.

Table 42 coefficient of importance of infrastructure and coefficient of importance of the station for Infrabel Belgium

the coefficient of the importance of infrastructure	Cu
origin	4
destination	3.5
Intermediate station	3

C	the coefficient of the importance of the station
station category	goods
Bruxelles-Midi TGV	N/A
1	2
2	1
3	0

Table 43 Energy consumption rates for Infrabel Belgium

energy consumption	normal	off-peak	
Charge for the transport and distribution of the traction energy	23	22	[€/MWH]
Charge for the supply of traction energy by Infrabel	57	38	[€/MWH]

Table 43 Displays the two components for the cost of energy supply. The components are for the supply of traction energy for the electric locomotive and the distribution of electrical traction energy. These rates are with respect to normal. Table 44 is the type of train reserve coefficient (right) and reserve capacity cancellation fee percentage charge. (left)

Table 44 Infrabel Belgium Reserve capacity and train priority (Pt) coefficients

reserve capacity		
the announcement of the cancellation	**amount to pay for the rate of use**	
<24 hours of departure	**100**	**[%]**
<30 days and up to 24hours before departure	**30**	**[%]**
<60 days up to 30 days from departure	**15**	**[%]**
>60 days	**0**	**[%]**

category	**type of train**	**[Pt]**
1	**High-speed train**	**1.5**
2	**classical passenger train**	**1.5**
3	**IC; ICT;IR; CR**	**1.4**
4	**train P Train L and fast goods**	**1.2**
5	**slow goods Technical**	**1**
6	**Empty, Light**	**1**

France tariff structure:

The procedure and components for each tariff component can be summated as follows:

1. Rate of use: base price X distance + Access rate + other taxes + reserve rate

1.1 Base price: Freight trains and light running freight trains,
Running charge 0.601[€/train-km]

1.2 Rate of reserve: (Base price fixed term + adjustment term X-Coefficient of velocity-distance) x distance of section

1.3 The rate of access:

1.3.1 Charge for use by freight trains and for the rate per train path-km to allow for the investment incurred by SNCF Réseau 1.101[€/train km]

1.3.2 Charge per accessing train local interest corridor Le Havre 135 [€/train]
Charge per accessing train main accessing corridor 197 [€/train]

2.0 Performance scheme: The rate of performance is undefined for France

3.0 Energy: Energy costs has two associated components for electrical freight trains;

3.1 Charge for use of electric traction installations 0.226 [€/train-km]

3.2 Charge for transmission and distribution of electric power 0.033 [€/train-Km]

Table 45 Reservation charge for France SNCF Resau

the rate of reserve			Adjustment term		
		Fixed term	HC	HN	HP
line category		[€ /train km]	[€ /train km]	[€ /train km]	[€ /train km]
classic line LC	A	0.019	2.475	6.735	19.478
	B	0.019	1.004	1.939	4.388
	C	0.019	1.004	1.004	2.074
	D	0.019	0.013	1.004	0.068
	E	0	0	0.006	0.006
	E-Pr	0	0	0.006	0.006
high velocity	SE-1	1.378	7.998	16.238	19.852
	SE-2	1.378	1.871	7.284	10.427
	ATL-1	1.378	7.998	16.238	19.852
	ATL-2	1.378	1.871	7.284	10.427
	NOR-1	1.378	7.998	16.238	19.852
	NOR-2	1.378	1.871	7.284	10.427
	ICO-1	1.378	1.342	3.727	6.285
	EST-1	1.378	1.191	3.331	5.74
	RH-1	1.378	1.758	3.516	5.275

The reservation charge for booked train Kilometer can be seen in Table 46 With the fixed term rate per section Line type and the adjustment in accordance with the traffic congestion periods. The congestion periods were broken down in proportion to daily timetable division. The adjustment factor costs addition was summed as a total percentage of each period cost adjustment. The division of proportionality is 1:2:1 for the adjustment factor.

The reserve rate following The ATL charge for reserve rate resulted in a charge of 15960[€/train] The charge rate was then taken in accordance with the tariff rate for the medium traffic of the conventional lines D

Table 46 adjustment for freight trains and light running freight trains on conventional lines (distance velocity coefficient)

conditions conventional lines	coefficient
L<300km or V<70km/h	0.6
L>300km or 75km/h<V<85km/h	1
L>300km or 85km/h<V<105km/h	1.15
L>300km or V<105km/h	1.3

Table 46 distance velocity coefficient is associated with conventional train lines and hence is omitted from the Atlantic High-speed line section. The coefficient is adjustment to the speed and section distance on the fixed term price

Train tariff structure for Germany:

The procedure and components for each tariff component can be summated as follows:

1. The rate of use which is determined by:

$$base\ price * product\ factor + component\ weight$$

1.1 base price [€per train-km]

1.2 Branch cost

1.2.2 Minimum velocity multiplier

1.2.2.1 minimum velocity greater than 50km/h: 1.0 [coefficient]

1.2.2.2 minimum velocity below 50km/h: 1.5 [coefficient]

1.3 component weight

1.3.1 Heavy trains above 3000 ton: 1.00 [€ per train km]

Performance regime

2.1 Infrastructure Management penalty with non-responsibility 15% of product value

2.2 Infrastructure Management penalty with responsibility greater than 6 minutes [€/min]

2.3 low index utilization line 40 of rate of use [%]

2.4 non-constructed planned line 10% of regular price

2.5 discount for new portions 10% of regular price

3.0 Reserve rate 80€ per portion

4.0 Asking rate capacity: capacity per portion or part of the utilized Section 10% of non-used section

5.0 Cancellation Rate: 80€ per portion + % of the base price

    5.1 up to 60 days before cancellation 0%

    5.2 up to 30 days before cancellation 10%

    5.3 Less than a month and before 24 hours of departure 20%

    5.4 24 hours before departure 40%

6.0 Surcharges

Noise from goods trains 2.5% of the rate of use

6.1.1 Telecommunications: [€11.95/user/month]

6.1.2 Workstation scheduling for Karlsruhe operating center 1068.23 [€/month]

6.1.3 Data license 750.56 [€/month] and Live maps 900 [€/month]

7.0 Energy: Electrical Power consumption rate is 20.05 [€/MWh] and additional charge for Electrical pre-heating of traction units for the Saarbrücken region 6.59[€/hour]

Table 47 Base price long distance rail sections of Germany´s Deutsche Bahn routes

Long-distance		
Name	Description	[€ per km]
F+	Vmax>280km/h rapid importance cargo	9.74
F1	280km/h>Vmax>200km/h high velocity and mixed traffic	4.97
F2	200km/h>Vmax>161km/h high velocity and mixed traffic	3.44
F3	160km/h>Vmax>101km/h mixed traffic	3.1
F4	160km/h>Vmax>101km/h intercity high velocity passenger	2.98
F5	Vmax>120km/h intercity	2.2
F6	280>Vmax>200 local and regional service rail passenger	2.94

Table 48 Germany´s Deutsche Bahn Product factor for freight transportation and the velocity coefficient

Product factors freight transport	
description	[coefficient]
Express	1.65
Standard	1
Freight transport route	0.65
feeder route	0.5

Minimum velocity penalties	
description	[coefficient]
Minimum velocity >50km/h	1.0
Minimum velocity <50km/h	1.5

Table 48 displays the coefficient for the products transported and the related speed coefficient of the respective train. The coefficient of speed is for electric trains with a speed of 100Km/h and the product factor is for freight routes

Table 49 base price of rail sections of Germany´s Deutsche Bahn feeder and fast urban traffic line routes

Name	description	[€/ km]
Z1	100km/h>Vmax>51km/h	3.03
Z2	Vmax<51 simple or no signals	3.13

Name	Description	[€/km]
S1	Fast urban service transport	1.97
S2	Fast Urban transport in Berlin	2.63
S3	Fast Urban transport in Hamburg	3.13

The base price is for Z1 routes which correlate to freight traffic for the Ten-T trains that travel at 100km/h

Holland tariff structure:

The procedure and components for each tariff component can be summated as follows:

1.1 Rate of use: base rate x distance + rate of excess capacity

1.2 Rate of excess capacity 100 [€] (applied for peak period congestion)

2. Performance scheme: yet to be determined per measured node the cancellation penalty under scheme 2a can be seen in table
3. Compensation regime: in accordance with section under maintenance the operator is compensated a set value per section from management infrastructure
4. Energy: access to catenary 0.030164 [€/kwh]

Table 50 Route compensation charge

Compensation		Gouda-Harmelen	330
Route	section	Herfte-Mariënberg	990
charge	[€]	Haarlem-Amsterdam sloterdijk	770
Amersfoort-Deventer	550	Harmelen connection-Breukelen	770
Amersfoort-Deventer	330	Harmelen-Utrecht	110
Amersfoort-Duivendrecht	770	’s-Hertogenbosch-Lunetten	550
Amersfoort-Utrecht	550	Kijfhoek - Lage Zwaluwe	550
Almelo-Mariënberg	110	Leeuwarden-Groningen	1210
Alphen a/d Rijn-Gouda	330	Leeuwarden-Meppel	550
Amsterdam-Centraal-Breukelen	550	Meppel-Onnen	550
Breda-Roosendaal	550	Roermond-Sittard	1210
Breda-Tilburg	550	Gouda-Rotterdam zuid	330
Breukelen-Utrecht	110	Deventer-Oldenzaal	770
Boxtel-Eindhoven	770	Sittard-Eijsden border	550
Tilburg-Vught	330	Tilburg-Boxtel	55
Beverwijk-Haarlem	770	Tilburg-Vught connection	33
Eindhoven-Roermond	330	Utrecht-Zevenaar oost	110
Eindhoven-Venlo	770	Lage zwaluwe-Breda	330
		Lage zwaluwe-Roosendaal	1210

Table 50 shows the route compensation charge per section. In the event of possession measures that affect multiple route sections, the compensation charge is done on a case by case basis, where a specific compensation charge is then determined. The compensation charge is therefore not applied in this analysis.

Table 51 Pro Rail Base rate in accordance with the load capacity

Category Weight	tariff
(T)	[€/km]
up t0 120	0.8466
121 to 160	1.0595
161 to 320	1.342
321 to 600	1.8751
601 to 1600	3.0028
1601 to 3000	3.6156
>3001	3.922

Table 51 shows the charge per weight of train loaded per kilometer of track traveled. Table 52 shows the charge per path and the charges related to using along Havenspoor track line. The charges increase depending upon the time given before cancelation of the Route.

Table 52 has the cost penalization associated with the notice period for the cancellation of a route.

Cancellation rail freight operator, penalty on the Betuwe Line	Standard path	Local traffic path Havenspoor Line	Light locomotive Havenspoor Line
	[€]	[€]	[€]
Submitted in annual timetable, change sheet and ad-hoc phase to OSS	0	N/A	N/A
Submitted between 3 hours before departure and 90 minutes before planned departure	100	0	0
Less than 90 minutes before departure up to 30 minutes before planned departure	250	100	50
Within 30 minutes of planned departure	400	200	100

Portugal tariff Costs:

The procedure and components for each tariff component can be summated as follows:

1. Base rate: Base price [€/train km] depending on the traction type of the line
2. Performance regime: 0.15 € per 30-minute delay
3. Rate of reserve capacity: in accordance with the capacity request history
4. Administrative costs: In accordance with the service type
5. Energy consumption costs: Is determined by the units without meters method. The specific consumption of electrical power per kilometer (kWh/km)

The tariff for essential services Is as follows:

$$TSE = \sum_{i=1}^{n} (T_i + T_v) * CK_1$$

Where:

TSE – Charge for providing essential services when using a train path for a rail composition.

i – Section in operation

Ti – Base charge defined in the Network Statement for each section of track, depending on the kind of service and kind of traction used

Tv – Shared value fee, only applying to the operating track sections with inclusion of new investments in the infrastructure.

CKi – Distance covered by a rail composition in each section in operation. Ck (train kilometers)

The amount each operator must pay depends on the kind of service and traction used and the distance covered between the origin and destination of the service. The total amount is the sum of all the sections covered by multiplying the length of each section by the applicable charge.

1. The Base Rate: The basic fee is calculated by the following formula

$$T_i = C_o * C_1 * C_2 * C_3 * C_4 * C_5 * C_6$$

Ti – Tariff of Section i

C0 – Tariff Base Component

C1 – Traffic Control Component

C2 – Electrical Facilities Component

C3 – Section Operational Value Component

C4 – Safety and Telecom Facilities Component

C5 – Station Buildings and Associated Costs Component

C6 – Type of Service Component

Components C1 to C5 are calculated using the following formula:

$$C_i = \left[\frac{W_i}{(WO * CU + \sum W_j)} \right] + 1$$

for i = 1 to 5, j= 1 to i, and where:

Wi – Cost directly attributable to component i in the last finished year

W0 – Tariff base component, set by law at 0.762 €/TK

CU – Useable capacity in last finished year

Parking of rolling stock:

$$T_e = 1.48\text{€} * H$$

The rolling stock is the price per hour the hourly rate is assumed to be equal with relation to the move rate of rail mounted gantry cranes of Lisbon Port. The train parking is for the hours required to transfer the containers from Portuguese ports. An assumption is made that the rolling stock will be for the diesel locomotive on the current situation for the period of container transfer. During which time, the refueling and minor maintenance can occur.

On the current route, A diesel engine locomotive is used from the RRT terminal at entrenchment which will continue over the Spanish border where electrification is still to occur between the following section Medina del Campo – Salamanca – Fuentes de Oñoro (ES/PT border).

This cost is omitted from the calculations for both the Projected routes as the Portuguese rail system as of 2017 has a completely electrified route from Sines, through Lisbon and onto Vilar-Formoso at the Spanish border. The Atlantic corridor proposed track is intended to be a uniform electric supply the direct line transfer this cost is omitted as there is no refueling requirement. Small maintenance time will be neglected in this case study.

Table 53 Rate of access charge per train-km

					Freight		Empty Freight	
No.	Line	from	up to		CKE	CKNE	CKE	CKNE
				[km]	[€]	[€]	[€]	[€]
8	Linha Norte	Lisboa Sta Apolónia	Pampilhosa	233.5	1.46	1.32	0.94	0.81
20	Linha Beira Alta	Pampilhosa	Vilar Formoso Fronteira	228.8	1.34	1.21	0.9	0.81
37	Linha sul	Pinhal Novo	Ermidas Sado	37.6	1.49	1.35	0.99	0.90
38	Linha Sines	Ermidas Sado	Porto Sines	27.2	1.34	1.21	0.9	0.81
	Ramal da Sidurgia Nacional	Pinhal Novo	Liscont	40.4	0.63	0.63	0.42	0.42
	Ramal Sines	Port of Sines	PSA Terminal	1.9	0.63	0.63	0.42	0.42
				569.4	1.15	1.06	0.76	0.70

In Table 53 The charging rate per train kilometer for the various line sections of the Portuguese part of the Atlantic Corridor route. Table 53 considers the charges associated with empty returning freight and the costs of non-electric trains which applies to the section between Pampilhosa and Vilar Formoso and transfer branches at the Portuguese ports of Sines and Lisbon. The performance regime price is not considered as the cost of delays is not considered in the case study. In terms of the single track the returning trains are empty and as such, no congestion criteria will occur. Furthermore, upon completion of the Ten-T projects, the entire section will have double rail section. The single rail is currently along the southern line from Sines to Lisbon.

Freight	
Reserve Capacity	[€/train kilometer]
Equal or greater than 30 days	0.03

Administrative costs	[€/month]
Service type A	152
Service type B	228

Between 10 days incl. and 30 days excl.	0.04
Between 5 days incl. and 10 days excl.	0.05
With a rate of fewer than 5 days	0.08

Service type C	304

Table 54 reservation fee costs associated with ad-hoc requests (left) Administrative costs for Portuguese rail traffic (right)

There are three levels of administrative services depending on the kind of electric traction substation. The service type for the section under consideration is service type A for the line section north of Lisbon and for the South accounts for Service Type B

The Energy costs are determined by the following formula:

$$EEMZK_{ij} = CeEkm_j * Dkm_{jk}$$

Where:

EEMzkji = Electrical Traction Energy of unit j in the zone fed by SST k with reference to month i

CeEkmj = Specific electrical consumption per kilometer for unit j

Dkmjk = Distance in kilometers covered by unit j in zone k

Energy cost per zone is calculated by the following formula:

$$CmEEzk_i = \frac{CTEEzk_i}{EETzk_i}$$

where:

CTEEzki = Total cost of electrical energy supplied by the SST feeding zone k in month i (Amount given on the SST k invoice for month i of the FEE)

CmEEzki = Average cost per kWh supplied by the SST that feeds zone k in the month i;

EETzki = Total electrical energy supplied by the SST that feeds zone k in the month i (Amount given on the invoice from SST k in month i for FEE)

The rate for energy use is assumed to equal to the rate charged by the Entidade regulatora da Energia (Portuguese energy regulatory body for contracted global energy use 0.0064(€/Kwh].

Value added tax (VAT has been neglected in this study which is applicable to all charges)

Spain Train tariff structure:

The procedure and components for each tariff component can be summated as follows:

1. Rate of use: rate of access + rate of operation + reserve rate
2. Energy

Table 55 Spanish Rate of access to Rail line infrastructure based on traffic volume

Rate of Access		[€/year]
Level N1A	<0.2 million km/ trains per year	13 251.56
Level N1B	<0.2 and <0.5 million km/ train year	33 128.92
Level N1C	<0.5 and < 1 million km/ train year	66 257.83
Level N2A	>1 and 2.5 million km/ train year	116 178.60
Level N2B	>2.5 and 5 million km / train year	165 644.60
Level N2C	>5 and 10 million km / train year	364 418.11
Level N3A	>10 and 15 million km / train year	761 965.14
Level N3B	>15 and 20 million km/ train year	1 577 059.19
Level N3C	>20 and 30 million km / train year	1 577 059.19

Level N3D	>30 and 40 million Km / train year	1 577 059.19
Level N3E	>40 and 50 million/ train year	1 577 059.19
Level N3F	>50 million km / train year	1 577 059.19

The rate of access, charging rates, can be seen in Table 55. The volume of traffic is for the Spanish section of the route along the Atlantic corridor under The RNE CO6 which encompasses the section: Vilar Formoso-Valladolid-Hendaye/Irun. The rate of access charge is 13120.36 € per year in accordance with the number of km run per train per year. The annual freight train number is 4719 trains. (Secchi C. , 2016)

Table 56 Spanish Rate of operation based on the type of service and type of line

Rate of operation (Running Mode)						
Type of line	Type of operation					
	[€/train-km]					
	VL1	VL2	VL3	VCM	VOT	M
A1	2.2018	0.8484	2.2018	0.8484	0.8484	0.505
A2	2.1008	0.7676	2.1008	0.7676	0.7676	0.505
B1	0.7676	0.7676	0.7676	0.7676	0.1313	0.505
C1	0.1212	0.1212	0.1212	0.1212	0.1207	0.0606
C2	0.1212	0.1212	0.1212	0.1212	0.1207	0.0606

The rate of operation for freight in € per train-km can be seen in Table 56 where the category M is for the freight trains and C2 the line type.

Table 57 Spanish reserve capacity based on the type of line, type of service and timetable period

the rate of reserve capacity							
	Type of line	Type of operation					
		[€/train-KM reserved]					
		VL1	VL2	VL3	VCM	VOT	M
Peak	A1	2.8371	1.5089	2.8371	1.5089	1.5089	0.5757
	A2	2.7169	1.4241	2.7169	1.4241	1.4241	0.5757
	B1	1.4241	1.4241	1.4241	1.4241	0.404	0.5757
	C1	0.404	0.404	0.404	0.404	0.404	0.3333
	C2	0.404	0.404	0.404	0.404	0.404	0.3333
normal	A1	2.8371	1.5089	2.8371	1.5089	1.5089	0.5757
	A2	2.7169	1.4241	2.7169	1.4241	1.4241	0.5757
	B1	1.4241	1.4241	1.4241	1.4241	0.404	0.5757
	C1	0.404	0.404	0.404	0.404	0.404	0.0505
	C2	0.404	0.404	0.404	0.404	0.404	0.0505
low traffic	A1	2.8371	1.5089	2.8371	1.5089	1.5089	0.5757
	A2	2.7169	1.4241	2.7169	1.4241	1.4241	0.5757
	B1	1.4241	1.4241	1.4241	1.4241	0.404	0.5757
	C1	0.202	0.202	0.202	0.202	0.202	0.0505
	C2	0.202	0.202	0.202	0.202	0.202	0.0505

Table 58 Spanish Rail Timetable congestion period

Spanish rail timetable Congestion	
Period	Hour period
Start End	
Off-peak	0:00 5:59
Peak	6:00 9:29

Normal	9:30 17:59
Peak	18:00 20:29
Normal	20:30 23:59

Reserve capacity is calculated by the associated cost per traffic congestion period. The division of time from Table 57 and the reserve cost per train Km for freight trains were attributed 40% for peak and normal time and 20 % for Off peak time. Assumptions are made that trains Coming from Portugal through Spain from ports would be in a regular service with no delays anticipated.

Table 59 Energy costs associated with traction Power supply of trains

Traction Power Supply			
High-speed lines		Real cost	
Commuter electric power units	Thousands of TKB	8.303228	[€]
Medium distance electric multiple unit sets	Thousands of TKB	2.555925	[€]
Medium distance electric units	Thousands of TKB	2.555925	[€]
Long distance conventional trains	Thousands of TKB	3.288052	[€]
Long distance Euromed type	Thousands of TKB	3.163133	[€]
Long distance Alaris type	Thousands of TKB	3.163133	[€]
Long distance single locomotives	Thousands of TKB	3.288052	[€]
Long distance electric multiple unit sets	Thousands of TKB	3.163133	[€]
Freight single locomotives	Thousands of TKB	2.635221	[€]
Freight conventional train	Thousands of TKB	2.635221	[€]
management cost	MWh	1.12	[€/MWh]

The Energy Cost associated with the locomotive Is related to the traction power of the section of rail requiring Diesel Fuel has a price of 1.26€/liter. When considering the consumption 0.14 gallon per mile and the expected time of the route section is 10 and a half hours as such the effective cost of resupply of the train is expected to be 109.91€ per trains.

The number of trains is relating to the limiting current weight of 1000 tons total weight that can be hauled along the line section.

Table 60 Stabling of Spanish trains

Category	[€/TRAIN]		
	A	B	C
1ST	2.2458	3.3688	4.4917
2ND	1.12 €	1.70	2.2458
3RD	–	–	–

Table 61 shows the train stabling cost per train which is used for refueling and minor maintenance. The values in Table 60 are only applicable to the current situation of the rail route on the Atlantic corridor since the section between Vilar Formoso and Valladolid is not complexly electrified and is still being run with use of diesel locomotives. This implies the need for trains to stop while containers are transferred. The proposed route for simplification does not encompass delays or congestion situations and is direct from the Portuguese port of Sines to Mannheim and therefore this cost is omitted in the projected cost.

Table 61 Handling of intermodal units

HANDLING INTERMODAL TRANSPORT UNITS	Invoicing unit	Charge Year 2016	
ITU between 0 and 2 days of transit through the Facility	ITU	22.45	[€]
ITU up to 7 days of transit through the Facility	ITU	39.4	[€]
More than seven days of transit through the Facility	ITU/day	6	[€]
Additional handling for more than 7 days of transit	ITU	22.45	[€]

Additional train costs for the current train route is associated with the transfer of containers through a terminal this will occur at Entroncamento and Valladolid. These costs require for the transfer of the containers from the electric trains to diesel trains Along this section the section of rail. At Valladolid, the Containers must be transferred again from the diesel trains to the electric trains. The assumption made in this case that transfer allowance of up to 7-day pricing structure was incorporated

Appendix 2 South American Route Vessel Auxiliary Equipment and in Port fuel consumption.

Auxiliary fuel costs:

Auxiliary fuel costs were calculated by from the fuel consumption rates of specific equipment specifications from the ship´s description these included the electrical power of generators and electrical plants. The power that is to be required was verified by use of the U.S. Navy usage and simultaneous usage factors (United Sates Navy, 2012)

Table 62 Electrical genaration components onboard and relative estimated consumption

Electric installations			[No]	Utilization factor (u_f)	Simultaneity factor (s_f)	P*u_f*s_f
Shaft generator	[kVA]	2450	1	0.2	1	490
Generators	[kVA]	3625	3	0.2	1	2175

Table 63 Fuel consumption related to electrical generation activities considering type of fuel required

Electrical			voyage	port time	electric power	sfoc	HFO	IFO 380	ULSFO
South Bound	[nm]	[Kn]	[days]	[days]	[Kw]	[g/kwh]	[ton]		
Hamburg-Bremerhaven	36	16	0.756	1.11	8290.25	160	6.02		6.02
Bremerhaven-Le-Havre	580	16	1.9	0.7	8290.25	160	15.12		15.12
Le-Havre-Lisbon	1042	16	2.3	0.6	8290.25	160	18.30		18.30
Lisbon-sines	73	16	0.346	0.958	8290.25	160	2.75	2.75	
Sines-Rio de Janeiro	5207	16	10.458	0.429	8290.25	160	83.23	83.23	
Rio de Janeiro-Santos	249	16	0.75	0.75	8290.25	160	5.97	5.97	
Santos TPB-Paranagua	202	16	0.458	1.083	8290.25	160	3.65	3.65	
Paranagua-Navegantes	66	16	1.16	0.33	8290.25	160	9.23	9.23	
total South Bound	7455		18.128	5.96	8290.25	160	144.27	144.27	
North Bound									
Antwerp-Rotterdam	144	16	0.433	1	8290.25	160	3.45		3.45
Rotterdam-Hamburg	341	16	1.23	0.547	8290.25	160	9.79		9.79
Navegantes-Santos	262	16	1.83	0.417	8290.25	160	14.56		14.56
Santos-Rio de Janeiro	249	16	0.833	0.917	8290.25	160	6.63	6.63	
Rio de Janeiro-Salvador	809	16	2.083	1	8290.25	160	16.58	16.58	
Salvador-Antwerp	5670	16	14.1	0.83	8290.25	160	112.22	112.22	
total Northbound	7475		20.509	4.711	8290.25	160	163.22	163.22	
total round trip	14930		38.637	10.671	8290.25	160	307.50	547.75	67.24

Fuel consumption for electrical generation considers the ECA region where fuel must be used in compliance with the sulphur reduction regulations imposed.

Table 64 Boilers fuel consumption during vessel voyage-South America

			voyage	Port time	CHO-Kangrim	CHO-Kangrim	oil steam	gas steam	MDO	Gas
South Bound	[nm]	[Kn]	[days]	[days]	[Kg/hr]	[Kg/hr]	[Kg/hr]	[Kg/hr]	[ton]	[ton]
Antwerp-Rotterdam	144	16	0.433	1	600	600	100	108	11.25	0.86

Rotterdam-Hamburg	341	16	1.23	0.547	600	600	100	108	13.95	1.07
Hamburg-Bremerhaven	36	16	0.756	1.11	600	600	100	108	14.64	1.12
Bremerhaven-Le Havre	580	16	1.9	0.7	600	600	100	108	20.40	1.56
Le-Havre-Lisbon	1042	16	2.3	0.6	600	600	100	108	22.76	1.74
Lisbon-Sines	73	16	0.346	0.958	600	600	100	108	10.23	0.78
Sines-Rio de Janeiro	5207	16	10.46	0.429	600	600	100	108	85.44	6.53
Rio de Janeiro-Santos	249	16	0.75	0.75	600	600	100	108	11.77	0.90
Santos - Paranagua	202	16	0.458	1.083	600	600	100	108	12.09	0.92
Paranagua Navegantes	66	16	1.16	0.33	600	600	100	108	11.69	0.89
Total South Bound	7940		19.79	7.507	600	600	100	108	214.	16.4
North Bound										
Navegantes-Santos	262	16	1.83	0.417	600	600	100	108	17.63	1.35
Santos -Rio de Janeiro	249	16	0.833	0.917	600	600	100	108	13.73	1.05
Rio de Janeiro-Salvador	809	16	2.083	1	600	600	100	108	24.20	1.85
Salvador-Antwerp	5670	16	14.1	0.83	600	600	100	108	117	8.96
Total North Bound	6990		18.846	3.164	600	600	100	108	172	13.21
Total Round Trip	14930		38.637	10.671	1200	1200	200	216	387	29.58

The different types of boilers that were stated to be onboard the vessel consumption rates were calculated according to the time the vessel was at sea and the time at port with an estimated approximation of the percentage of this time that the boilers would have to function per each section of the voyage. The consumption values would provide the quantity in tons for both gas oil and marine diesel oil boilers fuel consumption per leg section and the overall journey consumption.

Table 65 Time in Port for performance of maneuvers estimation

	MSC Krystal	Terminal Maneuver Distance	Average Manoeuvre Speed	
	Days	nm	Kn	[hours
Antwerp	1	3.5	3	1.17
Rotterdam	0.547	3.6	3	1.20
Hamburg	1.11	2.08	3	0.69
Bremerhaven	0.7	4.68	3	1.56
Le-Havre	0.645	7.5	3	2.50
Lisbon	0.958	0.63	3	0.21
Sines	0.429	0.946	3	0.21

	MSC Krystal	Maneuver Distance	Maneuver speed	
	Days	nm	Kn	hours
Rio de Janeiro	0.75	0.8	3	0.27
Santos	1.083	1.11	3	0.37
Paranagua	0.333	0.879	3	0.29
Navegante	0.417	0.9	3	0.30
Santos TPB	0.917	1.11	3	0.37
Rio de Janeiro	1	0.8	3	0.27
Salvador	0.83	0.617	3	0.21

Table 66 Fuel consumption related to navigating through and maneuvering port zone

						Route A		Route B	
	Port distance	Average speed in ports		docked time	consumption	IFO 380	ULSFO	IFO 380	ULSFO
	[nm]	[kn]	[hours]	[hours]	[t]	[t]	[t]	[t]	[t]
Antwerp	35	10	3.5	19.33	2.135	0.000	2.135	-	
Rotterdam	25	13	1.92	10.00	2.574	0.000	2.5734	-	2.574
Hamburg	5	16	0.312	25.63	0.785	0.000	0.785	-	-
Bremerhaven	5	16	0.312	14.93	0.799	0.000	0.799	-	-
Le-Havre	6	10	0.6	12.38	0.404	0.000	0.404	-	-
Lisbon	2.7	10	0.27	22.51	0.1667	0.000	0.167	-	-
sines	6	10	0.6	9.38	0.368	0.368	0.000	0.3679	0.000
Rio de Janeiro	25	16	1.56	16.17	3.873	3.873	0.000	3.8734	-
Santos	25	16	1.56	24.06	3.875	3.875	0.000	3.8751	-
Paranagua	25	16	1.56	6.14	3.874	3.874	0.000	3.8738	-
Navegantes	25	16	1.56	8.15	3.873	3.874	0.000	3.873	-
Santos TPB	25	16	1.56	20.08	3.875	3.875	0.000	3.875	-
Rio de Janeiro	25	16	1.56	22.17	3.873	3.873	0.000	3.873	-
Salvador	25	16	1.56	18.15	3.872	3.872	0.000	3.8724	-
Antwerp	35	10	3.5	23.34	2.135	0.0000	2.135	-	-
				total	30.4754	23.61	6.8633	23.6126	2.5738

Table 67 Fuel consumptions for maritime of the vessel route A (left) Route B (right)-South America

	MDO	HFO 380	ULSFO
	[t]	[t]	[t]
Boiler	386.9		
electrical	-	548	67
Main engine	-	1880	685
Maneuvering	-	24	6.9
total	387.9	2 451	759

	MDO	HFO 380	ULSFO
	[t]	[t]	[t]
Boiler	473.5		
electrical		793	342
Main engine		2464	385
Maneuvering		24	2.57
total	473.5	3 281	730

Appendix 3 Port Loading / Off Loading Characteristics

Average Terminal Rate Route 1								
	Loading time	Quay length	cranes loading	Moves	Moves	full containers	Intl containers on board	empty containers
	[hours]	[m]	[No.]	[moves/hour]		[TEU]	[TEU]	[TEU]
Rotterdam off load	48	3550	3	70	3344	2842	0	502
Rotterdam on load	29	3550	3	70	2006	1705	2006	301
Cape town off load	17	2803	1	40	680	578	1326	102
port Elisabeth offload	17	925	4	40	684	581	642	103
Durban off load	16	3899	1	40	642	545	0	96
Durban on load	36	3899	1	40	1444	1227	1444	217
port Elisabeth on load	21	925	4	40	820	697	2264	123
Cape town on load	27	2803	1	40	1080	918	3344	162
Route 2								
	Loading time	Quay length	cranes loading	Moves	Moves	full containers	Intl containers on board	empty containers
	[hours]	[m]	[No.]	[moves/hour]		[TEU]	[TEU]	[TEU]
Sines off load	28	946	3	60	1672	1421	335	251
Lisbon off load	28	630	1	60	1672	1421	0	251
Lisbon on load	17	630	1	60	1003	852	1003	150
Sines on load	17	946	3	60	1003	852	2005	150
Cape town off load	17	2803	1	40	680	578	1325	102
Port Elisabeth off load	17	925	4	40	684	581	641	103
Durban off load	16	3899	1	40	642	545	0	96
Durban on load	36	3899	1	40	1444	1227	1444	217
Port Elisabeth on load	21	925	4	40	820	697	2264	123
Cape Town on load	27	2803	1	40	1080	918	3344	162

Table 68 South African route vessel in port loading/ offloading

	Port Time	Quay Length	Cranes Loading	Transfer rate	Moves	Off loaded	International containers on board	on board containers

Route 1	hours	m	No.	moves/hour		[TEU	[TEU]	[TEU]
Antwerp	19	3550	3	40	2320	1740	2440	3020
Rotterdam	10	3600	3	40	1201	900	1540	1840
Hamburg	26	2080	3	40	3076	1538	2	1540
Bremerhaven	15	4680	2	40	1194	896	0	940
Le-Havre	12	1050	3	40	1486	743	743	940
Lisbon	23	630	1	40	900	225	1418	2133
Sines	9	946	3	40	1126	563	1981	3552
Rio de Janeiro	16	800	3	40	1941	1552	1999	2387
Santos	24	1108	2	34	1636	1309	690	1406
Paranagua	6	879	3	25	460	368	322	1130
Navegantes	8	900	2	25	407	322	0	893
Santos TPB	20	1108	2	34	1365	341	1024	1576
Rio de Janeiro	22	800	3	40	2661	665	2784	2906
Salvador	18	617	3	25	1361	340	3805	3587
Route 2								
	Port Time	Quay Length	Cranes Loading	Transfer Rate	Moves	Off loaded	International containers on board	on board containers
	hours	m	No.	moves/hour		TEU	TEU	TEU
Sines	19	3600	3	40	2320	1740	2440	3020
Rotterdam	58	3600	3	40	6956	4077	743	2880
Sines	17	946	3	40	2026	788	1981	4072
Rio de Janeiro	16	800	3	40	1941	1766	2307	2481
Santos	24	1108	2	34	1636	1489	818	992
Paranagua	6	879	3	25	460	410	408	582
Navegantes	8	900	2	25	407	341	0	343
Santos TPB	20	1108	2	34	1365	341	1024	1025
Rio de Janeiro	22	800	3	40	2661	85	2784	2936
Salvador	18	617	3	25	1361	525	3805	3432

Table 69 South American route vessel in port loading/ offloading

Average Terminal Rate North American Route								
Route 1	Loading Time	Quay Length	Cranes Loading	Transfer Rate	Moves	Moves	Full Containers	International containers on board
	[hours]	[m]	[No.]	[moves /hour]	[moves /hour]	[TEU]	[TEU]	[TEU]
Rotterdam off load	47.35	3550	4	40	70	3 315	2 817	0

Rotterdam on load	47.35	3550	4	40	70	3 315	2 817	3 315
Newark off load	47.35	1097	2	40	70	3 315	2 817	0
Newark on load	47.35	1097	2	40	70	3 315	2 817	3 315
Route 2								
Route 2	Loading Time	Quay Length	Cranes Loading	Transfer rate	Moves	Moves	Full Containers	International containers on board
	[hours]	[m]	[No.]	[moves /hour]	[moves /hour]	[TEU]	[TEU]	[TEU]
Lisbon off load	27.63	630	2	40	60	1 658	1 409	1 658
Lisbon on load	27.63	630	2	40	60	1 658	1 409	0
Sines on load	27.62	946	4	40	60	1 657	1 409	1 658
Newark off load	47.35	1097	2	40	70	3 315	2 817	3 315
Newark on load	47.35	1097	2	40	70	3 315	2 817	3315

Table 70 North American route vessel in port loading/ offloading

Appendix 4 European Rail Corridor Track Investment Estimations

Rail investment estimation costs TEN.T Atlantic and the Rhine-Alpine corridors in terms of infrastructure and preliminary study costs calculations resulting values based on Professor Baumgartner Prices and cost of the rail sector criteria

Table 71 Portugal Rail Investment preliminary study estimation cost

Portugal		
section 1		
Sines_Vilar Formoso		
distance	613	[KM]
new railroad		
Feasibility study	833680	[€]
Preliminary study	8336800	[€]
total	9170480	[€]

Netherlands		
Rail sections required		
distance	435	[KM]
new railroad		
Feasibility study	591600	[€]
Preliminary study	8336800	[€]
total	8928400	[€]

The feasibility study estimations are based on prices suggested by Baumgartner adjusted for the cumulative depreciation from 2001 of 36% The costs are charged for the feasibility and the preliminary project study which is charged at a rate per km of track to be installed

Table 72 Investment costs per Acquisition of land rights along Atlantic Corridor

Investments infrastructure land and rights Atlantic Corridor					
			Land and rights	Infrastructure	
Average population density			cost/density	cost / terrain	total
			[€]	[€]	[€]
Sines to Lisbon	180	[km]	24480000	1713600000	1738080000
Average population density	25	[per/km^2]			
Entroncamento Pampilhosa	116	[KM]	15776000	3155200000	3170976000
Average population density	80	[per/km^2]			
Pampilhosa -Vilar Formoso	317	[Km]	43112000	8622400000	8665512000
Average population density	40	[per/km^2]			
Fuentes del Oñoro-Medina del campo	201	[km]	27336000	1913520000	1940856000
Average population density	80	[per/km^2]			
Medina del Campo-Miranda de Ebro	252	[km]	34272000	2399040000	2433312000
Average population density	60	[per/km^2]			
Miranda de Ebro-Alssasurra	77	[km]	10472000	733040000	743512000
Average population density	60	[per/km^2]			
Alassura-Irun	105	[km]	428400000	2856000000	3284400000
Average population density	100	[per/km^2]			
Hendaye-Bordeaux	233	[km]	31688000	2218160000	2249848000

Average population density	80	[per/km^2]			
Bordeaux-Poitiers	247	[km]	33592000	2351440000	2385032000
Average population density	80	[per/km^2]			
Poitiers-Tours	104	[km]	14144000	990080000	1004224000
Average population density	80	[per/km^2]			
Tours-Paris	221	[km]	901680000	2103920000	3005600000
Average population density	100	[per/km^2]			
Paris-Lerouville	305	[km]	1244400000	2903600000	4148000000
Average population density	100	[per/km^2]			
Lerouville-Metz	65	[km]	265200000	618800000	884000000
Average population density	150	[per/km^2]			
Metz-Saarbrücken	74	[km]	301920000	704480000	1006400000
Average population density	240	[per/km^2]			
Saarbrücken-Mannheim	139	[km]	567120000	1323280000	1890400000
Average population density	200	[per/km^2]			
total			3943592000	34606560000	38550152000

Table 73 Investment costs per Acquisition of land rights along Rhine-Alpine Corridor

Investments infrastructure land and rights Rhine-Alpine Corridor					
			Land and rights	infrastructure	
Average population density			cost/density	cost / terrain	total
			[€]	[€]	[€]
Netherlands	435	[km]	5916000000	4141200000	10057200000
Average population density	1000	[per/km^2]			
			mass installed track	Track cost	
Investment track			[t]	[€]	
Nether lands to Germany	435	[km]	21750	177480000	
			Trains to Germany	traffic	Maintenance costs
			[No]	[GTK/year]	[€/year]
Netherlands	435	[km]	64.5175	103228	76125

Table 73 and 74 are the costs associated with the acquisition of land rights to conduct the installations of newly built track the charges are generally towards legal fee matters for newly acquired sections of land not currently under the jurisdiction for exclusive use by the rail operator. The charges for rights also relate to the administration charges for requests to government bodies for the use of the land. The cost of land acquisition is related to a rate which is dependent on the length of track and the population density through which that track is to be installed

In the current situation, the New track would require infrastructure installations a newly acquired land to install the new track Gauge. Table 73 shows the Atlantic corridor sections requiring infrastructure installation. Table 74 shows that Netherlands requires 435 km of new track to still be installed for the Rhine-Alpine links to Germany. Germany is nearly completely compliant with European directives.

Table 74 Atlantic Corridor Investment per track section

Atlantic Corridor Track Investment				
			mass installed track	Track cost
Investment track			[t]	[€]
sines to Lisbon	180	[km]	9000	73440000
Entroncamento Pampilhosa	116	[KM]	5800	47328000
Pampilhosa -Vilar formosa	317	[Km]	15850	129336000
Fuentes del Oñoro-Medina del campo	201	[km]	10050	82008000
Medina del Campo-Miranda de Ebro	252	[km]	12600	102816000
Miranda de Ebro-Alssasurra	77	[km]	3850	31416000
Alassura-Irun	105	[km]	5250	42840000
Hendaye-Bordeaux	233	[km]	11650	95064000
Bordeaux-Poitiers	247	[km]	12350	100776000
Poitiers-Tours	104	[km]	5200	42432000
Tours-Paris	221	[km]	11050	90168000
Paris-Lerouville	305	[km]	15250	124440000
Lerouville-Metz	65	[km]	3250	26520000
Metz-Saarbrücken	74	[km]	3700	30192000
Saarbrücken-Mannheim	139	[km]	6950	56712000
total				1075488000

New track lengths need to be installed along sections of the Atlantic Corridor which were stated in the Atlantic Corridor Annual reports. The Investment costs depend upon several factors. The first factor is the train speed taken as 100Km/h. The type of track which was considered as double track and the type of topography which was reviewed in accordance with Google maps to ascertain the topography type.

Table 75 Fixed Electrical Traction Substation installation and gross tonnage track maintenance costs

Fixed equipment for electric traction					Maintenance costs	total
Investments sub stations	[km]	[no.]	[€]		[€/year]	[€]
Serqueux Gisors	397	13	3599467		1800	3601266
Paris-Hendaye	805	27	7298667		3649	7302316
Spain	635	21	5757333		2879	5760212
Portugal	613	20	5557867		2779	5560646
total						22224440
Netherlands	435	-	-		76125	76125

Table 75 Shows the estimated costs for the estimation of the respective number of electrical traction energy supply substations that are expected to be installed along the respective track sections based on Atlantic corridor reports on expected projects. The maintenance costs are related to the speed that trains that travel over the respective tracks and the gross tonnage in

millions of gross kilotons per day of freight transported over the respective track, in accordance with base rates for these criteria.

Table 76 Electrical equipment control, catenary supply, and maintenance costs

	distance	Electrification Gauge	Signaling equipment	catenary	Maintenance costs	total
	[km]	[€]	[€]	[€]	[€/year]	[€]
Serqueux Gisors	397	142920000	142920000	59.55	1071.9	285841131
Paris Hendaye	805	289800000	289800000	120.75	2173.5	579602294
Spain	635	228600000	228600000	95.25	1714.5	457201810
Portugal	613	220680000	220680000	91.95	1655.1	441361747
total						1764006983

Table 77 displays the costs for the various section s requirements of electrical equipment for the gauge control for the track directions, lowering of floor tunnels raising of over passes, these costs are found from a rate of euros per km of track. The signaling equipment is for all telecommunication equipment type needed along the track and is based on a rate per track length. The catenary is according to the rate per track length and the type of catenary depends on the traction power type being supplied and they speed of trains on the track.

Table 77 Investment costs associated with signaling installations

Investments for signaling							
Signaling		Germany	France	Spain	Portugal	Total	Netherlands
Distance	[Km]	139	1388	635	313	2475	435
Cables	[€]	5004000	49968000	22860000	11268000	89100000	15660000
ABS	[€]	15012000	149904000	68580000	33804000	267300000	46980000
Spot repetition	[€]	2502000	24984000	11430000	5634000	44550000	7830000
Cab signal	[€]	2502000	24984000	11430000	5634000	44550000	7830000
Radio link	[€]	750600	7495200	3429000	1690200	13365000	2349000
Maintenance costs	[€]	34360.8	343114	156972	77374	611820	107532
total	[€]	25805100	257679702	117886607	58107886	459479295	80756967

The TEN-T European directives require investments to be made regarding ERTMS (European Rail Traffic management systems) Table 77 shows the estimated costs towards investments needed for rail signaling requirements. The cabling for signaling and telecommunication estimation cost is found by a rate per km. Similarly, the cost for the automatic brake systems (ABS) is found by the rate per block section. The rate for the ABS was charged for a unit catering for travel in both directions. The spot repetition is for the advanced train protection unit which is charged at a rate per traction unit. The same was for the Cab signal for automatic train control. The Radio link between train and dispatcher is at a rate per track length. The maintenance costs were assumed at 4% of the commission costs.