Miguel Simões Ferreira Nobre

Licenciado em Ciências da Engenharia e Gestão Industrial

The role of short sea shipping and European rail corridors in intermodal freight transportation

Dissertação para obtenção do Grau de Mestre em
Engenharia e Gestão Industrial

Orientador: Professor Doutor Tiago Alexandre Rosado Santos
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FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

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"It is not the strongest of the species that survives, not the most intelligent that survives.
It is the one that is the most adaptable to change."

Charles Darwin

Agradecimentos

Primeiramente, gostaria de deixar uma nota de especial apreço à instituição de ensino que me acolheu e que enriqueceu a minha formação académica, um muito obrigado à Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa.

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Abstract

This dissertation explores the possibility of combining short sea shipping with European Union rail corridors and inland waterways to carry freight towards regions located away from the coastline. The contributions of this dissertation is the expansion of a network model and the introduction of new transport chains in new areas not covered before. A review of intermodal transport policies in the European Union and of transport cost and transit time models in intermodal transport chains is carried out.

A network-based model of intermodal transport chains in the Atlantic façade of Europe is developed, including different combinations of modes of transportation (road, short sea shipping, rail and inland waterways). These models are applied to the quantification of total transport cost, transit time and a combination of both using value of time for creating a generalized transportation cost. Results are presented for transport chains from Porto and Bragança to 75 NUTS 2 regions (Nomenclature of territorial units for statistics) in northern Europe. The regions for which the different intermodal combinations are more competitive are identified. Parametric variations of critical transport parameters are carried out, allowing the identification of changes in the scope of regions for which the different intermodal combinations are more competitive.

The results obtained by the model identify the competitiveness of intermodal solutions using short sea shipping rail and inland waterways in the transport of freight. Intermodal solutions prove to be slow when comparing with road haulage, which proves to be cost competitive for certain regions.

Keywords: Short sea shipping, Rail, Inland waterways, Road haulage, Intermodal transportation, Network based model

Resumo

Esta dissertação explora a possibilidade de combinar o transporte marítimo de curta distância com os corredores ferroviários da União Europeia e vias navegáveis para transportar mercadorias para regiões distantes da costa. As contribuições desta dissertação são a expansão de um modelo de rede e a introdução de novas cadeias de transporte em novas áreas. É efetuada uma revisão das políticas de transporte intermodal na União Europeia e dos modelos de custos de transporte e de tempo de trânsito nas cadeias de transporte intermodal.

É desenvolvido um modelo baseado em rede de cadeias de transporte intermodal na fachada atlântica da Europa, incluindo diferentes combinações de modos de transporte (rodoviário, marítimo de curta distância, ferroviário e vias fluviais). Estes modelos são aplicados à quantificação do custo total de transporte, tempo de trânsito e uma combinação de ambos utilizando o valor do tempo para a criação de um custo generalizado de transporte. São apresentados resultados para cadeias de transporte entre o Porto e Bragança e 75 regiões NUTS 2 (Nomenclatura de unidades territoriais para estatísticas) do norte da Europa. São identificadas as regiões para as quais as diferentes combinações intermodais são mais competitivas. São realizadas variações paramétricas de parâmetros críticos de transporte, permitindo a identificação de mudanças no escopo de regiões para as quais as diferentes combinações intermodais são mais competitivas.

Os resultados obtidos pelo modelo identificam a competitividade das soluções intermodais utilizando os modos marítimo, ferroviário e fluvial no transporte de mercadorias. As soluções intermodais mostram-se lentas quando comparadas com o transporte rodoviário, mas competitivas em termos de custos para determinadas regiões.

Palavras-chave: Transporte marítimo de curta distância, Ferrovia, Transporte fluvial, Transporte rodoviário, Transporte intermodal, Modelo baseado em rede.

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List of abbreviations

CCNR - Central Commission for the navigation of the Rhine

CIP - Customer Information Platform

EC - European Commission

ECA - Emission control area

ECMT - European Conference of Ministers of Transport

EU - European Union

FEU - Forty-Foot Equivalent Unit

GTC – Generalized transportation cost

IA - Intermodal Analyst

IWW - Inland Water Ways

JIT - Just in Time

LO-LO - Lift-on-lift-off

MoS - Motorways of the Sea

NUTS Nomenclature of territorial units for statistics

Pap - Pre-arranged path

RFC - Rail Freight Corridors

RO-RO - Roll-on-roll-of

SSS - Short Sea Shipping

TEN-T - Trans-European Transport Network

TEU - Twenty-foot Equivalent Unit

VoT – Value of Time

1. Introduction

This first chapter is dedicated to framing the theme underlined in this dissertation and its due justification for choosing it. Subsequently, the objectives intended with the investigation and the methodology considered most appropriate for it is made. Finally, a brief summary of the dissertation structure is presented to facilitate the general understanding of the covered topics.

1.1 Study Background

The world is becoming ever more global, a fact evident in the time of propagation of the corona virus to the rest of the world. The world economy is going to face an enormous challenge to get back to where it was at the beginning of the crisis. Many companies will have to cut costs so it is necessary that when the transportation of cargo is made, it is in an efficient way.

Inherent to the globalization process there are opportunities that include access to new routes, the exploitation of knowledge worldwide, the possibility of participation in global transport networks and easier trade, for example the northwest passage which might facilitate the trade between the Atlantic and Pacific Oceans. However, this new paradigm challenges organizations to strategic restructuring to ensure agility and operational efficiency, along with the inevitable geographical expansion.

Freight transportation has become corner stone in the logistics industry and the time of transportation and its respective cost are important factors. When transporting products every company tries to find the best option. The option that is not only the cheapest but also the fastest according with the cargo that is being transported. A balance between these factors is quite difficult to achieve, so it is necessary to compare different ways of transportation.

Intermodal transport is an alternative to unimodal, especially to road transport. However since most terminals are not connected either by sea, rail or inland waterways (IWW) a road connection is needed for the transport.

There is an increase in the use of intermodal transportation, however the use of short sea shipping (SSS) in the Atlantic corridor is still very low, the competition between rail and road is high nevertheless there are certain issues in crossing from the Iberian Peninsula to mainland Europe. SSS seems a good alternative but it is important to make sure which are the unique determinants that impact significantly the transportation after the cargo has been switched from SSS to others modes, albeit it be IWW, rail or road.

In this dissertation four modes of transportation are selected, each being the dominant in several parts of Europe. Road haulage is the most used followed by SSS and then rail and IWW. However, even though IWW is the least used in Europe it provides great access to Rhine region of Germany, through the Port of Rotterdam in the Netherlands.

1.2 Justification of the theme and objectives of the dissertation

The relevance of the chosen theme comes from the more and more imperative analysis of the sustainability of the way freight is transported across Europe, as it contributes to the performance and efficiency of a logistics organization.

The transportation of goods to and from terminals is a dominant factor towards regional development, with the transportation of goods, they can be produced on one side of the world and sold on the other. This way they are transported to their final customer determines the final price. With this in mind, this dissertation aims to evaluate different ways of transporting cargo from Porto and Bragança to certain regions in northern Europe that are represented by the nomenclature of territorial units for statistics (NUTS) and determine which parameters dictate the choice of transport, and what mode favors those parameters.

The main objective of this dissertation is to analyze the sustainability of the use of SSS in freight transport and combining SSS with the other three methods of transporting freight. For this study transport cost and transport time are the main parameters chosen. The reason for this selection is that they represent a substantial share of the information required by governments and companies to make decisions regarding investment. As such it becomes important to study the costs, to evaluate the competitiveness of intermodal connections versus the usage of road haulage for single transport, also the change from road to intermodal. If practical would with almost all probability help to improve the environment.

Such a study will help the transport companies and relevant stakeholders to formulate strategies on the significant determinants and investment in the related projects.

The practical contributions of this dissertation are to expand the previous network model and the introduction of new transport chains in new areas not covered before, which will allow the analysis of their respective viability as well as the addition of IWW to the model.

1.3 Research methodology

For the development of this dissertation, the methodology is presented in the diagram in figure 1.1.

This methodology is divided into 7 parts: setting goals, research of the theme, the literature review, the understanding of the model, the research and analysis of data to be inputted in the model, the application of the model to the geographical location, finally, the analysis of results and presentation of main conclusions.

The detailed procedures for each stage are presented below:

1. Definition of objectives: this phase has already been presented in chapter 1.2. Justification of the theme and objectives of the dissertation.

2. Research of the theme: in this first phase, a brief study of intermodality and information about the four transport modes in the respective geographical conditions. As well as the impact of transport on modern logistics. And the role of high capacity modes of transport in promoting port regionalization.

3. Literature review: in this phase, research related to the parameters of transportation processes is made, with a focus on time and cost.

4. Understanding of the model: this phase will involve, firstly, the comprehension of the mathematics that go into the model.

5. Research and analysis of data to be inputted in the model: during this fase a an analysis of the intermodal hubs and the characteriscics of the modes of transportation.

6. Application of the model to the geographical location: in this stage a comparison of the numerical results provided by the model with hand calculations is made.

Finally, the main conclusions of the study are presented, through the analysis of results achieved through the model.

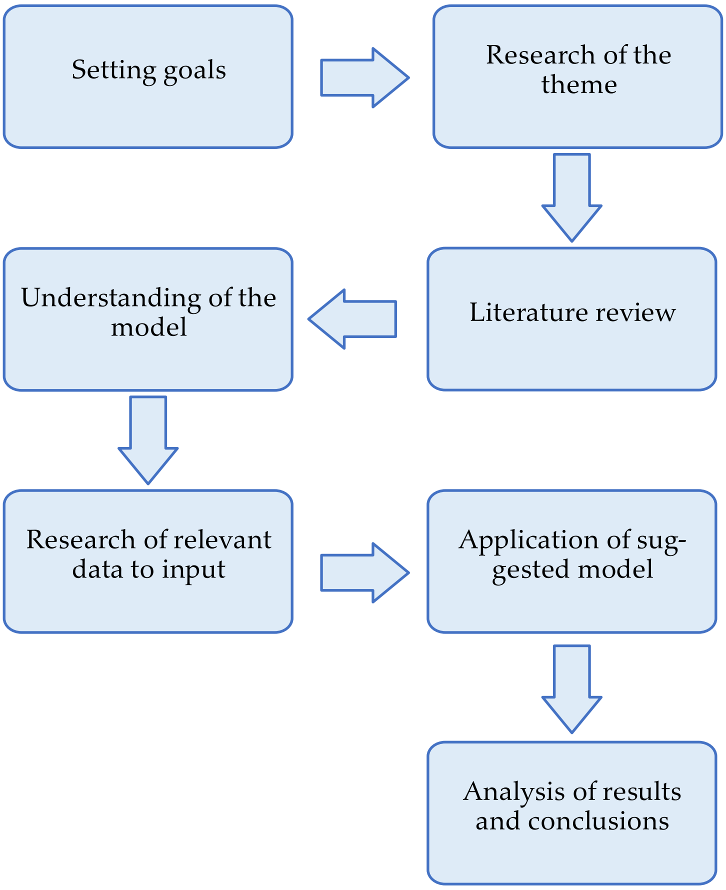

Figure 1.1 Methodology used in the dissertation

1.4 Dissertation Structure

For the remaining chapters of this dissertation the following will be covered:

Chapter 2 will firstly introduce intermodal freight transportation in the European Union (EU) as well as the different modes of transportation. It will also cover the importance of transport in modern logistics and Role of high capacity modes of transport in promoting port regionalization. In the end of the chapter it will cover the existing literature related to our research.

Chapter 3 will explain the mathematical model used to make the calculations for the regions, and the transport parameters.

Chapter 4 will present the Application of the model to intermodal transportation from Portugal to Northern Europe first by introducing the intermodal hubs, then by the transport network model. Followed by an explanation of the four paths the cargo might take and the validation of the model. Finally, it will proceed to the analysis and presentation of the results provided by the model.

Lastly, Chapter 5 concludes the research.

2 Literature Review

This chapter addresses fundamental topics for the perception of the studied concepts, according to scientific articles, theories and studies by various authors of reference. The content is presented in order to facilitate the understanding and identification of points relevant to the mechanisms and measures currently adopted.

2.1 Intermodality

Intermodality is a form of transportation which is becoming more used, consisting of combining different types of transportation. Reggiani *et al*. (2000) have compiled a list of definitions by the European Conference of Ministers of Transport (ECMT) and the European Commission (EC), the main definitions are for "intermodal transport", "multi-modal transport" and "intermodality".

Intermodal transport is the movement of goods (in one and the same loading unit or vehicle), which uses successfully several modes of transport without handling of the goods themselves in transshipment between the modes (Reis, 2014), while Multimodal transport is the carriage of goods by at least two different modes of transport (Multimodal Transport, 2019).

Intermodality is characteristic of a transport system that allows at least two different modes to be used in an integrated manner in a door-to-door transport chain. In addition, it is a quality indicator of the level of integration between different transport modes. In that respect more intermodality means more integration and complementarity between modes, which provides scope for a more efficient use of the transport system (Commission of the European Communities 1997).

To facilitate intermodality the EC has a Trans-European Transport Network policy whose objective is to close gaps, remove bottlenecks and technical barriers, as well as to strengthen social, economic and territorial cohesion in the EU (Pereira, 2019).

All types of transport with an exception of aerial transport have suffered a great transformation in international freight distribution chains. This part due to containerization which is one of the core pillars of globalization, allowing the use of intermodal transport since it allows cargo to be be switched from a transport mode to another with ease.

2.2 Short sea shipping

Short sea shipping does not have a unique definition, the European Union defines it by "the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe" (EU commission, 1999). Whereas the United States of America defines it "as waterborne transportation that does not cross an ocean" (MARAD, 2005). Sea transport in the EU accounts for approximately 31% of all cargo transported (Union, 2019).

According to Paixão and Marlow (2002), SSS uses four categories of ships: single decker's, container feeder vessels, ferries, and tankers or bulk carriers. A type that is becoming ever more used is roll-on-roll-off (RO-RO) this ship is a ferry designed to carry wheeled cargo, such as cars, trucks, semi-trailer trucks, trailers, and railroad cars if the ship is equipped with rails. The use of this ships are having an impact in transportation of goods, because when applied it follows certain rules that best take advantage of its characteristics it must be regular, reliable and integrated with door to door logistic chains, this concept is called Motorways of the Sea (MoS). This concept was first introduced in Europe in 1992 to connect Sicily and continental Italy (Lupi *et al.* 2017). The other type mostly used is lift-on-lift-off (LO-LO) these are usually single deck ships in which the cargo is transported in containers. When comparing RO-RO with LO-LO it is important to note that containers are a cheaper way of carrying goods, but they are also the slowest due to the inherent characteristics of their operations (Paixão and Marlow, 2002).

The use of SSS needs to have an interface with other types of transportation, which implies the prerequisite of having an effective inland transportation system.López-Navarro, (2013) analyzed the interaction between road transport firms and shipping companies in which shared planning improves the performance of road company performances.

A difference that has been mentioned in literature between SSS and road transport is the speed, which is significantly low on SSS. To counter this factor, the other periods of time such as loading and unloading should if possible be reduced which is why RO-RO ships are best suited when time is a significant factor, for their lower handling and dwell times in harbors (Paixão and Marlow, 2002).

SSS has been a focus of the European authorities (EC, 2011). An example is the creation of Marco-Polo programs with the aim of transferring freight from the road to sea, rail and inland waterways. However, these programs have been unsuccessful in the transference of traffic from the road to the sea and there is no concrete proof of the benefits to the environment if such a transfer did occur (European Court of Auditors, 2013).

Cullinane and Bergqvist (2014); Zis and Psaraftis (2017) have made a study on the impact of emission control areas (ECA) on shipping, the main factor being the fuel cost which may influence significantly the economic viability of SSS versus other types of transport.

SSS is the mode of transportation in which its speed varies significantly due to the state of the sea and winds, also the existence of ECA dictates the speed of the ship. Sambracos and Maniati (2012) considered the speed of typical RO-RO between 14 and 17 knots, Fagerholt *et al*. (2015) analyses speeds and fuel consumption within and outside ECAs. The ECA regulations imply that ship operators have to decrease vessels speed. When a ship reduces its cruising speed, the fuel consumption decreases significantly and so do the emissions. However, the slow speed implies a longer transit time which means that fewer deliveries will be made to combat this impact the number of vessels needs to be increased. According with Psaraftis and Kontovas (2010) containerships typically have higher speed as 25–26 knots as opposed to 14–15 of tankers and RO-RO ships. The type of SSS considered in this dissertation is RO-RO.

2.3 Inland waterways

Inland water ways are a way of offering an alternative to road and rail transport. According with the EC there are more than 37,000 kilometers of waterways that connect hundreds of cities and industrial regions. This way of transport is characterized for its reliability and energy efficiency. European rivers provide the places of some to the biggest and most developed capitals and cities, some of these cities were originally settled there because of the river which provided water and way of transport Mihic *et* *al.* (2011). IWW in the EU accounts for approximately 4% of all cargo transported (Union 2019). In figure 2.1 it can be seen the connections of IWW in central Europe.

When transporting cargo via IWW the roads used by these ships are rivers, canals or lakes. This way of transporting goods is considered economical, energy-efficient and environmentally friendly when compared to other transport modes especially road transportation, a downside of IWW is the speed of transport which is usually slow. It is suitable for the transportation of bulk, general and liquid cargo (Dávid & Madudová, 2019).

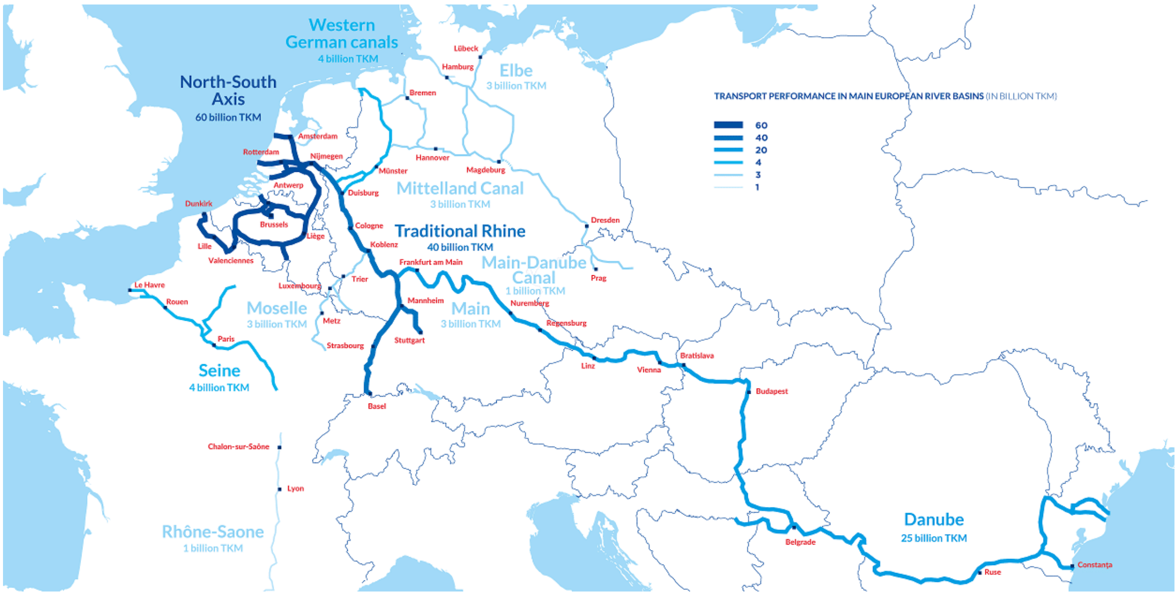

Figure 2.1 Inland waterways in Europe, source ((Central Commission for the navigation of the rhine, 2019)

In Europe a case of success in IWW transport is in the Netherlands in which approximately 40% of freight transportation is made by IWW (Union, 2019). The main reason for this is the existence of waterways. The majority of canals and rivers connect to the port of Rotterdam, which increases its hinterland significantly. To increase the use of IWW the EC proposes some measures with the objective of promoting transport by inland water ways (European Commission, 2001).

The IWW that will be used in modelling is the Traditional Rhine seen in figure 2.2 The river and most of its basin is considered an inland water way (IWW), in this dissertation the part that will be analyzed is the traditional Rhine (from Basel to the

German-Dutch border) it is the second longest river in Europe with about 1,230 km. In 2018, 165 million tons of cargo were transported. The river is divided in three parts the lower, the middle and upper Rhine.

Figure 2.2 Traditional Rhine, CCNR (2019)

Container transport on the middle and upper Rhine account for 49% of all transport performance of container transport on the traditional Rhine. The main products transported in decreasing order are mineral oil products, coal, building materials, iron ores, chemicals, food products, containers and metals. The main ships that operate in the Rhine river are dry cargo and liquid cargo vessels and push & tug boats. The number of vessels operating in 2018 was 9 702.

A problem that impacts transport is a low water period in which vessels have to limit their loads and container ships have to stop sailing. This was the cause in the decrease that can be seen in table 2.1, which resulted in a shift towards rail transport.

Table 2.1 Waterside traffic in major Rhine ports (million tons), adapted from (CCNR (2019)

	2016	2017	2018	2018/2017
Duisburg	55,6	52,2	48,1	-7,7%
Cologne	11,0	10,7	8,9	-17,6%
Neuss	7,7	8,0	7,6	-4,3%
Mannheim	8,7	9,7	7,5	-22,1%
Karlsruhe	6,2	7,2	6,4	-11,3%
Strasbourg	7,5	8,0	5,9	-26,4%
Basel	5,9	5,8	4,7	-18,9%
Mulhouse	4,9	4,8	4,4	-9,7%
Krefeld	3,2	3,4	3,3	-1,1%
Dusseldorf	1,8	1,7	1,6	-6,3%

IWW is by far the slowest mode of transportation. Nevertheless, it can achieve the speed of 12km/h which is the case of Basel-Rotterdam downstream link European Commission (2004). Furthermore, the CCNR (Central Commission for the Navigation on the Rhine) requires that all ships be able to achieve at least 13 km/h relative to the water.

2.4 European rail corridors

Rail transportation consists in the transport of cargo via rail. The EC has designated certain parts of the rout as a Rail Freight Corridor (RFC) which is defined as "a list of nodes – the principal "route" of the RFC. The RFC is further defined by the RFC governance structure through the designation of railway lines connecting the nodes and terminals. In 2010 the EC published the Rail Freight Corridor regulation (Regulation 913/2010). This regulation stipulates that exist 9 corridors these are described in table 2.2 Their objective is to promote clean fuel and other innovative transport solutions, advancing telematics applications for efficient infrastructure use.

Table 2.2 Rail freight corridors source: (Regulation (EU) No 913/2010 of the European Parliament, 2010)

RFC Corridors	Rail Freight Corridors Description
RFC 1	Zeebrugge-Antwerp/Rotterdam-Duisburg-[Basel]-Milan- Genoa
RFC 2	Rotterdam-Antwerp-Luxembourg-Metz-Dijon-Lyon/[Basel]
RFC 3	Stockholm-Malmö-Copenhagen-Hamburg-Innsbruck- Verona-Palermo
RFC 4	Sines-Lisbon/Leixões — Madrid-Medina del Campo/ Bilbao/San Sebastian-Irun- Bordeaux-Paris/Le Havre/Metz Sines-Elvas/Algeciras
RFC 5	Gdynia-Katowice-Ostrava/Žilina-Bratislava/Vienna/ Klagenfurt-Udine-Venice/ Trieste/ /Bologna/Ravenna/ Graz-Maribor-Ljubljana-Koper/Trieste
RFC 6	Almería-Valencia/Madrid-Zaragoza/Barcelona-Marseille- Lyon-Turin-Milan-Verona-Padua/Venice-Trieste/Koper- Ljubljana-Budapest-Zahony (Hungarian-Ukrainian border)
RFC 7	Bucharest-Constanta Prague-Vienna/Bratislava-Budapest — Vidin-Sofia-Thessaloniki-Athens
RFC 8	Bremerhaven/Rotterdam/Antwerp-Aachen/Berlin-Warsaw-Terespol (Poland-Belarus border)/Kaunas
RFC 9	Prague-Horní Lideč-Žilina-Košice-Čierna nad Tisou (Slovak/ Ukrainian border)

Rail transport in the EU accounts for approximately 11% of all cargo transported (Union 2019).

In this dissertation the RFC studied is the Corridor Rhine- Alpine (RFC1) figure 2.2, this rail network passes through 5 countries, has approximately 3,900 km of corridor lines, has more than 100 terminals and connects the port Genoa to the North Sea through the ports of Antwerp, Ghent and Zeebrugge in Belgium and Amsterdam, Rotterdam, Moerdijk and Vlissingen in the Netherlands. In 2019 more than 105 000 trains passed through this corridor (EEIG Corridor Rhine Alpine EWIV, 2019).

Figure 2.2 RFC 1 Zeebrugge-Antwerp/Rotterdam-Duisburg-[Basel]-Milan- Genoa

source: www.corridor-rhine-alpine.eu

The average speed of a train heading from north to south is 59.83 km/h, and 60.53 km/h for the opposite direction (Corridor Rhine Alpine EWIV, 2019). The trains follow a pre-arranged path (PaP) which is an international pre-constructed path based on standard parameters for rail freight and offered by the Corridor One-Stop-Shop on the basis of Articles 13 and 14 of EU Regulation 913/2010.

On this RFC PaPs are an assembly of several PaP segments and not an entire PaP from Rotterdam, Antwerp, Amsterdam, Vlissingen or Zeebrugge to Genoa. According to the "supply offer model" a PaP does not include terminals or other facilities however the connection from/to a terminal or facilities can be requested in the form of feeder/outflow paths which are paths that connect the origin / destination point of a freight train with the point where the train starts / ends to run on a pre-arranged path.

The corridor has a platform, the Customer Information Platform (CIP), this provides an interactive, internet-based information tool. With the use of a Graphical User Interface, CIP provides precise information on the routing, terminals and track properties, as well as infrastructure investment projects.

The specific part of the RFC that is of interest to this dissertation is the route between Rotterdam and Oberhausen, called the Betuweroute shown in red in figure 2.3.

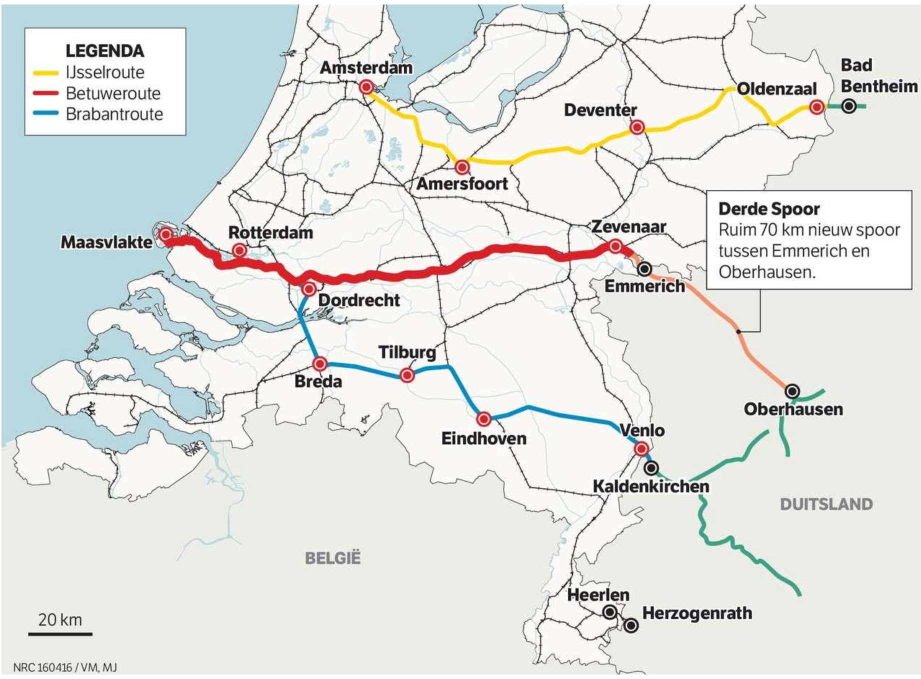

Figure 2.3 Track routes in the Netherlands with connection in Germany
Source:https://cms.dordrecht.nl/Inwoners/Overzicht_Inwoners/Projecten/Verkeersprojecten/Derde_spoor_Betuweroute

The Betuweroute, has 172 km of track especially for freight transport. However, the connection to the European rail network towards Oberhausen is not optimal. An additional, third track will be built along the line between Zevenaar and Oberhausen, allowing more trains to run on the line. This third track will be completed in 2026 at the earliest (Zaken, 2013). Transport on the Betuweroute has been growing steadily with its best year in 2014, when 25,100 trains passed. The prediction is that between 34,500-37,500 trains will pass along this route in 2025 (van Leijen, 2019).

Out of a total of 43,400 freight trains on all border crossings between the Netherlands and Germany, more than 50% are accounted for by the Zevenaar border crossing. Currently, there is room between Zevenaar and Oberhausen for a maximum of about 110 freight trains per day in both directions. The maximum is already reached on busy days. Therefore, further growth is not possible within the current capacity (Pro Rail 2016).

The forecasts from 2012 show that in 2020 there will be between 135 and 160 freight trains per day in both directions. The Betuweroute can handle this, but the track between Zevenaar and Oberhausen cannot. So a third track is being built, as well as a renovating and improving several parts of the original track (EEIG Corridor Rhine Alpine EWIV, 2019; Pro Rail 2016).

Rail transport speed in European RFC is variable according European Court of Auditors (2016) where the average speeds vary between around 18 km/h and 50 km/h depending on the RFC.

2.5 Road haulage

Road haulage consists in the transportation of freight by road. In this dissertation the roads considered are of three types: roads, motorways and urban roads (streets, avenues). The majority of the transport will be made using motorways. These roads connect the northern part of Portugal to Northern France, Belgium, Netherlands, Luxemburg and Germany and to the rest of Europe as it can be seen in figure 2.4.

Europe has always depended on roads for the transport of cargo as it is exemplified in figure 2.5, which shows the modal split in the European Union. Road transport in the EU accounts for a least 50 % of the transport of freight (Union, 2019).

Europe has a dense network of motorways. The majority of the development of the network occurred during the twentieth century and has stabilized in recent years. There is a greater density in the north and centre but, in general, there are good accesses to the highway from anywhere in in central Europe.

Figure 2.4 Roads from Portugal to northern Europe. Adapted from https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/en/maps.html

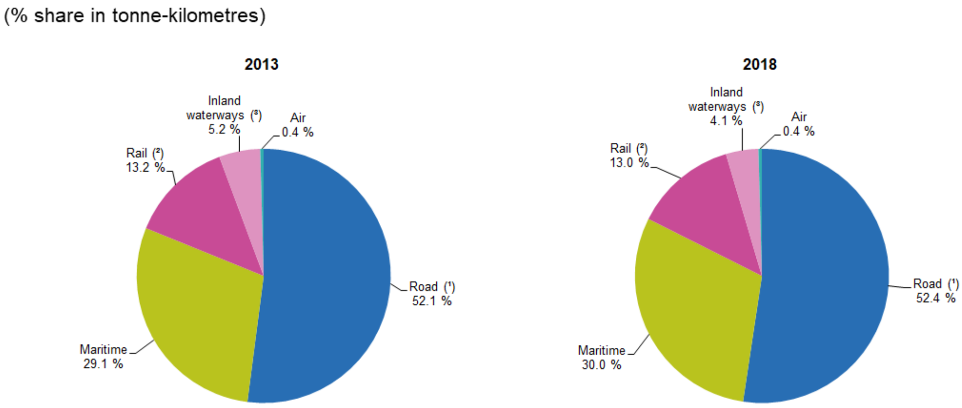

Figure 2.5 Modal split of freight transport EU 27 source: Eurostat 2018

The main reason why road transport is one of the most used transport modes is that when, comparing the initial investment costs, they are lower. For example, building a motorway is generally cheaper than building a railway. There is also a significant lobby behind road transport for it employs a large number of workers either directly and indirectly. It provides the ability to facilitate door to door logistics in which there is not time wasted in transferring cargo from one method to the other is also one of the fastest modes of transporting with the exception of aerial transport which helps when transporting perishable goods.

However there are certain disadvantages to the use of road transport which is responsible for the majority of greenhouse gases emissions when considering all types of transport it is responsible for approximately 73% of emissions (EEA 2016). With governments wanting a modal shift there is an increase in taxes. It is unsuitable for long distances as it is required by law that drivers rest and so it causes delays. If directly compared with train that never stops although slower due to the rest times, the train might be a faster solution and with a less chance of having accidents and breakdowns.

In road haulage the speed depends on traffic and the type of road it drives (Malta, 2015)as made a survey of the speeds a truck may travel between Portugal and Germany the average speed considered is 70 km per hour, as well as all the restrictions to circulation. The speeds limits permitted according with article 27th of the road code for heavy goods vehicles for road haulage are presented in table 2.1.

Table 2.1 Speed limits for road haulage per type of road

Type of road	Speed (Km/h)
Motorway	90
National Road	80
Urban Road	50

2.6 Transport in modern logistics

According with the council of supply chain management professionals (2013) logistics is:

The process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements.

Transportation is one of the most important sectors in logistics systems. Around one third to two thirds of the expenses of enterprises' logistics costs are spent on transportation (Tseng, Yue, and Taylor, 2005).

Transportation in Europe is responsible for 27% of CO2 emissions (European Environment Agency, 2017). In table 2.3 the Energy Use and CO_2 emissions can be seen by mode of transportation.

Table 2.3 Energy Use and CO_2 emissions per vehicle of transportation Source: Zou *et al.*, (2008)

Mode	Type	Energy Use (MJ/ton-km)	CO_2 Emissions (g/ton-km)
Truck	35 tons GVW (Gross Vehicle Weight)	1,34	100
	20 tons GVW	2,77	200
Train	Diesel	0,95	69
	Electric	0,83	38
SSS	Diesel	0,19	13
	Fuel Oil	0,17	12

Transport is a fundamental sector that helps to create and developing economies. Transport services embrace a complex system of around 1.2 million private and public companies in the EU, employing around 11 million people and providing goods and services to people and businesses in the EU and all over the world. Transport also provides mobility for Europeans, thus contributing significantly to the free movement of persons within the internal market (EC, 2019).

Transportation has an important part among the several steps that results in the change of resources into suitable goods in the name of the ultimate consumer. It is the planning of all these processes and sub-processes into a system of goods movement in order to minimize the cost and to maximize the service level to the customers that constitutes the concept of business logistics. The system, once put in place, must be effectively managed (Tseng, et al., 2005).

Transportation is fundamental in several processes to connect the raw materials to manufactures that transforms them into intermediary goods and, then, consumer goods. It is the good planning of all the transport between these stages of production that allows the minimization of costs and the maximization of service so that production never stops and there is a continuous flow of raw materials and finished products.

Like individual consumers, who expect to get shipments faster so do industrial customers, as well as more flexibly, and with more transparency at a lesser price. No surprise that across the industry, both operating models and profitability are under a continuous tension. The pace of transformation for large manufacturing and retail customers may turn out to be even faster than for private final consumers, mostly due to the fact that companies are changing their production systems to just in time (JIT). This implies that the transport system needs to be almost flawless, so that companies mat expect receiving the products as they are needed, rather than days before. This allows businesses to significantly cut inventory costs by having fewer supplies on hand and far less material to store, (Veselko & Jakomin, 2006).

Since some transport companies cannot compete at that level and keep a profit, their customers tend to expand their own business to include logistics offerings to fill their own needs and beyond, successfully moving from customers to competitors. They purchase small logistics companies to help cover major markets, and use their own understanding of customer behaviour to optimise supply chains (Tipping & Kauschke, 2016).

2.7 Transportation role in promoting port regionalization

In today's economy a port plays a pivotal role in logistics which leads to its growth. However most of the time there is not sufficient physical space for its expansion, so a regionalization tends to occur. Port regionalization happens in part due to the expansion of its hinterland. This expansion is caused by the development of intermodal corridors of both rail and barge and sometimes road. These corridors connect the ports to inland terminals these are responsible in part to a shift from road transport to intermodal solutions. With these terminals, part of the distribution function of ports is transferred away from them allowing a reduction in the congestion of roads entering and leaving the ports proximity (Notteboom, 2009).

With this expansion, the hinterland, becomes discontinuous, sometimes by creating an "island" (figure 2.6) in another port hinterland, which increases the competitiveness among ports in close distances.

The use of inland terminals has several advantages, for they usually have lower land costs, which allows that they serve as depots which helps with the problem of the empty leg, so that the modes of transport if possible always have the possibility of carrying cargo. They are also expected to increase their role in supply chains, as there is an increasing pressure on capacity for storing freight. Terminals will play a more active role in supply chains in the near future by increasing the challenge on logistic players with the aim of optimizing terminal capacity and make the best use of the land, by providing a better dwell time charges, truck slots, etc (Notteboom, 2008).

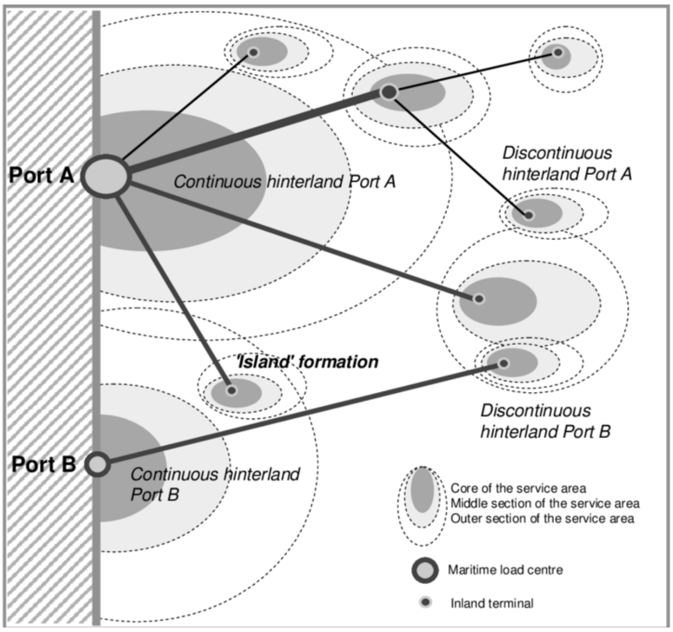

Figure 2.6 Hinterlands and islands source: Notteboom, (2009)

Figure 2.7 provides an outline of the main multi-port gateway regions in Europe as well as transhipment hubs and stand-alone gateways. Comparisons of container throughput figures are classically based on individual ports. This might be misleading when analysing the gateway function of specific port regions. An alternative approach consists in grouping load centres within the same gateway region. These gateways are nodal points where intercontinental transport movements are being transhipped onto continental areas and vice versa together to form multi-port gateway regions. The locational relationship to nearby identical traffic hinterlands is one of the criteria that can be used to cluster adjacent load centres (Notteboom, 2008)

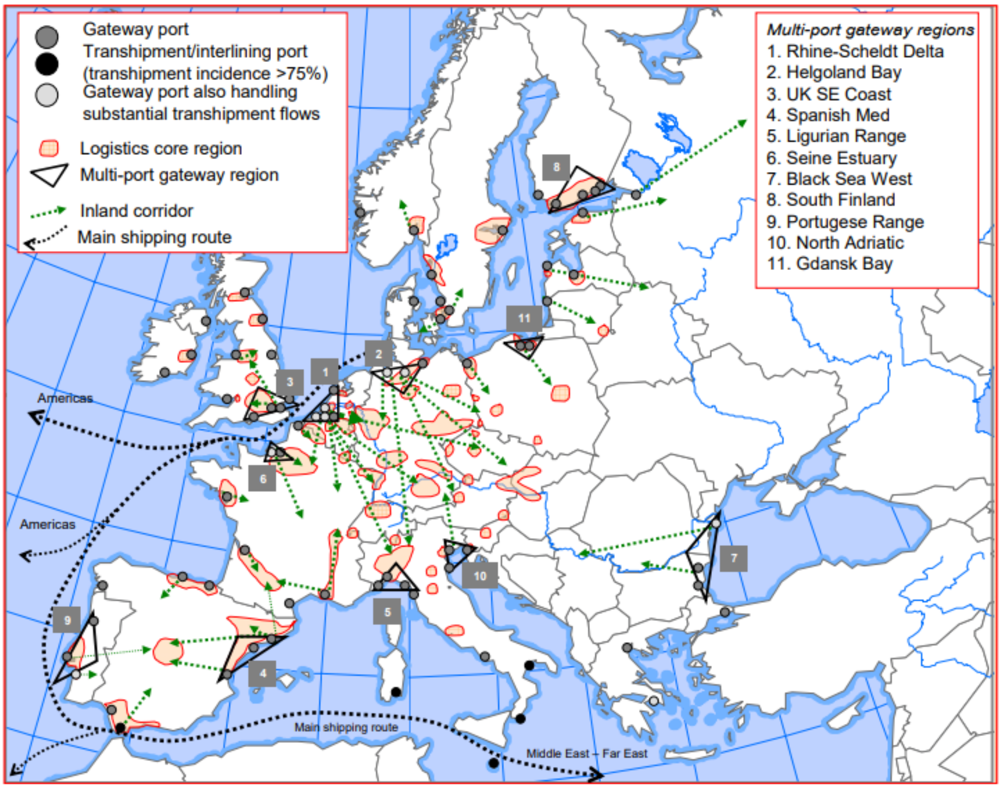

Figure 2.7 The European container port system and logistics core regions in the hinterland source: Notteboom, (2008)

Regionalization represents a new stage in the development of ports, which have usually focused on the area around the port. In this stage, inland distribution is of prime importance in port competition, favoring the appearance of transport corridors and logistics poles. The port of Rotterdam is already well advanced in its hinterland expansion, as it has an extensive network of intermodal transport connections: rail, inland shipping, road, and pipelines. This dissertation will analyze if it is practical for cargo originating from the area around Braga or Bragança to take advantage of this extensive intermodal network to reach locations deep inland across Northern Europe.

The port themselves are not chiefly responsible for and instigating regionalization. Regionalization itself comes from a long process of logistics decisions and subsequent actions of shippers and third-party logistics providers. According with Notteboom and Rodrigue (2005), ports are advised to embrace and enhance the regionalization process with the main goal of solving certain port-related problems, mainly congestion, growing costs, limited handling capacity and the generation of additional traffic while being able to answer the requirements of modern freight distribution.

The connections and their capacities are the ones that are mainly responsible for their size for, without the capacity to transport cargo, inland ports would not be able to compete in today's economy (Notteboom & Rodrigue, 2005).

2.8 Main parameters in decisions on modes of transportation in logistics

Studies have been made comparing SSS with road transport. For example, Lupi *et al*. (2017) compares MoS with road transport. In this study, monetary cost and travel time are the most important decision parameters, but the authors note the lack of supply of MoS routes in the geographic area under study.

According with Combes (2012), shipment size choice and freight mode choice are simultaneous decisions. A parameter that is highlighted is the rate of the commodity flow in which value of time and commodity type are not the only ones.

Due to an increase in road congestion problems in the region of the port of Rotterdam to its hinterland, Pielage *et al*. (2007) think that a shift from road transportation to other modes is likely to happen in their proposal for a more efficient hinterland container transport a barge hub terminal is necessary and would facilitate the IWW transport of cargo to mainland Europe. Macharis and Pekin (2009) presents a geographic information system (GIS) based model that integrates IWW, rail and road in Belgium including intermodal terminals. Wiegmans, Witte, and Spit (2015) provide an analysis in Inland waterways ports development in the Netherlands. Meers *et al*. (2017) findings suggest reliability is a factor necessary to even consider certain alternatives, not only the cost.

An important factor as well is the speed of the transport mode. Table 2.4 shows an average speed in km per hour for transport modes, by Pekin *et al*. (2013). Some of these values match the previous analysed values with the exception of rail.

Table 2.4 Average speed in km per hour for transport modes, source: Pekin *et al*. (2013)

Transport mode	Average speed (km/h)
Unimodal road	60
Post haulage	35
Rail	25
Inland navigation	11

2.9 Internal and external costs

According to Janic (2007) "the external costs are costs that networks impose on society, including environmental cost". The European authorities have being concerned with environmental cost, which is why recently the EC has outlined a target reduction of 60% in greenhouse gas by 2050, (European Commission, 2011), which may imply tariffs in road transportation to try to reduce road transportation and cause a shift to less polluting modes of transportation. Maibach *et al*. (2008) adds other costs such as nature and landscape, soil and water pollution, costs in urban areas, up and downstream processes, costs in sensitive areas and costs of energy dependence.

Santos and Soares (2020) have made a review of external cost calculations in which is indicated two ways of calculating these costs: "bottom-up and top-down" and their respective upsides and downsides. Other approach to the calculation is presented in Tzannatos *et al.* (2014) where percentages are allocated to external costs. Also in Tzannatos *et al.* (2014), it is concluded that SSS is not more environmental friendly as road transport due to the quality of truck engines. Mostert and Limbourg (2016) have made a literature review of external costs focusing mainly on land transport.

Internal costs are the ones that are inherent to the transport itself and the vehicle of transport. Tzannatos *et al*. (2014) separates the costs into the variable cost and fixed cost each associated with a mode of transportation. On road transportation the variable costs include: vehicle's maintenance and repairs, road tolling costs, cost of fuel, cost of lubricants and cost of tyre replacement. The fix cost includes insurances, taxes, maintenance, personnel cost and the purchase cost. On SSS service, the fixed costs include crew cost, vessel's insurance, general expenses associated with administration and office cost, and the variable fuel costs (Tzannatos et al. 2014).

The cost of transportation is a very important factor when choosing the mode of transportation. Costs, in general, will include pre-haulage and post-haulage costs, port costs and ship (rail) freight costs. The bunker adjustment factor was cost that, in previous studies such as Santos and Guedes Soares (2020), was taken to account for high level of fuel costs. However, since there has been a decrease in fuel cost, this cost is less relevant.

2.10 Value of time in freight transportation

Morisugi (2017) defines value of time (VOT):

As marginal substitution rate between price and time and expressed it as the freight service fee per freight time multiplied by the elasticity of quality level indicator with respect to freight time for each of nonbusiness users and business users, respectively.

This value will influence the results of the study significantly (Feo *et al.*, 2011) this value represents the cost of time so, if it is an elevated number, it will prefer lower transit times and, if it is lower, longer transit times.

Izadi *et al.* (2020) made a literature review in which, according with Accent and Hague Consulting, a 1% increase in the probability of delay of 30 or more minutes is equivalent to 0.45–1.8 Euro per transport.

Also, in the same literature review Kurri *et al.* (2000) established an average value of time for road and rail transport for selected commodities and for the value of average delay. Pekin *et al*. (2013) analysis the VOT when choosing between intermodal and unimodal transportation.

2.11 Numerical models of transport cost and transit time

Lupi *et al*. (2017) model analyses the competitiveness between MoS and road transport in which the journey is divided into links. Each link depends on being maritime or road, has a monetary cost and transit time. The maritime link also has a waiting time. Russo, *et al* (2016) uses an aggregate discrete choice model, to simulate the split between RO-RO and LO-LO services.

Lim and Thill (2008) and Thill and Lim (2010) use nodes and links to model road and rail networks, to measure accessibility across the USA from different parts of the world based on transportation costs. The model also includes connections between the two types of transportation, so that a route can have several combinations of means of transportation. Santos *et al.* (2019) has a model to evaluate the competitivity in multimodal transport solutions using SSS, rail, IWW and using road transportation to connect to multimodal terminals.

Frémont and Franc (2010) have a study comprising of the analysis of IWW and road transport versus the single solution of road transport from the port of Le Havre to the regions around Paris.

Costs in transportation come in different forms such as €/ Twenty-foot Equivalent Unit (TEU). km, €/Forty-Foot Equivalent Unit (FEU).km, €/trailer.km, €/ton.km or even per movement. RECORDIT (2003) has made through analysis of the costs including internal and external and using intermodal transportation and all road transport. Santos *et al.* (2019) attempted to summarize a literature review in relation with transport costs in the EU Table 2.5.

Table 2.5 – Transportation costs (€/FEU.km), source: Santos *et al*. (2019)

	Road – short distance	Road – medium distance	Road – long distance	Rail	Inland waterways	Short sea shipping	Deep sea shipping
RECORDIT (2003)	1.23-3.78	-	0.94-1.16/0.75-0.89	0.46-1.35	0.26	0.54-1.67	-
Schade *et al.* (2006)	-	-	0.45 Eastern Europe; 1.1 Western Europe	0.5 Eastern Europe; 1.2 Western Europe	-	-	-
Janic (2007)	-	-	0.72	0.6	-	-	-
Panagakos and Psaraftis (2017)	-	-	-	1.12	-	2.18	-
Maritime Executive (2017)	-	-	-	1.29-1.44 (in US)	-	-	-
Searates (2018)	2.0-13.0	1.3-4.0	1.0-3.0	1.5-3.0	-	-	-
Kreutzberger (2010)	-	-	-	0.46-0.68	-	-	-
Notteboom (2008)	4.0	1.5	-	-	0.5-1.5	-	0.12
European Court of Auditors (2015)		2.6	1.6	1.3-2.9	0.4-0.5	-	-
KombiConsult *et al.* (2015)	-	-	-	-	0.7-0.9	-	-
Shortsea Promotion Center (2012)	-	-	0.95-1.1	-	-	0.88-1.05	-

3. Intermodal transport model

3.1 Numerical tool Intermodal Analyst

In order to analyse the different intermodal transport chains, the software used is Intermodal Analyst (IA), it is in version 2.0. This software was developed in the beginning of 2016 in the research unit CENTEC of IST, University of Lisbon. This software is a research tool, it is coded in Fortran, and runs through an executable file. The main purpose of the software is to calculate the cost and time of transport between an origin and a destination. The origin is considered to be a point in space where the cargo is loaded on a mode of transportation and the destination is the point in space where the cargo is unloaded. It uses a transport network model exemplified in Figure 3.1.

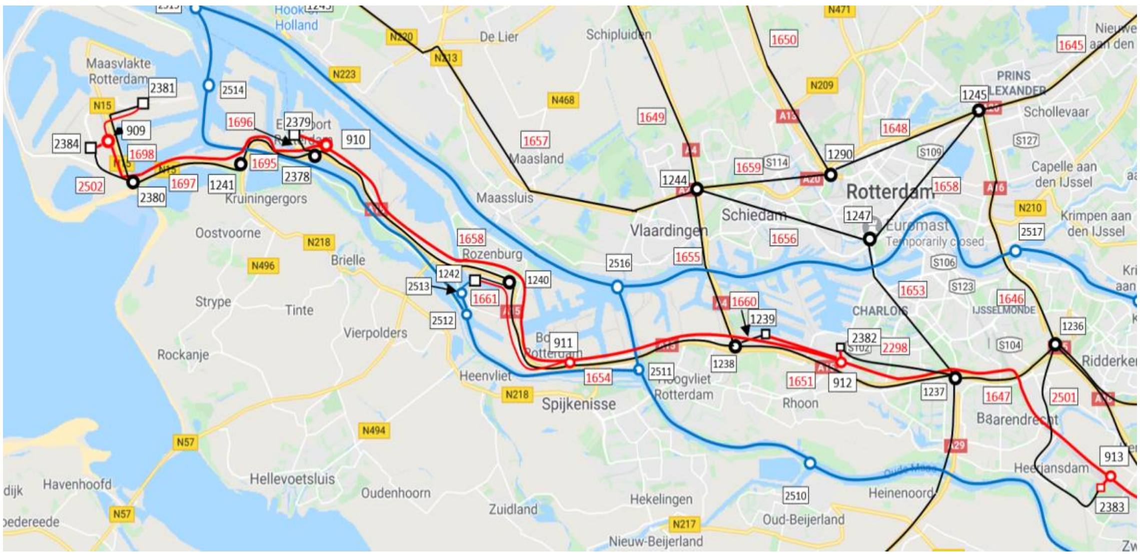

Figure 3.1 Transport network model.

This figure shows only part of the existing model, mainly covering the area of the port of Rotterdam. The complete model covers countries in western Europe, from Portugal to Germany, and also the United Kingdom and Ireland. The road network covered in this model corresponds mainly with that included in the Trans-European network (core and comprehensive network) while the rail network includes only relevant rail freight corridors and the Portuguese network. Inland waterways include the Rhine river up to Duisburg and Douro river. Most European ports in the core network are also included. This model had already been built but it was refined and completed for the area between Rotterdam and the Ruhr area in Germany, especially as regards the rail and inland waterways connections with Rotterdam.

The voyage undertaken by the cargo may be unimodal or intermodal and the typical cargo unit if a full truck load is considered it is equivalent roughly to a Forty Feet Unit (FEU). The modes of transport available in the transport network are the road, rail, maritime (container ship or RO-RO ship) and IWW (barge). As explained above, the software does not cover the initial and last mile, thus enabling a coarse modelling of the road network across a vast geographical extent. In Portugal, road network is modelled as far as needed to fully connect each municipality to ports and other countries. In Spain (provinces of Zamora, Salamanca, Caceres, Badajoz) the road network is modelled to the same detail level as Portugal. The rest of Spain is modelled so that capital cities of provinces are fully connected to the network. For the rest of the covered EU countries, the core and comprehensive road network are the red roads, all major city (including NUTS 2 capitals) are fully connected. In this dissertation the rail and IWW network was from Rotterdam to Duisburg/Oberhausen it is further explained in chapter 4.2.

Figure 3.2 is a flowchart of Intermodal Analyst. The input data files for the network database are the nodes database and the links database. These files tare inputted into this program in text format and its details may be seen in figures 3.3 and 3.4 respectively.

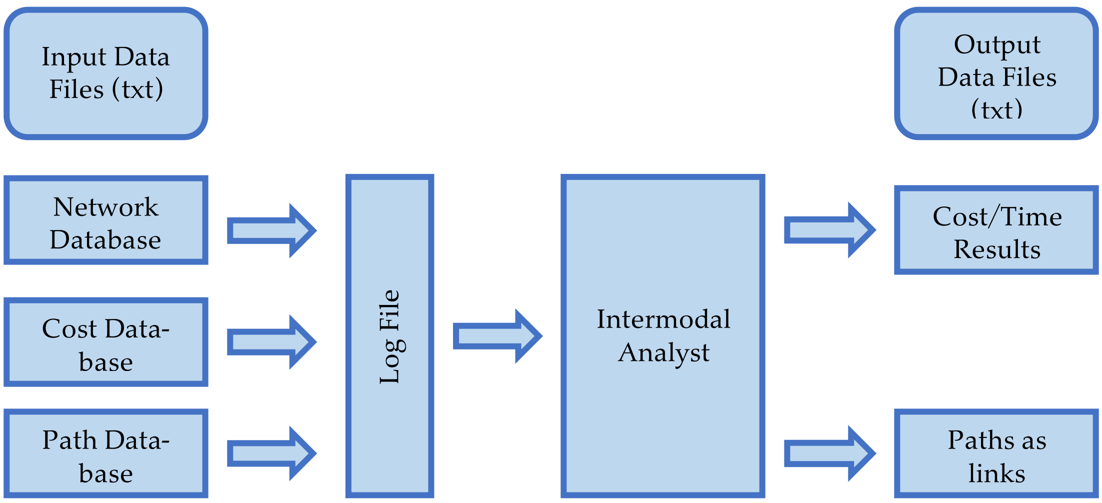

Figure 3.2 Flowchart of Intermodal Analist

Nodes are characterized by time delays (representing dwell time in hours) and costs (cargo handling costs in euros). The majority of nodes have these values as zero, the ones that have values are intermodal hubs where there is a change of transport modes. Links are characterized by distance between nodes in kilometers, type (road, motorway, maritime, rail, inland waterway), speed between nodes in kilometres per hour, congestion level and country. Congestion level is not applied in this dissertation A database has been developed containing all these parameters and an extract from this database is shown in figure 3.5.

Model of Transport Networks in European Union and Morroco---
Number Nodes
3326

NumNode	Name	Country	Type	Active	CostUnload	CostLoad	Time	FreeTime	TimeCost	TimeCall
1	Alcabiceche	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
2	Ranholas	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
3	Belas	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
4	Queluz	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
5	EstadioNac	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
6	CruzQuebrada	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
7	Alges	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
8	Caselas	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
9	Benfica	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0
10	BaixaLoures	PT	RR	1	0.0	0.0	0.0	0.0	0.0	0.0

Figure 3.3 Extract from nodes database

In order to calculate the transport time between an origin/destination let us consider a path p which is a sequence of links. For each origin/destination pair several paths exist and may include different modes of transportation, which are modelled as sub-paths.

The path is characterised by L links. These exist in a network database. An extract is presented in figure 3.6 where type indicates the type of link which can be: R-road, M-motorway, U-urban road, F-rail, I-IWW, C-container ship, S-RO-RO. The zone where a link is located may be either R-rural, S-suburban or U-urban. Direct is if it has traffic in both ways. Count is for the country and ECA is if it passes through an ECA.

The cost database is presented in figure 3.5, the values of this database are explained in depth in chapter 3.3. Certain values are not used in this dissertation such as margins for competition. The units used in the data base are Kilometers for the distances, and for cost is €/TEU.h. This cost functions are better understood in graphical form in figure 3.8.

```
NumLinks
4168
Numlink Active Node1 Node2 Type Zone  Direct Count ECA    Descri                      Distance  Speed
1       1      65    1     R    S     1      PT    N      Cascais                     5.0       60.0
2       1      1     3238  M    S     1      PT    N      CascaisToEstadioNac         11.0      80.0
3       1      92    3238  U    U     1      PT    N      OeirasToEstadioNac          3.0       40.0
4       1      5     6     M    S     1      PT    N      EstadioNacToCruzQuebrada    2.5       80.0
5       1      6     7     U    U     1      PT    N      CruzQuebradaToAlges         3.0       40.0
6       1      7     20    U    U     1      PT    N      AlgesToNoAlcantara          6.0       40.0
7       1      5     8     M    S     1      PT    N      EstadioNacToCaselas         5.0       80.0
8       1      8     7     M    S     1      PT    N      CaselasToAlges              2.5       80.0
9       1      5     4     M    S     1      PT    N      EstadioNacToQueluz          6.0       80.0
```

Figure 3.4 Extract from links database

```
Definition of costs of transportation ----------------------------------------------
Road
18
1.0   10.0  20.0  30.0   40.0  50.0  60.0  75.0  100.0 200.0  300.0  500.0  1000.0 1500.0 2000.0 2500.0  3000.0  3500.0
8.0   7.0   6.0   5.0    4.0   3.5   3.0   2.6   2.1   1.65   1.5    1.3    1.0    1.0    1.0    1.0     1.0     1.0
Rail
14
1.0   10.0  20.0  100.0  140.0 260.0 360.0 460.0 700.0 1000.0 1500.0 2000.0 2500.0 3000.0
1.80  1.70  1.70  1.20   1.00  0.75  0.55  0.47  0.47  0.47   0.47   0.47   0.47   0.47
Inland Waterway
10
1.0   10.0  20.0  100.0  140.0 260.0 360.0 1000.0 1500.0 2000.0
1.60  1.50  1.50  1.05   0.80  0.65  0.60  0.52   0.52   0.52
Short Sea Shipping (RoRo)
10
1.0   50.0  100.0  200.0  500.0 1000.0 1500.0 2000.0 2500.0 3000.0
10.50 7.00  4.50   2.50   1.50  0.90   0.60   0.30   0.30   0.30
Container
10
1.0   50.0 100.0  200.0  500.0 1000.0 1500.0 2000.0 2500.0 3000.0
8.50  5.5  3.00   1.90   1.20  0.70   0.40   0.20   0.20   0.20
Correction to road costs PT,ES,FR,BE,ND,DE,LU,UK,IR,SE,DK,IT,GR,MA
1.00 1.00 1.50 1.50 1.50 1.50 1.50 1.00 1.00 1.00 1.00 1.00 1.00 0.50
Margins for competition in cost (%)
15.0 30.0
Margins for competition in time (%)
15.0 30.0
Time value in money (Euro/TEU.h)
6.82
Daily rest (h) and break rest (h)
12.0 0.75
End of definition of cost of transportation ---------------------------------------------
```

Figure 3.5 Cost database

Figure 3.6 shows an extract of the numerical results file. It is with these results that the analysis will be made. This file provides several results, not just time and cost of transportation but provides several other results such as the distances in road: the total distance and the distance from the origin to the port of Leixões. It also provides the distance for the others modes of transportation as well as the time in each one. The total time in ports/terminals is also provided as well as the total time in transit. The costs for each mode of transportation are discriminated. Finally, the total transport cost, total transit time and the generalized transportation cost (GTC) are presented.

Results from SHORTSEACHAIN-----------------------
Data files: DbTrans8(6)(c)(9)(1).txt Rotterdam\DBPathRott2.txt Rotterdam\DbCostRott.txt

NodeOri	NodeDest	SetName	PathNum	DistRd	DistRd1	DistFr	DistIW	DistSS	DistCC
538	2300	1RoutePortoStuttgart	101	2262.60	0.00	0.00	0.00	0.00	0.00
538	2300	1RoutePortoStuttgart	102	640.30	9.20	0.00	0.00	1720.00	0.00
538	2300	1RoutePortoStuttgart	103	445.60	9.20	216.40	0.00	1720.00	0.00
538	2300	1RoutePortoStuttgart	104	450.20	9.20	0.00	234.60	1720.00	0.00

DistCC	TimeRoad	TimeFr	TimeIW	TimeSS	TimeCC	TimePauses	TimePorts	CostRd	CostFr	CostIW	CostSS
0.00	29.68	0.00	0.00	0.00	0.00	38.25	0.00	2488.86	0.00	0.00	0.00
0.00	8.25	0.00	0.00	62.50	0.00	0.75	12.00	868.56	0.00	0.00	804.96
0.00	5.81	3.61	0.00	62.50	0.00	0.75	18.00	660.55	166.23	0.00	804.96
0.00	5.89	0.00	21.08	62.50	0.00	0.75	18.00	665.87	0.00	134.00	804.96

CostSS	CostCC	CostTolls	CostTrans	CostHand	CostTot	Time	GTC
0.00	0.00	0.00	2488.86	0.00	2488.86	67.93	2952.13
804.96	0.00	200.00	1873.52	150.00	2023.52	83.50	2592.97
804.96	0.00	200.00	1831.74	200.00	2031.74	90.67	2650.13
804.96	0.00	200.00	1804.83	200.00	2004.83	108.22	2742.86

Figure 3.6 Extracts of the results file

While the transport network database is a single file, a different path database was created for this study. A fragment of one path database is shown below in figure 3.7. Each line corresponds to a path between a cargo origin and destination. As there might be several possible paths between this pair these have been grouped in 4 possible paths between Porto (Portugal) and Stuttgart (Germany). It is with these paths that the calculations will be made. The first one is just road while the others will use the ship, rail, inland waterways.

Multiple pairs origin-destination may be assessed in a single run. The transport operation is supposed to cover a significant distance, either in national or international voyage, in this case an international one. It is recognised that cargo may be loaded in a point of consolidation (logistic company facility) and taken up to a another such facility for de-consolidation. These initial and final stages are generally neglected when using this software, as these comprise smaller distances compared with the main haul.

```
Definition      of      Paths   Database-------------------------------------------
Num     sets    of      paths
75
1RoutePortoStuttgart
4
101     1       83      538 620 540 541 528 526 523 521 520 516 466 468 508 509 478
102     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 1240 1238
103     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 911 912 91
104     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 2512 2511
2RoutePortoKarlsruhe
4
201     1       83      538 620 540 541 528 526 523 521 520 516 466 468 508 509 478
202     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 1240 1238
203     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 911 912 91
204     1       83      538 539 619 628 783 3322 3323 3324 3325 3326 1242 2512 2511
```

Figure 3.7 Fragment of a path database

3.2 Mathematical model

Road, SSS, Rail and IWW networks are modelled using nodes (road junctions, seaport terminals, intermodal hubs) and links (roads, motorways, maritime routes, rail tracks and canals) the objective of the model is to calculate the time, the cost and the GTC.

3.2.1 Time calculation

For the calculation of the time it was needed certain variables: the distance (length) D_{l_i} and an average speed S_{l_i}. The variable δ_{l_i} indicates whether the link *i* is operational or not, whereas the variable δ_{p_i} indicates whether link *i* is used in path *p*. A third variable, δ_{Rd_i}, identifies the type of link *i* as being of road or not these variables are binaries taking the value of 1 or 0. Considering these definitions, the transportation time taken by a cargo unit along a given path using road type links, T_{RDp}, is given by the following summation over all links existing in the database:

$$T_{RD_p} = \sum_{i=1}^{L} \delta_{l_i} . \delta_{p_i} . \delta_{Rd_i} . \frac{D_{l_i}}{S_{l_i}} \tag{3.1}$$

For road another time needs to added which is made according with the time on the road for successive links. This time is the rest time that is added after the time on the road for every 4 hours a 45 minutes break is added and after 9 hours a 12 hours day rest time is also added, this is only for road transport. The transportation time taken along path p is then given by:

$$T_{TR_p} = T_{RD_p} + T_{RL_p} + T_{IW_p} + T_{RR_p} \tag{3.2}$$

where time taken in links of other types, namely rail, inland waterways and maritime (using RO-RO ships), denoted as, respectively, T_{RL}, T_{IW}, T_{RR}.

The average time in each node needs to be considered therefore, equation (3.3) defines the total time between an origin and a destination using a certain path as the sum of actual transportation time, given by equation (3.2), with the time taken in nodes j along the path:

$$T_p = T_{TR_p} + \sum_{j=1}^{N} \delta_{p_j} . T_{Dw_j} \tag{3.3}$$

where δ_{p_j} is a binary variable representing whether or not node j belongs to the path p. T_{Dw_j} represents the average dwell time in node j.

3.2.2 Cost calculation

A similar process is used for calculating the total cost of freight transportation in each path. Firstly, the total distance travelled in path p is determined, D_{RD_p}. In the case of road transportation, the total distance travelled is given by:

$$D_{RD_p} = \sum_{i=1}^{L} \delta_{l_i} . \delta_{p_i} . \delta_{Rd_i} . D_{l_i} \tag{3.4}$$

The cost, C_{RD_p}, associated with such distance is then calculated by:

$$C_{RD_p} = D_{RD_p} . c_{RD} \tag{3.5}$$

where the cost coefficient c_{RD} is taken from the cost database in figure 3.5 . This coefficient is obtained by interpolation over a non-linear function of specific cost $f\left(D_{RD_{kp}}\right)$ (monetary units per km for a cargo unit). The function of specific costs is specified in a way that it is representative of current market values for the different modes of transportation. The same principle is applied to calculate the costs of other modes of transportation in the path, which are represented by C_{RL_p}, C_{IWW_p} and C_{RR_p}. The first for rail cost, the second for IWW cost and the third for SSS cost.

The total transportation cost is the sum of the costs associated with each mode of transport:

$$C_{TR_p} = C_{RD_p} + C_{RL_p} + C_{IWW_p} + C_{RR_p} \tag{3.6}$$

While the total transportation cost is the summation of the cost incurred in the transportation operations plus costs associated with transfers between transport modes occurring in nodes of the network:

$$C_p = C_{TR_p} + \sum_{j=1}^{N} \delta_{n_j} \delta_{p_j} . \left(C_{u_j} + C_{l_j} + C_{s_j}\right) \tag{3.7}$$

Where C_{u_j}, C_{l_j} and C_{s_j} represent the unloading, loading and storage costs in node j , δ_{n_j} is a binary variable which indicates whether or not node j is active and δ_{p_j} is a binary variable which indicates if node j is used in path p .

3.2.3 Generalized transport cost calculation

The total transportation time and cost on a given path, p, are combined to produce a generalized transportation cost (GTC), GTC_p, given by:

$$GTC_p = C_p + VoT . T_p \tag{3.8}$$

where *VoT* represents the value of time for the cargo in monetary units per hour.

3.3 Transport parameters specification

Table 3.1 shows the load/unloading costs and dwell times in seaport and intermodal terminals. Costs applicable to seaport terminals have been taken from port tariffs, see for example LISCONT (2020). Costs applicable to intermodal terminals have been taken from Infraestruturas de Portugal (2015) and when not available, taken in line with the values shown in Black et al. 2003 and P. Martins, 2015.

For a comprehensive review of cost parameters in intermodal operations, see Santos *et al*. (2019). The RO-RO terminal has a dwell time of 6 hours. These values vary significantly between terminals and countries, and the values taken here are below those given in PIANC, (2014), but this was found to be feasible within the scope of SSS.

Regarding dwell times in rail and IWW terminals, Martins (2013) indicates that the full transfer of cargo between trains (with 32 cargo units) may take 8 hours. Therefore, it is reasonable to assume that in Germany an average dwell time of cargo units of 6 hours is feasible and in Portugal twice as much (12 hours). For IWW terminals, it is reasonable to assume that the average dwell time would be slightly larger than in rail terminals due to the more complicated nature of the transfer, and it has been assumed at 9 hours.

In table 3.1. are shown the characteristics of the terminals used in the model. Cost Load/Unload is the cost of these operations in each terminal. Dwell time is the average time in each node. Free Time is the time of free storage. Time Cost is the value of the storage cost when the cargo stays in the container yard beyond the free time.

It has been assumed that road haulage would conform with standard rest times as per EU regulations, see Regulation *(EC) No 561/2006*, (2006), including a night time rest of 12 hours, which may exceed slightly EU regulations. It is assumed that road haulage is using only one driver, so these rest times have to be taken in consideration. Also, regarding the utilization of SSS (RO-RO ships), it is assumed that unaccompanied transport is used and road haulage is arranged for carriage to the port of loading and from the port of unloading towards the final destination.

Regarding costs of transport modes, it should be noted that Hanssen et al. (2012) indicate that pre and on carriage represent 25-40% of total costs of intermodal transport (thus impacting heavily on its competitiveness). Its cost per tonne-km may rise to eleven times that of rail for short distances and, therefore, intermodal terminals need to be located near shippers/receivers.

Table 3.1 Costs and average dwell times in seaport and intermodal terminals.

Terminal	Node	Cost Unload (€)	Cost Load (€)	Dwell time (Hours)	Free Time (Hours)	Time Cost (€)
Rail Terminal (Oberhausen)	1329	25,0	25,0	6,0	48,0	2,0
RO-RO Terminal (Leixões)	783	50,0	50,0	6,0	48,0	2,0
IWW Terminal (Duisburg)	1794	25,0	25,0	9,0	96,0	2,0
Rotterdam	1242	25,0	25,0	6,0	96,0	2,0

The specific costs used in this model have been aligned with these qualitative observations. Furthermore, Martins (2015) indicates that for international freight transport across large distances, values per km vary between 0.7 and 1.2 €. Further evidence on these values may be found in CEGE (2014) and Reis (2014).

Figure 3.8. shows the adopted cost functions that were interpolated from the cost database in figure 3.5, indicating that at short-medium distances (up to 500 km/h) RO-RO ships present the highest specific costs, followed by road haulage, while rail and inland waterways present the lowest costs. All transport modes increase in specific costs especially for short distances, but it should be noted that rail, IWW and ships are relatively less used for these shorter distances. Regarding the high distance range, it may be seen that road haulage remains the most expensive mode, followed by rail and inland waterways. Maritime modes present the lowest specific costs and, up to 2000

km, they are still able to take advantage of large distances. It is important to note that all these values are external to the numerical tool and may be replaced or updated according with specific circumstances.

In the case of maritime transportation, the values for this specific route (Leixões to Rotterdam), have been corrected according with information from shipping companies, to 1050 €/FEU for the RO-RO ship. Regarding rail cost, it is indicated in Martins (2013) that a freight train from Portugal (Pampilhosa) to Germany (Braunschweig), over a distance of 2700 km, costs about 41000 € and carries 32 swap bodies, implying that the cost per unit would be 1281 € (0.47 €/km). For inland waterways it is known by direct information that the cost of shipping a FEU from Rotterdam to Duisburg would be about 120 € over a distance of 230 km, implying a specific cost of 0.52 €/km. These costs for trains and barges relate to the case in which these vehicles travel fully loaded.

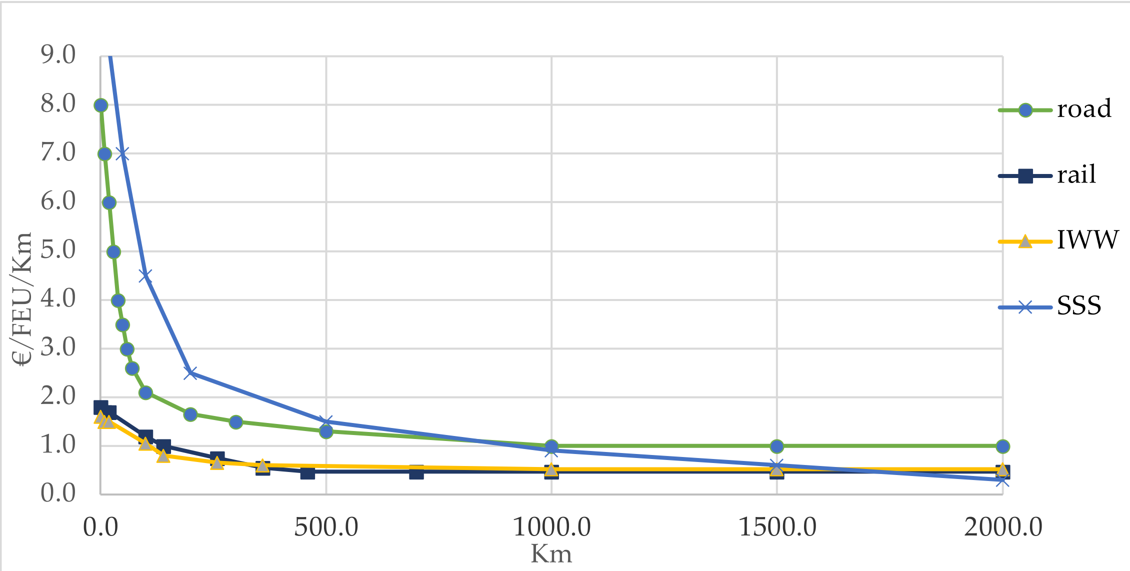

Figure 3.8 Transport modes specific costs

The distances between nodes included in the model of the transport networks, comprising the roads, railways and inland waterways included in TEN-T, were taken from Google Maps, while RFC specifications have been used for specifying distances in the rail network. In what concerns speeds, Table 3.2 shows the average speed assumed for the different modes of transportation. It may be seen that these speeds are adjusted according with the type of road (as consequence of speed limits and congestion levels), nature of the maritime area where the ship sails (decreases in speed in port approaches) and type or railway line (higher speeds for more modern parts of the rail corridors). The speed in IWW and seaways indicated in Table 3.2 considers the values found using marine traffic websites and also, as there was direct available information, that time taken through the Rhine river from Rotterdam to Duisburg would be approximately 20 hours. For rail, the average speed was set at 60 km/h this was based on the (Corridor Rhine-Alpine, 2019). Finally, the model of the transport networks is entirely parametric, so that other speeds may be considered on a link per link basis, instead of the values included in this table.

Table 3.2 Average speeds for different modes of transportation.

Transport Mode	Km/h	Knots
Road Haulage		
Motorway	80	-
National Road	60	-
Urban Road	40	-
Seaway		
Open Sea	28	15
Approaches to Ports	18,5	10
Inland Waterways		
Cruising	11,5	6,2
Rail		
Betuwe route	60	-

4. Application to intermodal transportation from Portugal to Northern Europe

The regions considered to be the origins of cargos are Porto and Bragança. These cities are the capitals of NUTS 3 regions: Área Metropolitana do Porto and Terras de Trás-os-Montes. The city of Porto is where the port from where the cargo will depart via the SSS route which is the Port of Leixões.

The destination of the cargos is to be the capital cities of NUTS 2 in Belgium, Netherlands, Germany, Luxemburg and northern France. The region of France studied is north of the Nantes Orleans line. The maps, the names of the capitals of NUTS 2 regions and the code of the NUTS can be found in Appendix A.

4.1 Intermodal terminal's technical and economic parameters

Intermodal hubs are part of freight transport systems (with access by road, rail and waterways) and may act as doorways between the sea and the inland transport (Nabais et al., 2015). The intermodal hubs considered in this model are the port of Leixões, the Port of Rotterdam, the Port of Duisburg and the rail terminal at Oberhausen.

The port of Leixões is where the cargo will depart from Portugal via SSS, it is in the north of Portugal, the majority of its transactions is in the export capacity, it caters for all types of ships and cargo as well as cruises. This port has connections to major European and global ports and has direct weekly connections to Angola and other African countries (ESPO, 2017).

Through the port it passes more than 18 million tons of goods, which accounts for about 25% of the Portuguese Foreign Trade by sea. Leixões is divided into two distinct physical locations inside the Port of Leixões; the north terminal and the south terminal shown in figure 4.1(YILPORT, 2017).

Figure 4.1 Overview of the south terminal Leixões Source: http://www.tcl-leixoes.pt/fotos/galerias/tsul_site_18728712215790dfa49ac95.jpg

In this port more than 2500 vessels dock on it, moving 685 810 TEU of all kinds of goods, including agri-bulk, paper and cardboard, scrap metal, scrap glass, iron and steel, granites, textiles, sugar, beverages, cements, cork, components for wind turbines and petroleum products, and even passengers from cruise liners. In 2019 the traffic of roro was responsible 1321 567 tons of cargo 6.7% of all cargo that passed through the port (APDL,2019)

It has 5 km of quay, 55 ha of embankments and 120 ha of wet area, combining with its economic density, industrial companies located in the hinterland and its great central geodemographic situation, make the Port of Leixões the largest port infrastructure in the north of Portugal (ESPO, 2017).

The Port of Rotterdam is where the cargo will enter northern Europe coming from Portugal, the annual throughput of the port amounts to some 450 million tonnes. This makes the Port of Rotterdam as the largest in Europe. The port area includes 12,500 ha. The total length of the port area is more than 40 km. Approximately 30,000 seagoing vessels and 110,000 inland vessels use the Port of Rotterdam every year. The

Port of Rotterdam is both a global hub and a strong industrial cluster. (ESPO, 2015) 24.253 containers of RO-RO passed through the port of Rotterdam in the 2019 (Port of Rotterdam, 2020).

The Port of Duisburg is the world's largest inland port and one of the leading logistics hubs in Central Europe. It is located in the heart of Europe's largest consumer market with more than 30 million consumers over a radius of 150 km. Each year approximately 20,000 ships and 25,000 trains are processed. It has an area of 1,550 ha, with 21 port basins, 200 km of track, 8 container terminals with 21 gantry cranes, 5 import coal terminals, 19 facilities for handling liquid goods and 2 RO-RO facilities figure 4.2 shows a RO-RO terminal ('Erich Staake', 2015) .

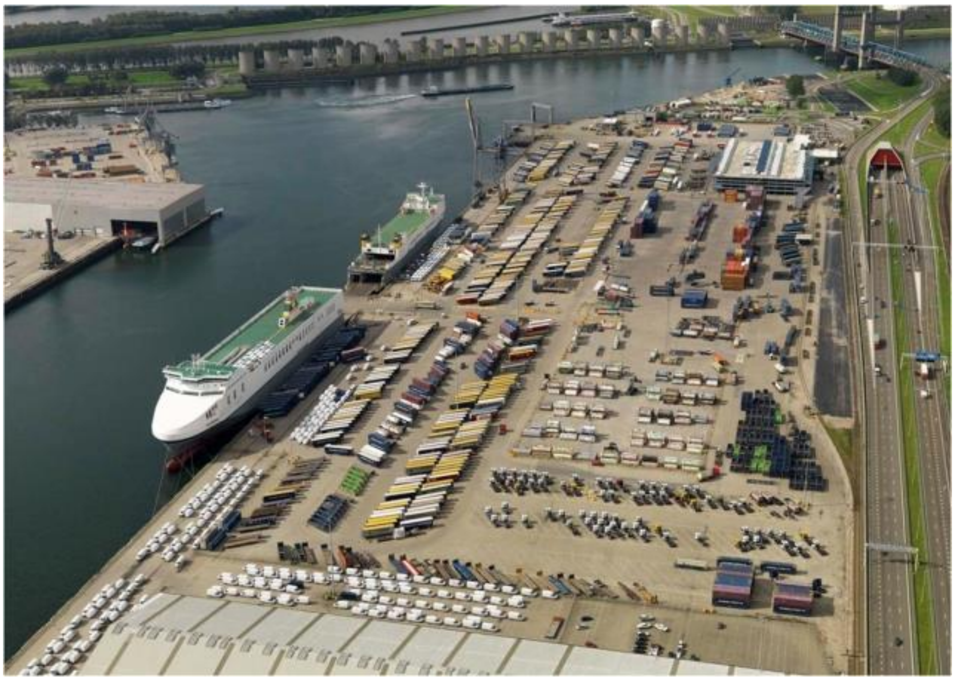

Figure 4.2 Brittaniehaven – Botlek RORO terminal Source:(C.RO - Ports - Stevedoring - Services)

The rail terminal in Oberhausen is close to the Duisburg port as it can be seen in figure 4.3. Every year more than 25 national and international railway service providers and operators with 25,000 trains targeting more than 100 destinations in Europe. 30 per cent of train traffic between Europe and China is already routed through Duisburg. Currently, between 35 and 40 trains run between the German port and various destinations in China every week (van Gurp, 2019).

Figure 4.3 The port of Duiburg and rail terminal Source: https://www.waz.de/staedte/duisburg/containerterminal-bahn-von-plaenen-des-hafens-ueberrascht-id227579497.html

As mentioned in chapter 3, certain nodes have important characteristics that needed to be considered this is the case for intermodal hubs. These characteristics are indicated in table 4.1. The free time is the time that a container can stay at the node without paying for park, since the time of permanence is lower, this cost will not occur.

Table 4.1 Characteristics of intermodal hubs

Node	Name	Cost Load (€)	Cost Unload (€)	Dwell Time (h)	FreeTime (h)
783	Leixões RO-RO terminal	25	25	6	48
1242	Rotterdam RO-RO terminal	50	50	6	96
1329	Oberhausen rail terminal	25	25	6	48
1794	Duisburg barge terminal	25	25	9	96

4.2 Transport network model

The transport from Portugal to the NUTS 2 regions can occur in four different ways, the first is via a unimodal solution, that is using the road system, the others are using intermodal solutions. These involve transport to the Port of Leixões using the road system, following with SSS to Rotterdam after arriving in this Port there are three possibilities using again road to their final destination or using rail to Oberhausen and, then road to the end or IWW to Duisburg and then road. In the figures 4.4 to 4.8 it is shown the paths from Rotterdam to the inland port of Duisburg, to Oberhausen and the road connections in the area. In blue are the IWW that a barge would follow as well as the possible stops represented by the nodes. In red it's the rail tracks and the possible railways stations, in black is the road network system that a truck would follow to deliver its cargo.

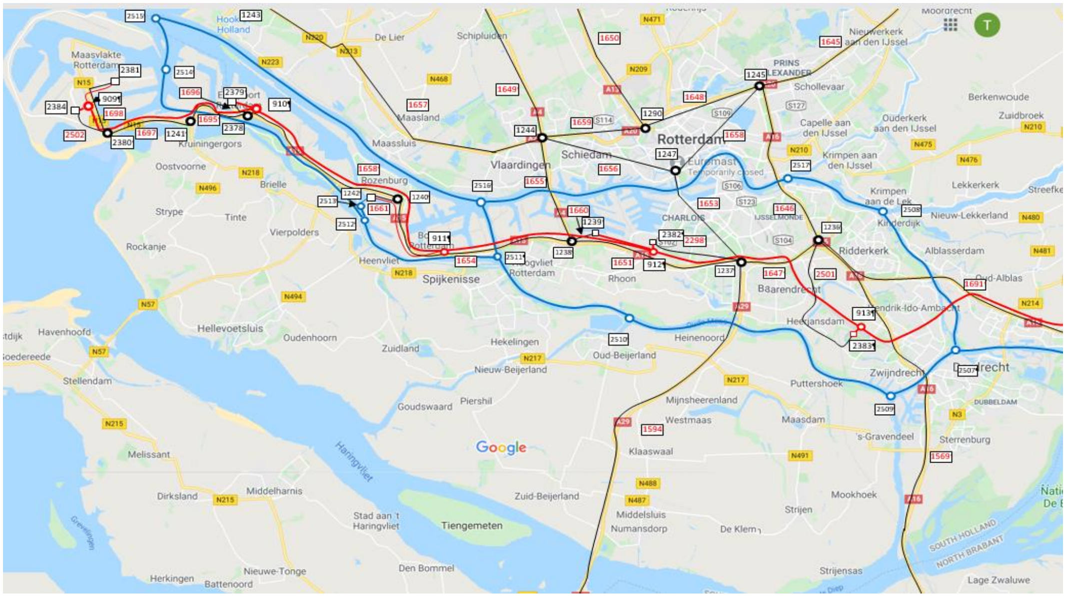

Figure 4.4 Map of the Rotterdam area

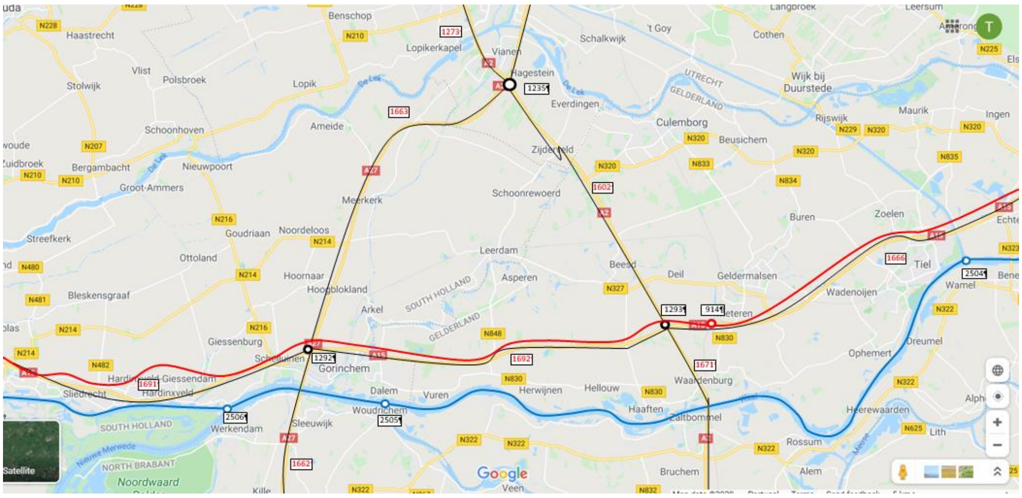

Figure 4.5 Map of east of Rotterdam area

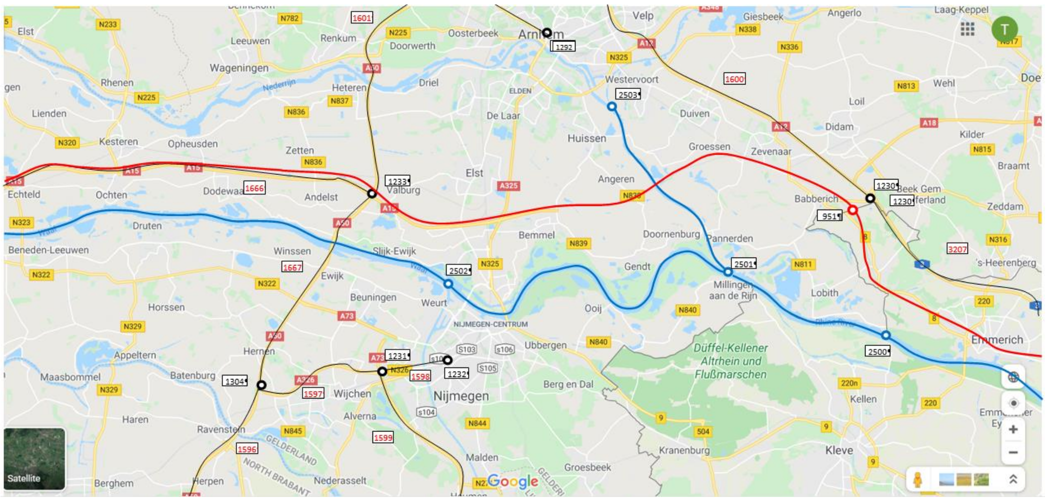

Figure 4.6 Map of the Nijmegen area along the river Rhine

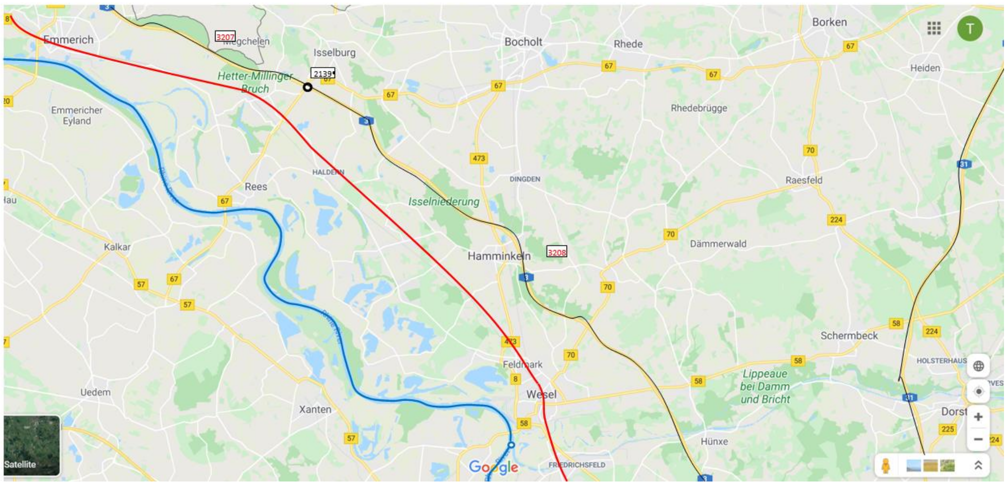

Figure 4.7 Map of the Wesel area following the river Rhine

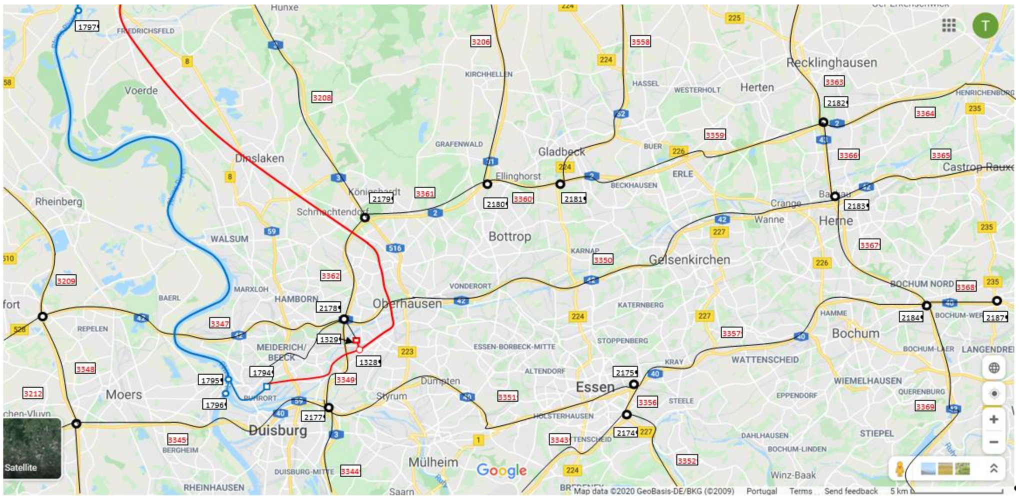

Figure 4.8 Map of the Duisburg and Oberhausen area

The paths from Leixões to Duisburg and to Oberhausen are identical and are as follows:

Leixões to Duisburg using SSS and IWW:

783 3322 3323 3324 3325 3326 1242 2512 2511 2510 2508 2507 2506 2505 2504 2503 2502 2501 2500 1797 1796 1794

Leixões to Oberhausen using SSS and rail:

783 3322 3323 3324 3325 3326 1242 911 912 913 914 951 1328 1329

From Duisburg IWW terminal and Oberhausen rail terminal the cargo is taken by road to each NUTS 2 capital.

4.3 Intermodal transportation options from Portugal to Northern Europe

As mentioned above there are four possible scenarios for each pair origin destination. These scenarios are explained in Figure 4.9, in which from an origin there are four possible paths. The first uses only road transport, the second uses road to the port of Leixões then SSS to Rotterdam and afterwards road to the final destination. The third and fourth options are similar to the second with the difference being that after Rotterdam instead of road, the third uses rail to Oberhausen and the forth IWW to Duisburg and afterwards both use road to their final destinations.

Two different cargo origins are studied: Porto and Bragança. The destinations are the NUTS 2 regions in northern Europe. The reason why Porto and Bragança were chosen as origins of cargo were their geographical locations, Porto being close to the coast and Bragança further away from the coast but closer to the border. So, for Porto the initial road path is smaller when considering the use of SSS whereas Bragança has a longer distance to go through to get to the port which will enable an analysis of the significance of the distance to port in this case of study. For each scenario, the numerical results will be shown using a map with a color code for differentiating the results. The maps will show the total cost of transportation, the total time of transportation and the Generalized Transportation Cost.

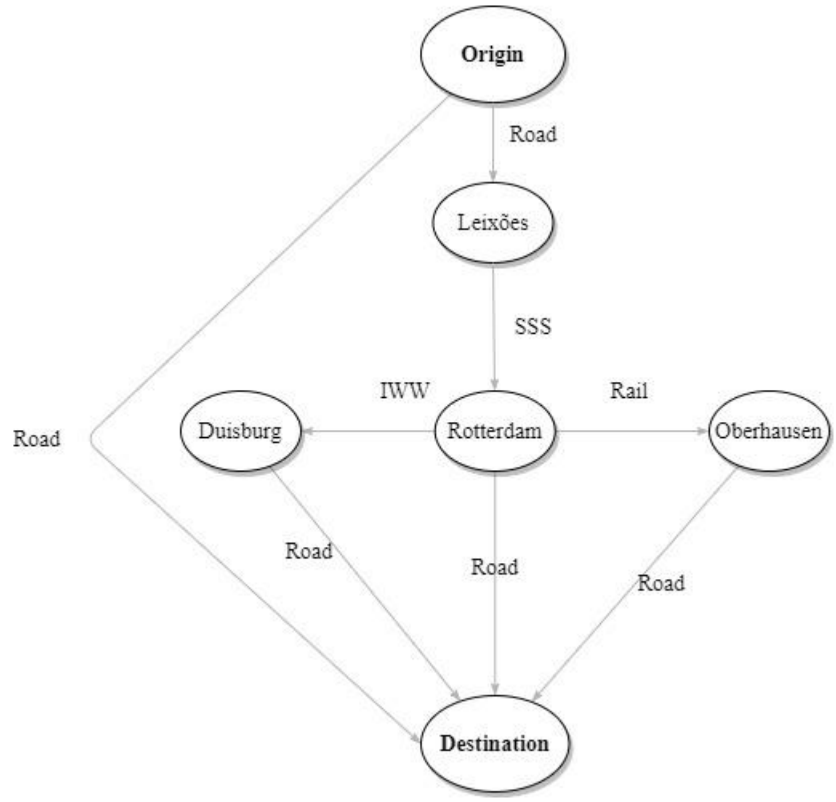

Figure 4.9 Methodology used for mathematical model

4.4. Validation of numerical results for Porto/Luxembourg

As mentioned above there are 4 possible paths for a pair origin/destination for the example Porto/Luxembourg are as presented in table 4.2:

Table 4.2 Paths form Porto to Luxembourg

Road solution	538 620 540 541 528 526 523 521 520 516 466 468 508 509 478 480 483 484 496 499 739 725 723 735 722 728 730 732 2823 993 1022 1034 1035 1036 1037 1038 1039 915 916 917 918 953 1117 1119 1120 1131 958 1330 1359 1360 1362 1368 1370 1371 1372 1346 1345 1344 1334 961 1157 1417 1314 1162 1205 1204 1203 1201 1180 1498 1153 1152
SSS and road solution	538 539 619 628 783 3322 3323 3324 3325 3326 1242 1240 1238 1237 1236 1225 1318 1197 2433 2432 1209 1288 1289 1313 1497 1201 1180 1498 1153 1152
SSS, Rail and Road	538 539 619 628 783 3322 3323 3324 3325 3326 1242 911 912 913 914 951 1328 1329 2178 2177 2163 1188 1189 1190 1191 1192 1193 1182 1181 1180 1498 1153 1152
SSS, IWW and road	538 539 619 628 783 3322 3323 3324 3325 3326 1242 2512 2511 2510 2508 2507 2506 2505 2504 2503 2502 2501 2500 1797 1796 1794 2178 2177 2163 1188 1189 1190 1191 1192 1193 1182 1181 1180 1498 1153 1152

Certain values of the model are fixed and are listed in Table 4.3 An additional 200€ are added to every path that passes through Rotterdam. This value is an adjustment of values interpolated from the SSS cost function for accounting for the reality of transport (current market values).

Table 4.3 – Distance, time and costs for pre arranged paths

	Leixões Rotterdam (SSS)	Rotterdam Oberhausen (Rail)	Rotterdam Duisburg (IWW)
Distance (Km)	1720	216	235
Time (h)	62,5	3,6	20,6
Cost (€)	805	182	160

Continuing with the previous example Porto/Luxemburg the final values can be found in table 4.4

Table 4.4

Table 4.4 Costs, time and GTC of transportation for Porto to Luxembourg

	Total Cost (€)	Time (h)	GTC (€)
Road	2098	52,9	2459
SSS + Road	1745	80,0	2290
SSS + Rail + Road	1938	88,4	2541
SSS +IWW + Road	1921	108,5	2661

The process used to determine the total cost using SSS+IWW+Road is as follows:

- First the distances between the points Porto, Leixões, Rotterdam, Duisburg and Luxemburg are respectively 9,2 Km, 1720 Km, 234,6 Km and 335,4 Km.
- Then the model uses the cost function in Figure 3.8 according to each way of transporting which translate into 556€ for road, 156€ for IWW and 805€ for SSS (including also 200€ added as a correction for SSS). For loading and unloading the cargo in ports 200€ are added bringing the total to 1921€ for transporting using SSS+IWW+Road.

For the time of transportation using SSS+IWW+Road the model follows the procedure explained in section 3.2. The time on sea for SSS is 62,5h and for IWW is 20,6h according with table 4.3, the time on the road is 4,4h this includes from Porto to Leixões and from Rotterdam to Luxembourg there is no rest time which gives a travel time of 87,48h afterwards the time in port is added 21 hours which puts the total of transport time at 108,5 h.

For the calculation of the generalized transportation cost (GTC) of SSS + IWW + road, the value of 108,48 is multiplied by the value of time 6,82 Euro/TEU.h and added to the transportation cost which gives a total of 2661,18€.

4.5 Intermodal transport from Porto and Bragança to Northern Europe NUTS 2

The Intermodal Analyst numerical tool was used in this dissertation to carry out the calculations for all transport options linking Porto and Bragança to the 75 Northern European NUTS 2 regions. Each region is represented by its capital, see Appendix A.

4.5.1 Intermodal transport from Porto

4.5.1.1 Transport cost, time and GTC

Figure 4.10 shows the results of transportation cost in euros using SSS+IWW+Road. The costs of transportation using other intermodal solutions are presented in appendix B for Porto and appendix C for Bragança. As it can be seen there are sections with different values range the ones close to Duisburg are the ones with the lower values and the further away the highest, intervals are of 110€.

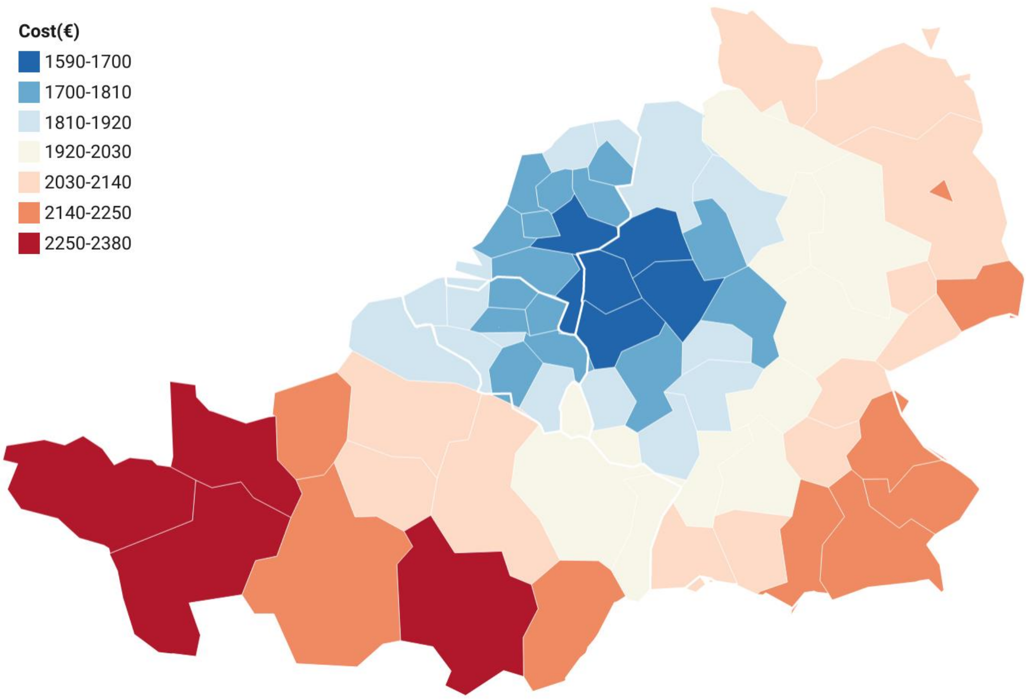

Figure 4.10 Transportation cost (in euros) from Porto to Northern European NUTS 2 regions using SSS+IWW+Road

Figure 4.11 shows time it takes from Porto to the NUTS 2 regions using SSS+IWW+Road, it is different from the previous figure as it can be seen kind of circumferences delimiting the regions. Most of the intervals are of 1 hour and three quarter and are continuously incrementing, with the exception of Brittany and the Pays de la Loire that are not following the same pattern for those regions now include a day rest. For others figures showing the travel times see appendix B for Porto and C for Bragança.

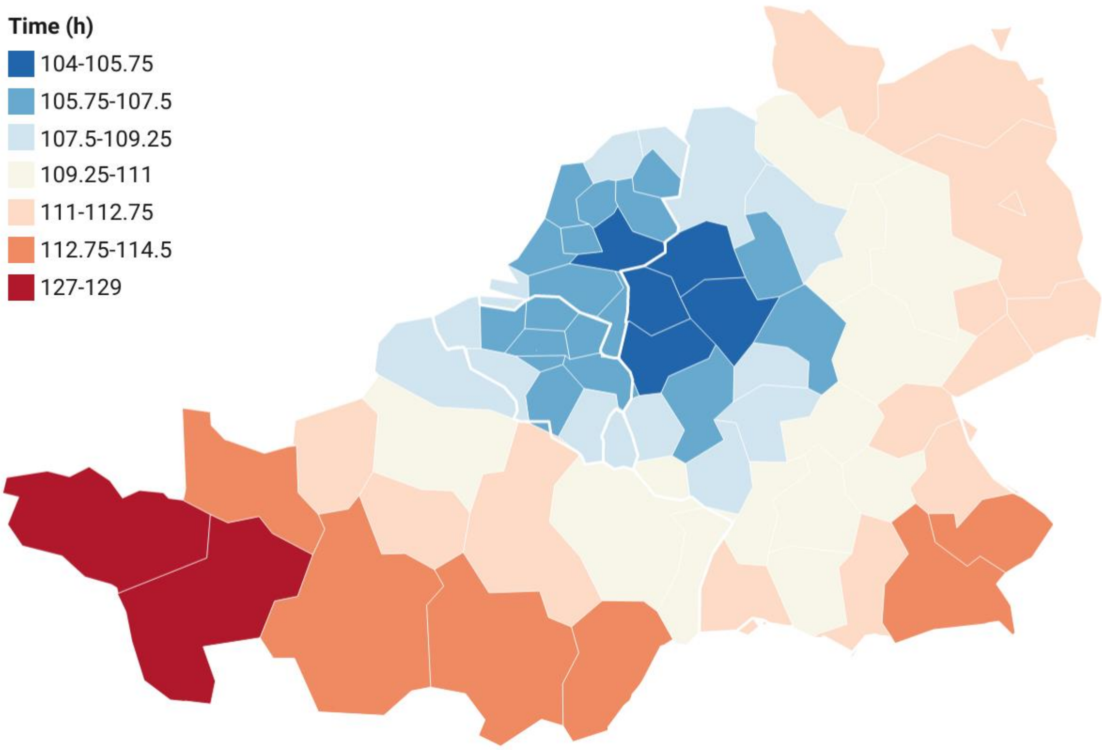

Figure 4.11 Transportation time from Porto to Northern European NUTS 2 regions using SSS+IWW+Road

Figure 4.12 shows the GTC for the NUTS 2 regions using SSS+IWW+Road for the other combinations see Appendix B and C. This figure is similar to the previous one as there are as well kind of circumferences around Duisburg are the ones with the lower values and the further away the highest, intervals are of 125€ and as in the previous figure Brittany and the Pays de la Loire there is a shift in the values it is exactly for the same reason.

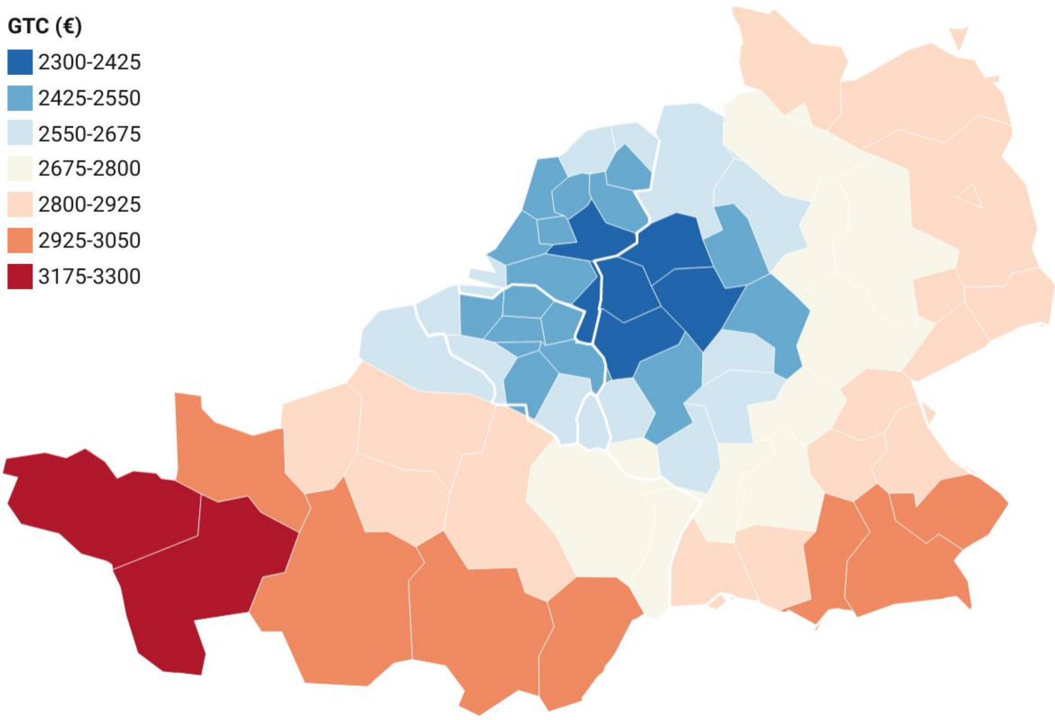

Figure 4.12 Transportation GTC from Porto to Northern European NUTS 2 regions using SSS+IWW+Road

4.5.1.2 Analysis of the modes of transportation

Figure 4.13 Cheapest option for total transport cost for each NUTS 2 region from Porto. It shows which mode of transportation is the cheapest, from the Portuguese city of Porto to the main cities which are considered to represent the numerous NUTS 2 regions in Northern Europe. It may be seen that most of France with the exception of Nord-Pas-de-Calais and Alsace-Lorraine, the cheaper option is road haulage, for the others regions in France the cheapest option is SSS+Road. In the case of Netherlands, Belgium and Luxemburg the option is SSS+Road. In what concerns Germany, even though the option which is in orange (IWW), is cheaper, it is very close to SSS+Road.

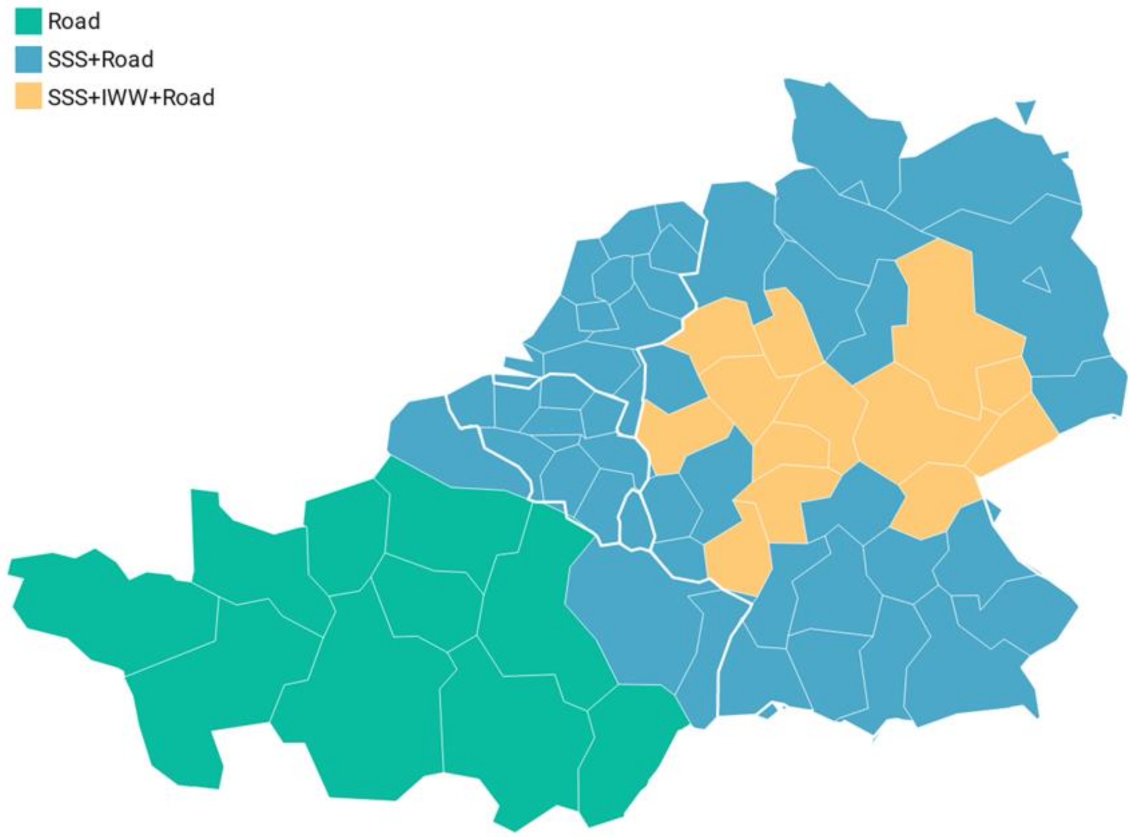

Figure 4.13 Cheapest option for total transport cost for each NUTS 2 region from Porto.

Figure 4.14 allows for a perception of those differences. Rail is on average more expensive than IWW by 17,26 €, with a standard deviation of 0,95€. The only significant difference in costs when comparing road with SSS+road is Picardie in which the difference is 7€.

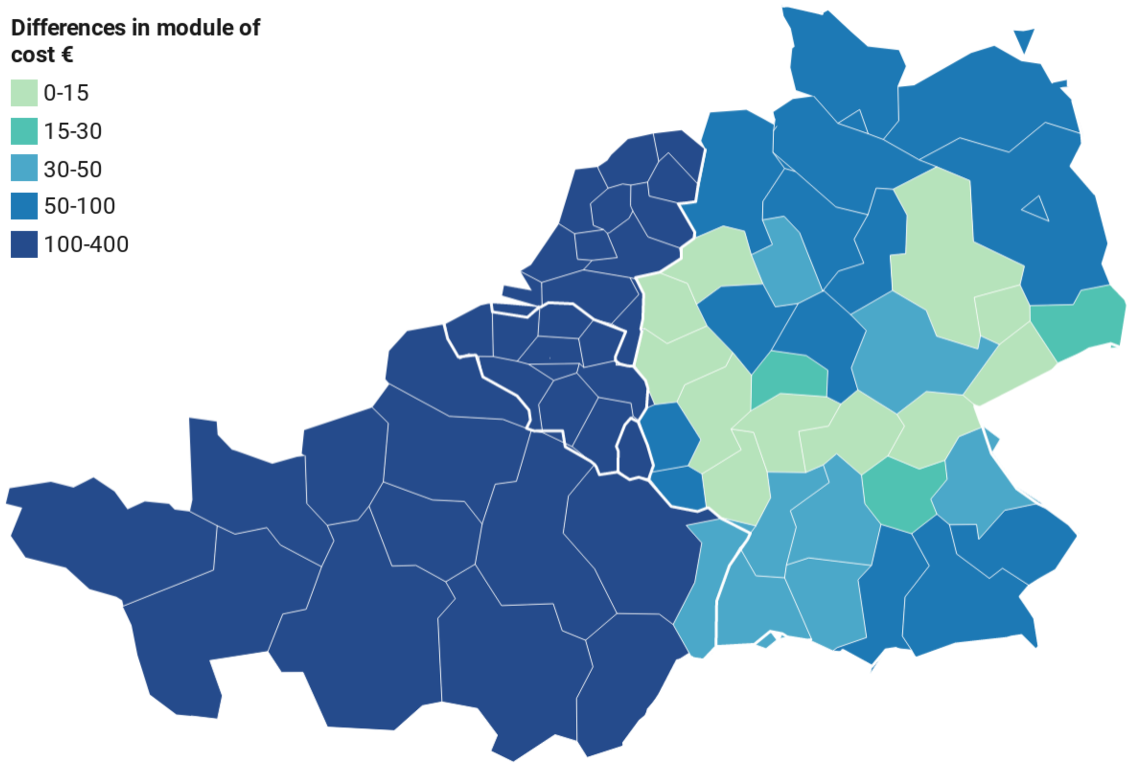

Figure 4.14 Differences in module of cost between SSS+road and IWW from Porto to NUTS 2.

Figure 4.15 shows which mode of transportation is the fastest if the road haulage is not an option from the city of Porto to the NUTS 2 regions. This is because, if speed is the most important parameter, road haulage is the fastest. However, for the regions further north the difference decreases. For example, for Schleswig-Holstein, which is the NUTS 2 region furthest away from Portugal, the difference between road and SSS is only 10.75 hours. IWW is on average 20.052h longer than Rail with a standard deviation of 0.086h. The options where rail is faster than SSS is only by on average 4.95h with a standard deviation of 0.53h. Inland waterways is slower than rail so it does not appear in this map.

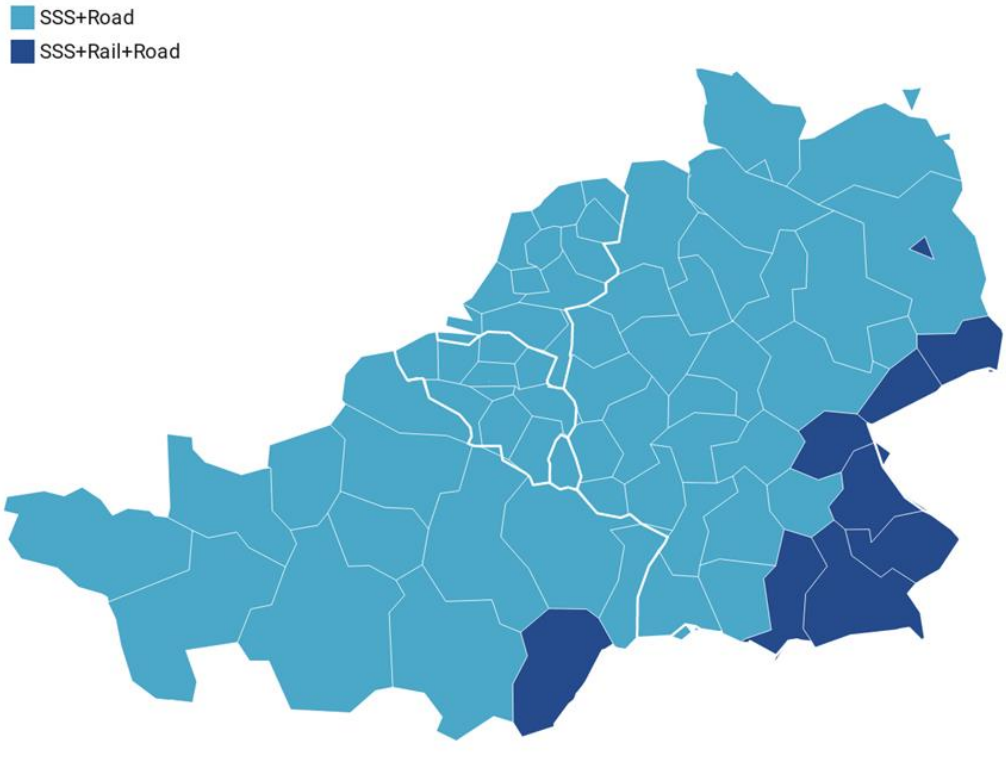

Figure 4.15 Fastest way of transporting cargo not considering road for each NUTS 2 region

Figure 4.16 shows which option of transport is cheaper when considering GTC. All of France with the exception of Nord-pas-de Calais favors road, Saarland and Freiburg in Germany also favor road. Arnsberg, Kassel, Oberfranken and Chemnitz are the only regions that prefer SSS+Rail+Road whereas the other regions prefer SSS+Road. The regions where the VoT (taken as 6.82€/hour) made a difference when comparing with Figure 4.13 are Alsace-Loraine, Saarland, Freiburg and all the regions where IWW is cheaper. In the four regions where SSS+Rail+Road is a cheaper option they switched from SSS+IWW+Road and the others regions also with IWW changed to SSS+Road.

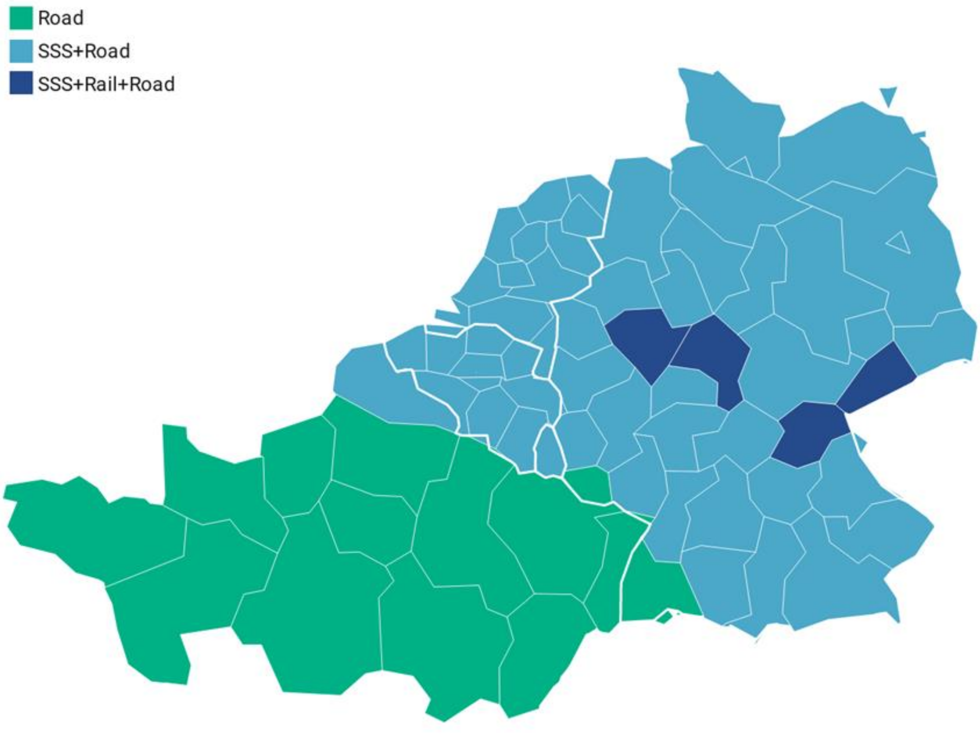

Figure 4.16 Cheapest option for GTC for each NUTS 2 region from Porto

Figures 4.17 and 4.18 show the regions for different VoT of, respectively, 2€/hour and 10€/hour, therefore lower or higher than the original value (6,82€/hour), which was that used to produce Figure 4.16. These three figures are mainly similar with only a few regions shifting options. Figure 4.17 is similar to figure 4.16 in terms of regions that prefer Road only difference are Alsace-Lorraine and Saarland, it is also seen the appearance of SSS+Rail+Road in 2 regions.

Figure 4.18, also comparing with figure 4.16, shows a slightly different picture with only Nord-Pas-de-Calais switching to Road. Regarding SSS+Rail+Road there is a swap between Arnsberg and Dresden. Should the VoT be bigger than 71.4€/hour then all regions would prefer Road. Should the value be 0€ then the results would be those given in figure 4.13.

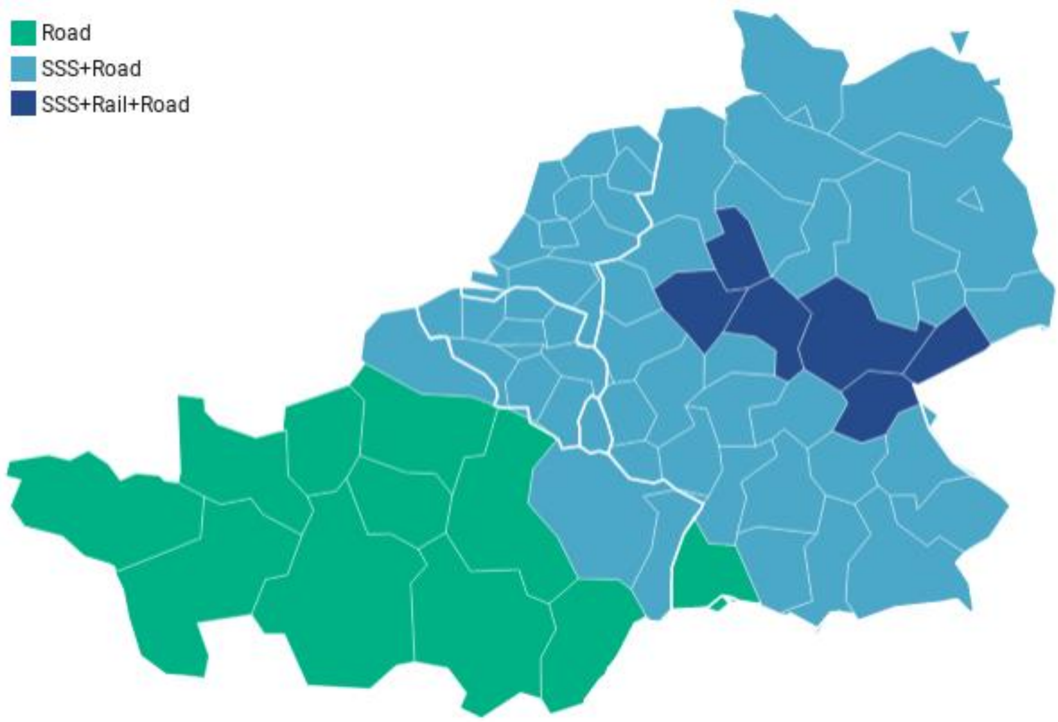

Figure 4.17 Preferences of NUTS 2 regions from Porto with a VoT of 2€/h.

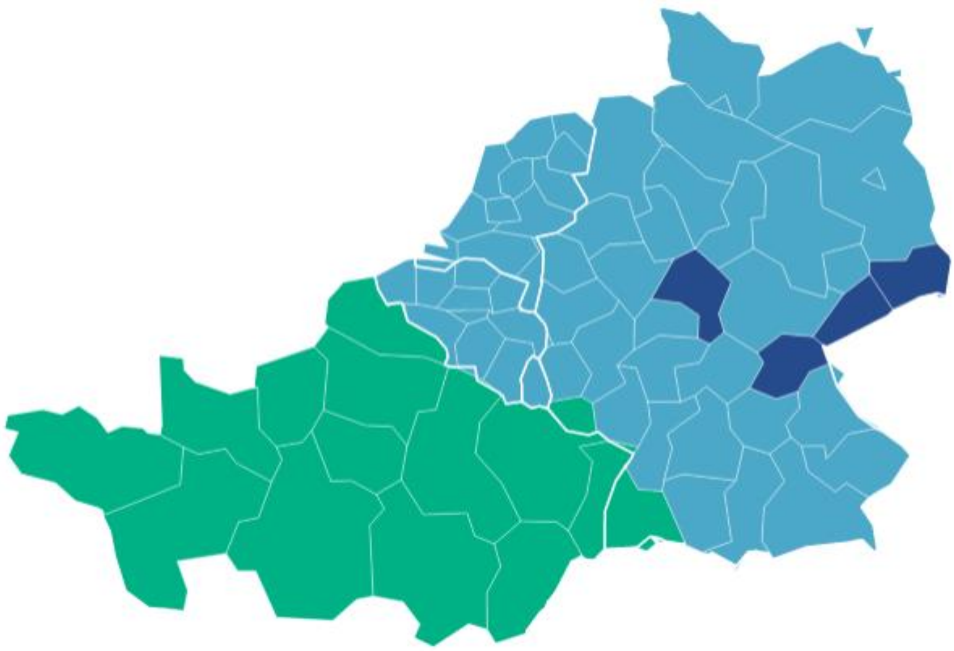

Figure 4.18 Preferences of NUTS 2 regions from Porto with a VoT of 10€/h.

4.5.2 Intermodal transport from Bragança

4.5.2.1 Transport cost, time and GTC

The Intermodal Analyst numerical tool was used to carry out the calculations for all transport options linking Bragança to the 75 Northern European NUTS 2 regions. Each region is represented by its capital, see Appendix A.

Figure 4.19 shows the results of transportation cost in euros using SSS+IWW+Road. As it can be seen, there are sections with different values range the ones close to Duisburg are the ones with the lower values and the further away the highest, intervals are of 110€. This figure is very similar with figure 4.10 as the only differences the addition to the paths is the route from Bragança to Leixões which increases the cost to all transport options with the exception of the road one, in which since the distance decreases so does the cost.

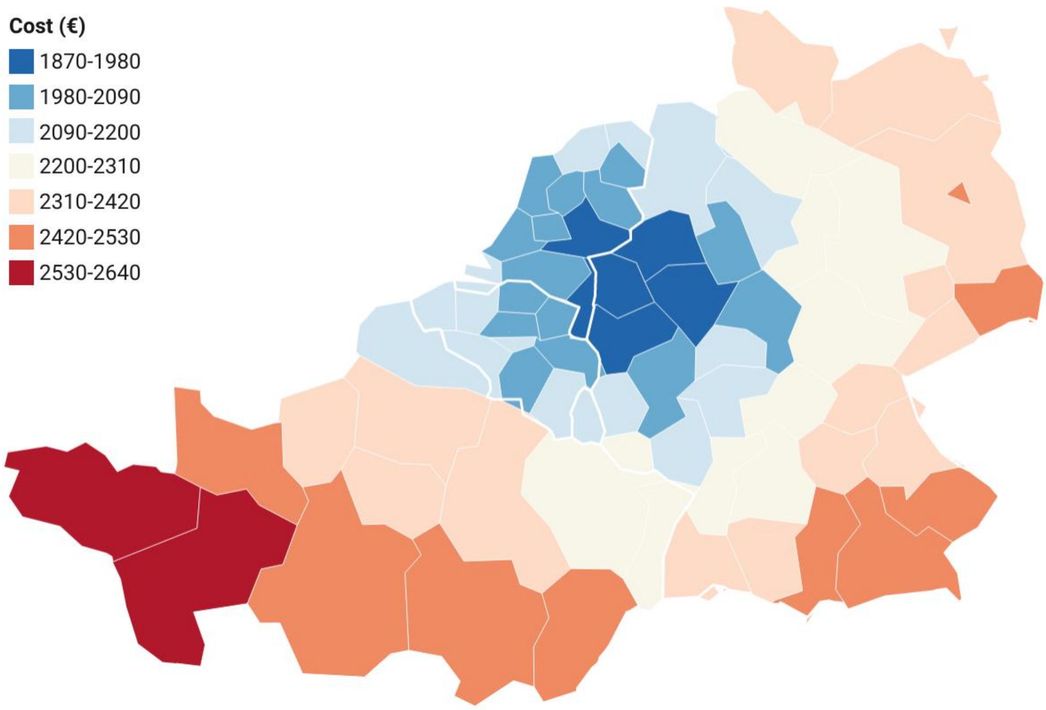

Figure 4.19 Transportation cost (in euros) from Bragança to Northern European NUTS 2 regions using SSS+IWW+Road

Figure 4.20 shows the time it takes from Bragança to the NUTS 2 regions using SSS+IWW+Road, it is similar to the previous figure as it can be expected with the circumferences delimiting the regions. Most of the intervals are of 2 hour and in this figure as in the previous figure 4.11, Brittany and the Pays de la Loire that are not following the same pattern for those regions still include a day's rest. The time is also bigger as it ads around 2 hours, for the road transport the time is more interesting for it is no longer necessary certain pauses which decreases it.

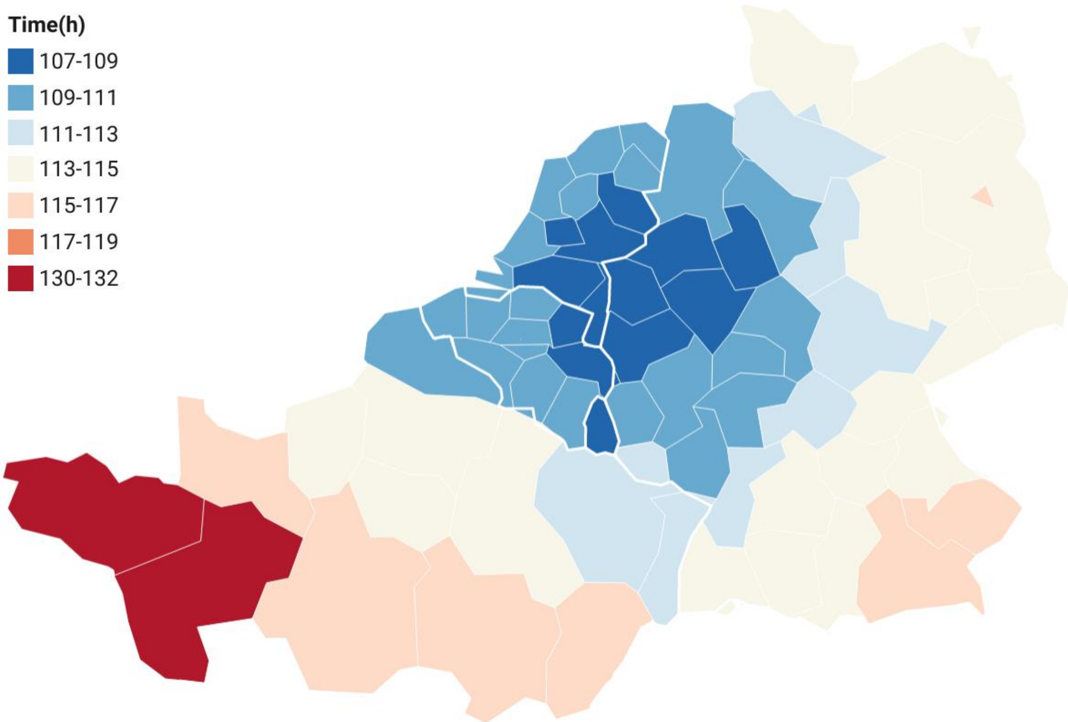

Figure 4.20 Transportation time from Bragança to Northern European NUTS 2 regions using SSS+IWW+Road

Figure 4.21 shows the GTC for the NUTS 2 regions using SSS+IWW+Road. The intervals are of 125€ and, as in the previous figure, in Brittany and the Pays de la Loire there is a shift in the values it is exactly for the same reason. In this figure, the values of GTC are significantly higher than the ones on figure 4.11 by more than 300€.

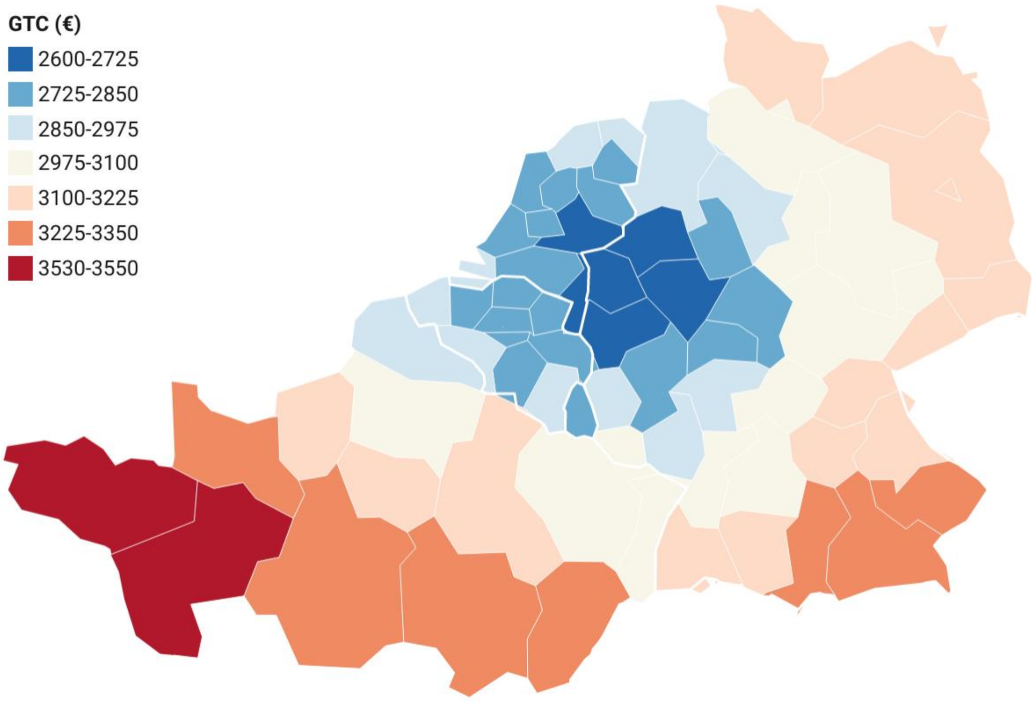

Figure 4.21 Transportation GTC from Bragança to Northern European NUTS 2 regions using SSS+IWW+Road

Table 4.5 shows the differences between Porto and Bragança for the Region of Luxembourg this table allows a better perception of the differences in values of the variances in the values of cost and time. This differences are of great importance when considering the regionalization of the port of Leixões, for as it will be shown in the following section, Luxembourg changes from SSS+ Road to the unimodal solution of just road.

Table 4.5 Costs and time of transportation for Porto and Bragança to Luxembourg

	Total Cost (€)		Time (h)	
Mode	Porto	Bragança	Porto	Bragança
Road	2098	1889	52,9	50,2
SSS + Road	1745	2022	80,0	82,5
SSS + Rail + Road	1938	2215	88,4	90,9
SSS +IWW + Road	1921	2199	108,4	111,0

4.5.2.2 Analysis of the modes of transportation

Figure 4.22 shows which mode of transportation is the cheapest, from the Portuguese city of Bragança to the main cities which are considered to represent the numerous NUTS 2 regions in Northern Europe. It may be seen that for France and most of Belgium with the exception of Antwerp, southern Germany and Zeeland, the cheaper option is road haulage. For Zeeland the difference between road and SSS is only 12€ but for Antwerp the difference is 30€. Rail is the same situation as it was for Porto, with a bigger cost of transportation by an average of 17.26 € with a standard deviation of 0.95€. These values are exactly the same as it was for Porto, the difference between them is that they are all increased by the distance of Bragança to Leixões.

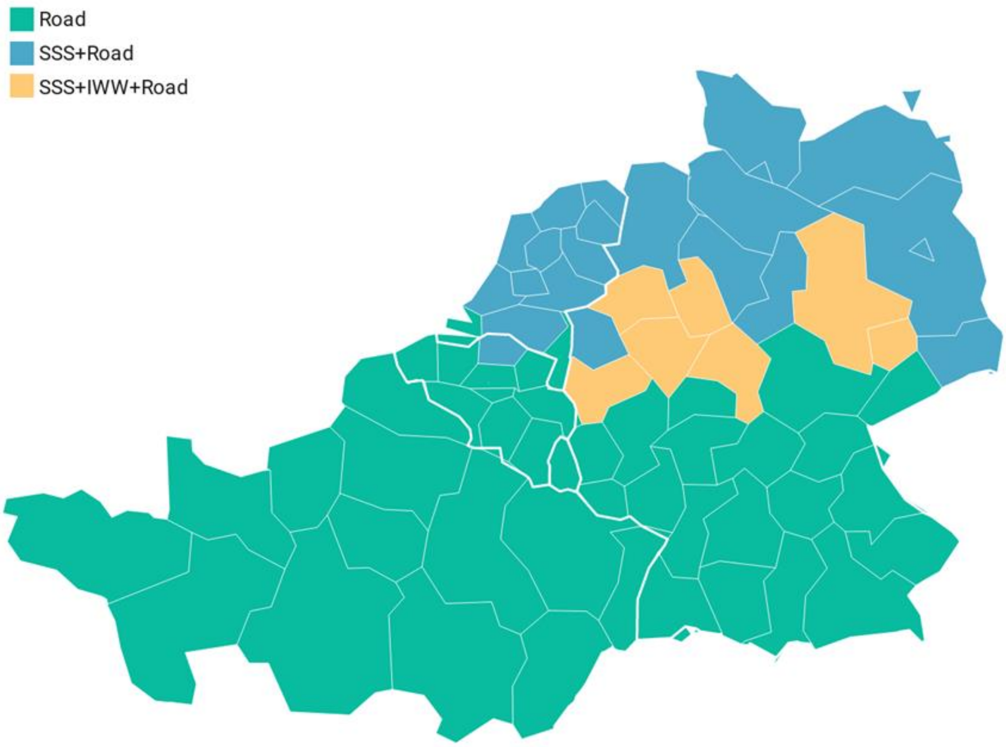

Figure 4.22 Cheapest option for total cost for each Nuts 2 region from Bragança

Figure 4.23 shows which mode of transportation is the fastest if just road haulage is not an option from the city of Bragança to the NUTS 2 regions. This is because if speed is the deciding criteria road haulage is the fastest. The difference between SSS and road for Schleswig-Holstein is 15.98 h, which is the smallest difference and the biggest is Pays de la Loire is 69.05h with only 31.12h from Bragança to Nantes by road and 100.17h by SSS+Road. IWW is on average 20.052h longer than Rail with a standard deviation of 0.086h exactly the same as it was for Porto. These time values, when comparing with Porto, are increased by 2.5 hours that is the additional distance from Bragança to Leixões. Whereas for road the time is reduced by 2.73 h our more because there may not be necessary for certain pauses so it can be reduced by 3.48 or 14.73. On the first case a 0.75h pause is no longer necessary and on the second a 12h is also no longer necessary this differences are illustrated in figure4.24.

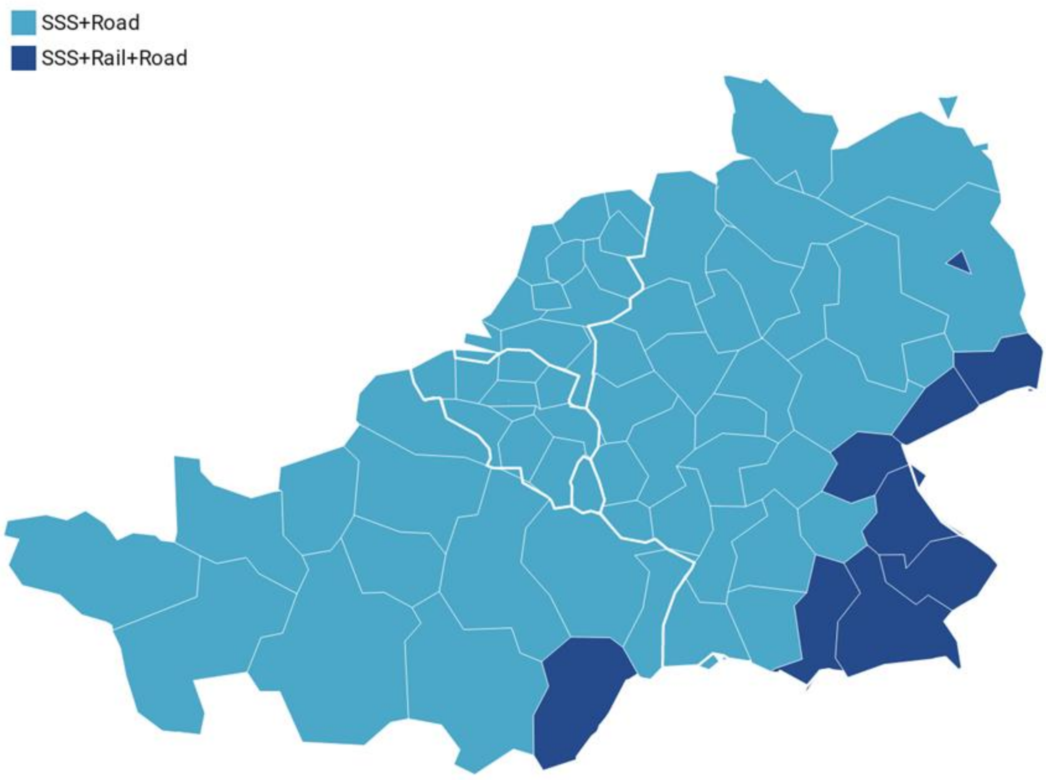

Figure 4.23 Fastest way of transporting cargo not considering road for each Nuts 2 region from Bragança

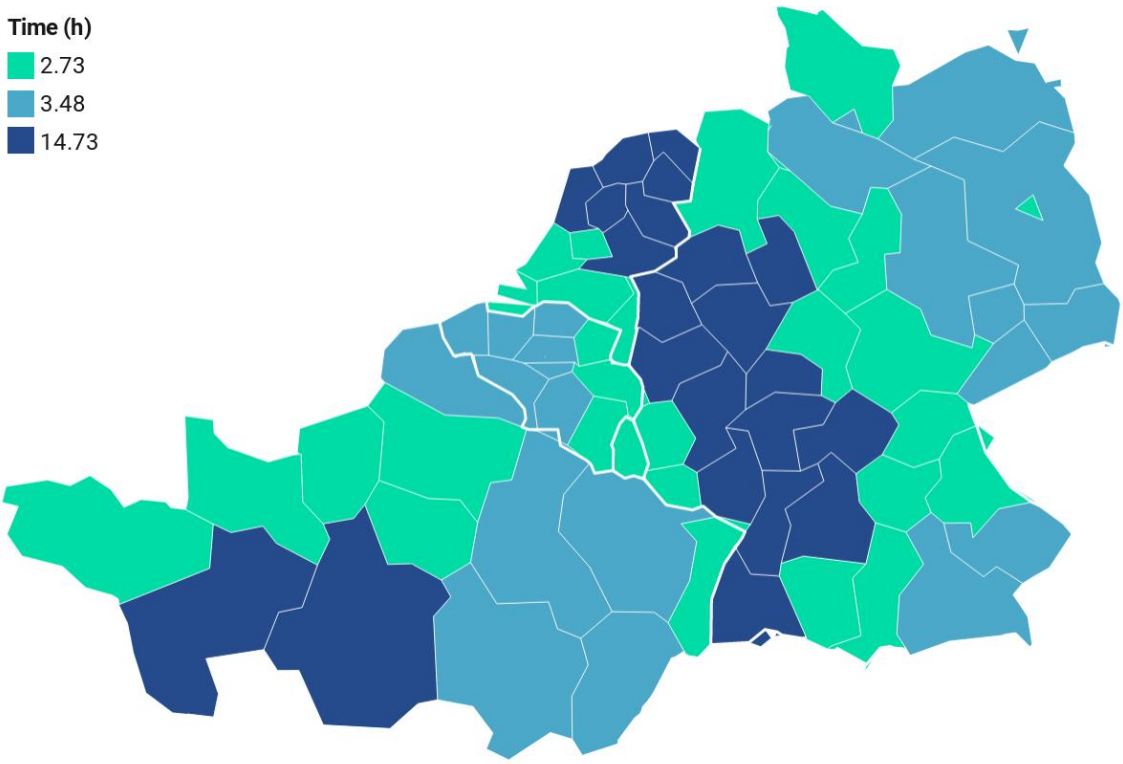

Figure 4.24 Differences in road travel time from Porto and Bragança

Figure 4.25 shows which option of transport is cheaper when considering GTC. All of France, Belgium and most of Germany and Netherlands favors road. In the Netherlands the costs for Road and SSS+Road are all very close. The regions next to the border of the Netherlands all prefer road but this is by a very small margin. A big difference between these two modes is the handling costs and time in ports whereas road has neither, which is the reason for the said regions preferring Road. In Germany, SSS+Road is preferable in the North, with the exception of Berlin for which Road is preferabe. SSS+Rail+Road and SSS+IWW+road are always more expensive.

The regions where the VoT (6,82€) made a difference when comparing with Figure 4.22 were the ones where IWW was cheaper but the time was to long so the option Road was selected. In the four regions where SSS+Rail+Road was preferred, they switched to SSS+Road and also many others altered to SSS+Road.

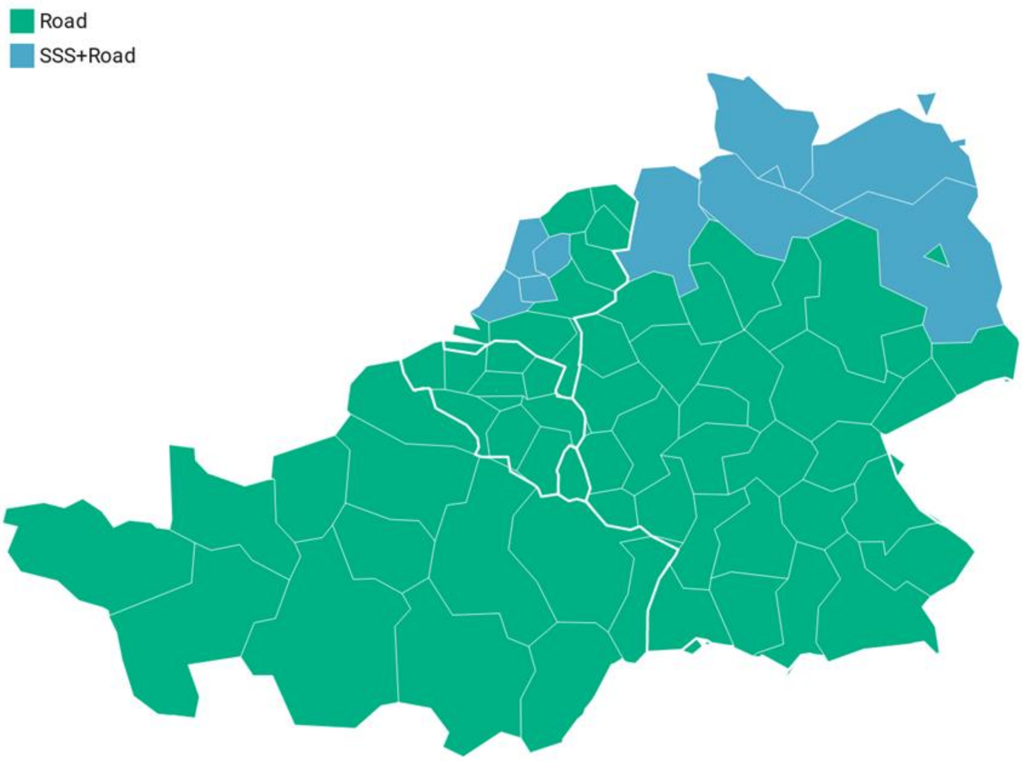

Figure 4.25 Cheapest option for GTC for each Nuts 2 region from Bragança with a VoT of 6.82€

Figure 4.27 and 4.28 show the regions for different VoT 2€ and 10€ respectively with these new values. There is a significant shift in the region's choice of mode for the transport of cargo. Figure 4.26 is similar to figure 4.22 in terms of regions that prefer Road. The only difference is Dusseldorf and Cologne. It is also seen the appearance of the option of SSS+Rail+Road in 3 regions. Figure 4.27 show a completely different image with Road being the choice with the exception of Schleswig-Holstein and Mecklenburg-Vorpommern Should the VoT be bigger than 11.5€ then all regions would prefer a unimodal solution.

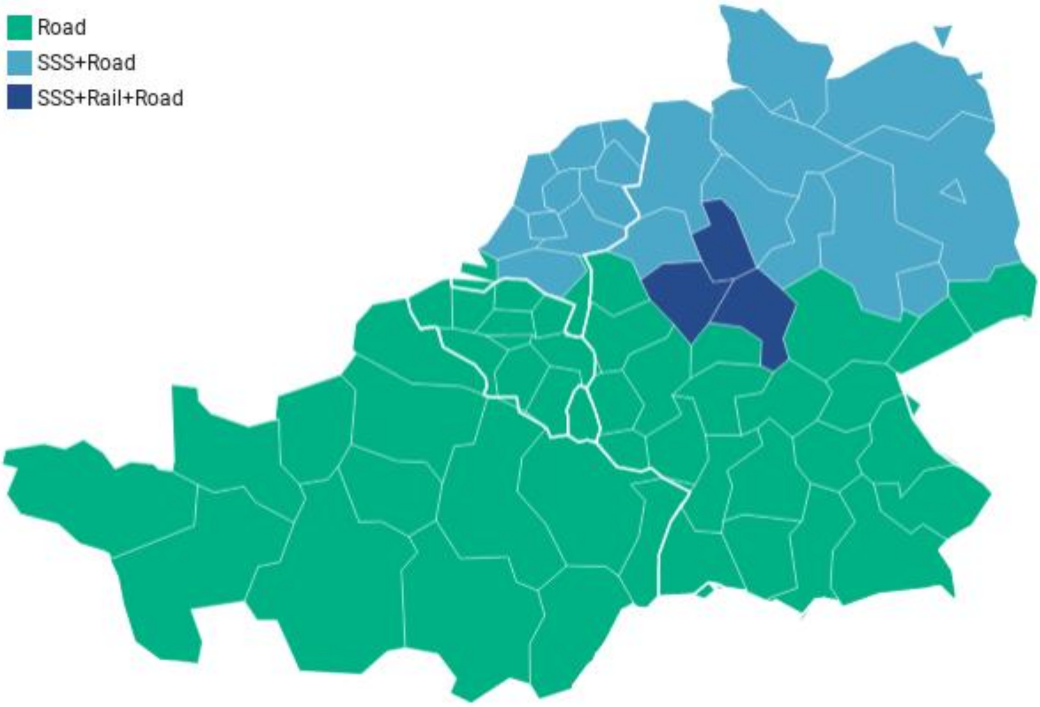

Figure 4.26 NUTS 2 region from Bragança with a GTC of 2€

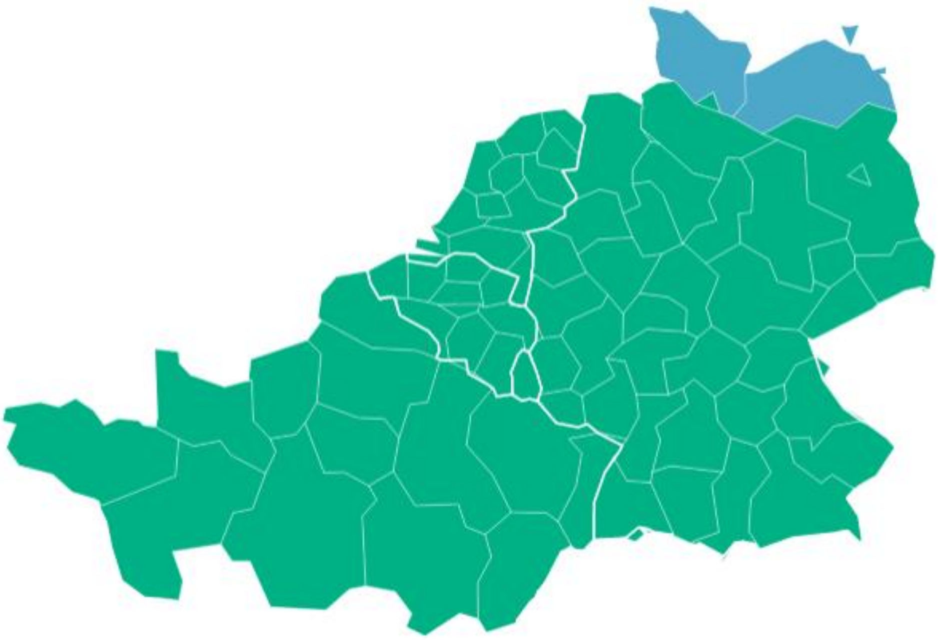

Figure 4.27 NUTS 2 region from Bragança with a GTC of 10€

5. Conclusions and Recommendations

This dissertation was developed with the aim of exploring the possibility of combining short sea shipping (SSS) and European Union (EU) inland waterways and rail corridors to carry freight towards regions located away from the coastline. The contributions of this dissertation was the expansion of the network model and the introduction of new transport chains in new areas not covered before, that allowed the analysis of their respective viability. This has been done by analyzing transport chains costs and transit time, from northern Portugal to Northern Europe. With that in mind two cities were selected, on opposite sides of the North of Portugal. One close to the Atlantic Ocean, the city of Porto, and the other close to the border with Spain, the city of Bragança. The regions in Northern Europe are NUTS 2 regions, the points of destinations are their respectively capitals.

Initially, an analysis was made to determine which modes of transportation and intermodal transport chains would be modeled and what parameters would be inputted into a numerical model. The modes of transportation selected were road, SSS, rail and IWW. These modes were grouped into four combinations, road, SSS+road, SSS+rail+road and SSS+IWW+road. Using these combinations paths were developed, representing the different transport chains, from the two cities to the 75 NUTS 2 regions in Northern Europe. The model of transport networks between Rotterdam and Duisburg-Oberhausen was added to an existing model. A numerical tool for analyzing intermodal transport chains was used to obtain the results.

The use of SSS in transportation proves to be cost competitive although slow moving. It is clearly preferable for cargo with low priority. Apart from road transport, SSS coupled to distribution by road is a good option for reaching extensive areas in Northern Europe, being preferable to combinations of SSS with IWW and rail.

Combining SSS with IWW proves to be cost competitive for those regions located further away from the coast and close to inland ports. The use of rail together with SSS proves to be efficient when the value of the cargo is higher and a faster mode than IWW is preferable, but not high enough so that a fully road-based transport solution is necessary. However, this is only when the cargo origin is close to a port, as is the case for cargos with origin in Porto. When the origin of the cargo in Portugal is more inland (Bragança) it is cheaper and faster to use a unimodal solution.

From the point of view of port regionalization, the port of Leixões needs to increase its competitiveness by decreasing dwell time and costs, seeking to attract cargos from areas further inland and taking the opportunity to develop infrastructures that might make the port more attractive to operators.

Regarding recommendations for further research on intermodal transport, it must be pointed out that in this case the Port of Rotterdam was the only destination port used, and the rail and IWW connections are very limited in their extent. Further studies could be made including other ports such as Le Havre, Antwerp, Emden, and Bremerhaven. The results might prove the feasibility of shifts from road to SSS in certain other regions. An increase in the model of rail and IWW networks might also demonstrate that an intermodal solution combining these three ways of transportation might be viable for cargos with a low VoT. If larger extensions of railway lines and IWW were used, the full benefit from cost savings allowed by these transport modes could be obtained. An example of a long distance railway line would be a direct railway connection from Portugal to Northern Europe, that might prove this to be a competitive transport solution.

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Appendix A - NUTS 2 regions

Figure A.5.1. NUTS 2 of the Netherlands

Table A.1 Codes of Nuts 2 and its respective Capitals of the Netherlands referring to Figure A.5.1

Code – Nuts 2 – Capital	Code – Nuts 2 – Capital
NL11 – Groningen – Groningen	NL31 – Utrecht – Utrecht
NL12 – Friesland – Leeuwarden	NL32 – North Holland – Haarlem
NL13 – Drenthe – Assen	NL33 – South Holland – The Hague
NL21 – Overijssel – Zwolle	NL34 – Zeeland – Middleburg
NL22 – Gelderland – Arnhem	NL41 – North Brabant – s'Hertogenbosch
NL23 – Flevoland – Lelystad	NL42 – Limburg – Maastricht

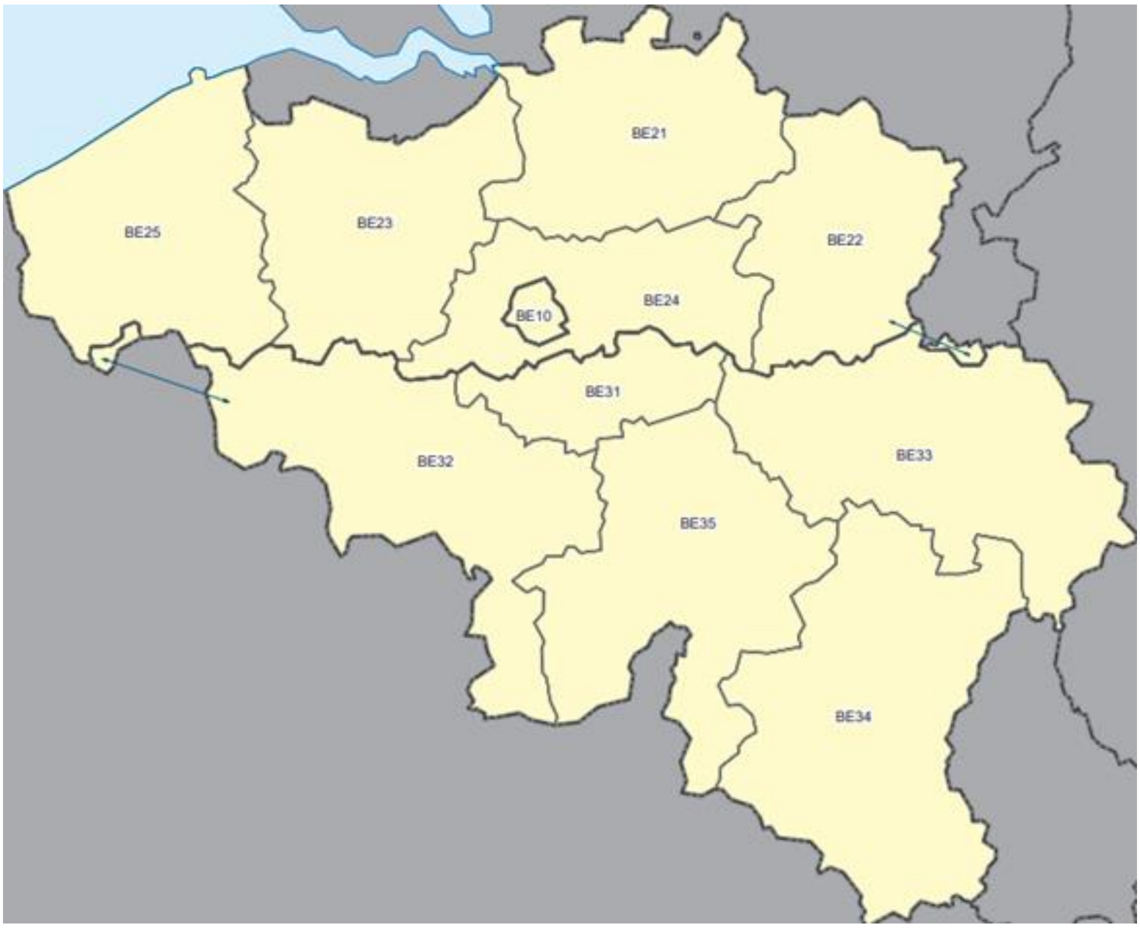


Figure A.5.2 Belgium NUTS level 2

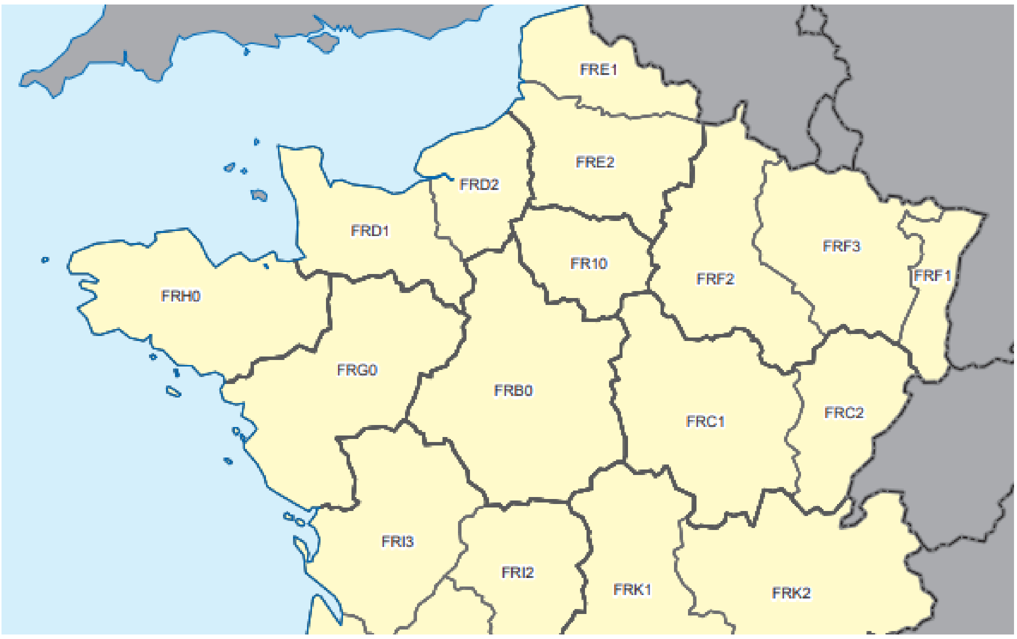
Table A..2 Codes of Nuts 2 and its respective Capitals of Belgium referring to Figure A.5.2

Code – Nuts 2 – Capital	Code – Nuts 2 – Capital
BE10 – Brussels – Brussels	BE25 – West Flanders – Bruges
BE21 – Antwerp – Antwerp	BE31 – Walloon Brabant – Wavre
BE22 – Limburg – Hasselt	BE32 – Hainaut – Mons
BE23 – East Flanders – Ghent	BE33 – Liège – Liege
BE24 – Flemish Brabant – Leuven	BE34 – Luxembourg (Belgium) – Arlon
	BE35 – Namur – Namur

Figure A.5.3 Germany NUTS level 2

TableA..3 Codes of Nuts 2 and its respective Capitals of Germany referring to Figure A.5.3

Code – Nuts 2 – Capital	Code – Nuts 2 – Capital
DE11 – Stuttgart – Stuttgart	DE91 – Braunschweig – Braunschweig
DE12 – Karlsruhe – Karlsruhe	DE92 – Hanover – Hanover
DE13 – Freiburg – Freiburg	DE93 – Lüneburg – Lüneburg
DE14 – Tübingen – Tübingen	DE94 – Weser-Ems – Oldenburg
DE21 – Oberbayern – Munich	DEA1 – Düsseldorf – Düsseldorf
DE22 – Niederbayern – Landshut	DEA2 – Cologne – Cologne
DE23 - Oberpfalz - Regensburg	DEA3 – Münster – Münster
DE24 - Oberfranken - Bayreuth	DEA4 – Detmold – Detmold
DE25 - Mittelfranken - Ansbach	DEA5 – Arnsberg – Arnsberg
DE26 - Unterfranken - Würzburg	DEB1 – Koblenz – Koblenz
DE27 - Schwaben - Augsburg	DEB2 – Trier – Trier
DE30 – Berlin – Berlin	DEB3 – Rheinhessen-Pfalz – Neustadt
DE40 – Brandenburg – Potsdam	DEC0 – Saarland – Saarbrücken
DE50 – Bremen – Bremen	DED2 – Dresden – Dresden
DE60 – Hamburg – Hamburg	DED4 – Chemnitz – Chemnitz
DE71 – Darmstadt – Darmstadt	DED5 – Leipzig – Leipzig
DE72 – Gießen – Gießen	DEE0 – Sachsen-Anhalt – Magdeburg
DE73 – Kassel – Kassel	DEF0 – Schleswig-Holstein – Kiel
DE80 – Mecklenburg-Vorpommern – Schwerin	DEG0 – Thüringen – Erfurt



FigureA.5.4 Northern France Nuts 2

Table A.4 Codes of Nuts 2 and its respective Capitals of Northern France referring to FigureA.5.4

Code – Nuts 2 – Capital	Code – Nuts 2 – Capital
FR10 – Île-de-France – Paris	FRE1 – Nord-Pas-de-Calais– Lille
FRB0 – Centre-Val de Loire – Orleans	FRE2 – Picardie – Amiens
FRC1 – Bourgogne – Dijon	FRF1 – Alsace – Strasbourg
FRC2 – Franche-Comté – Besançon	FRF2 – Champagne-Ardenne – Chalons
FRD1 – Lower Normandy – Caen	FRF3 – Lorraine – Metz
FRD2 – Upper Normandy – Rouen	FRG0 – Pays de la Loire – Nantes
	FRH0 – Brittany – Rennes

Figure A.5.5 Nuts 2 of Luxembourg which code is LU00 and the Capital is also Luxembourg

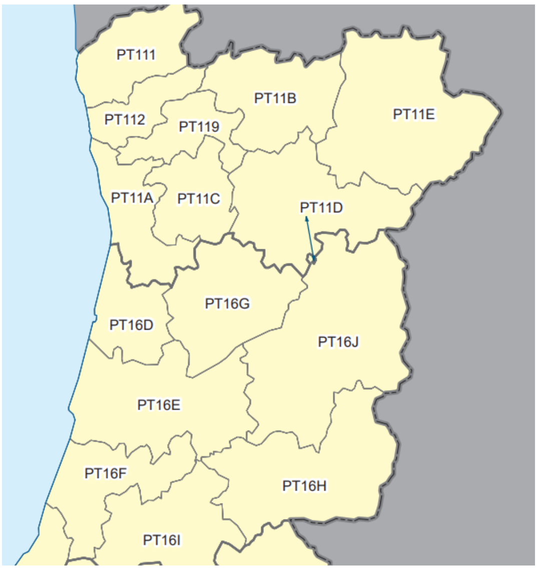


Figure A.5.6 Nuts 3 of northern Portugal

Table A.5 Codes of Nuts 3 and its respective Capitals of Northern Portugal referring to FigureA.5.4

Code - Nuts 3 - Capital
PT111 - Alto Minho - Viana do Castelo
PT112 - Cávado - Braga
PT119 - Ave - Guimarães
PT11A - Área Metropolitana do Porto - Porto
PT11B - Alto Tâmega - Chaves
PT11C - Tâmega e Sousa - Penafiel
PT11D - Douro - Vila Real
PT11E - Terras de Trás-os-Montes - Bragança
PT150 - Algarve - Faro
PT16B - Oeste Caldas da Rainha
PT16D - Região de Aveiro - Aveiro
PT16E - Região de Coimbra - Coimbra
PT16F - Região de Leiria – Leiria

Appendix B - Numerical results for cargos with origin in Porto

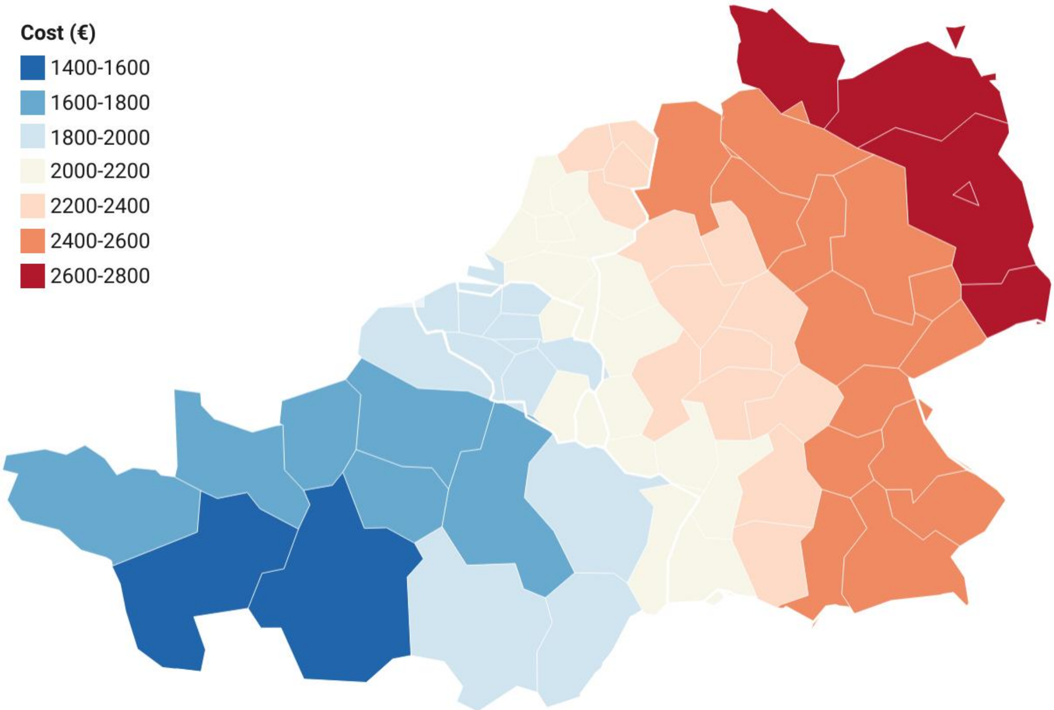


Figure B.5.1 Transport road total cost

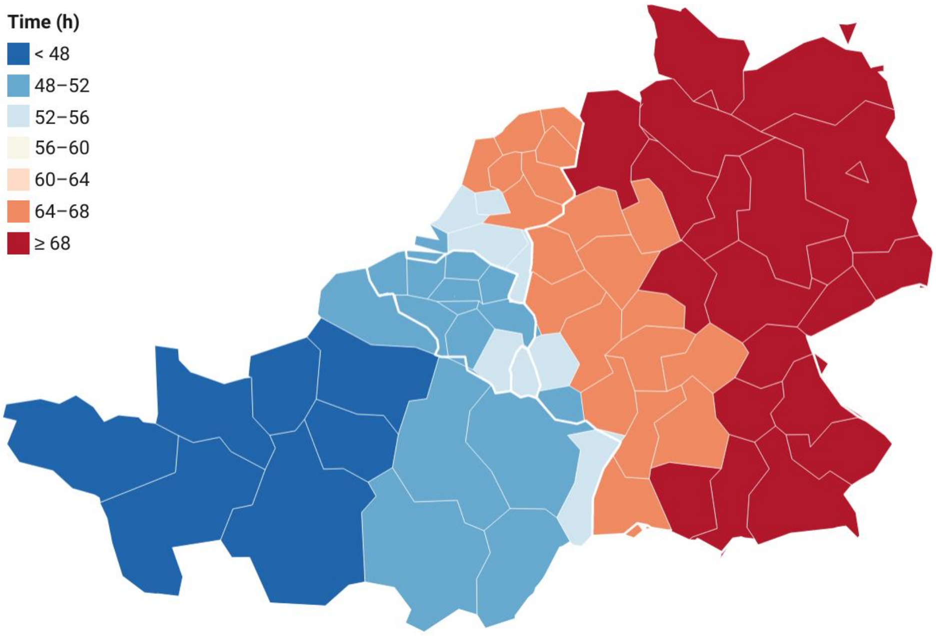


Figure B.5.2 Transport road total time

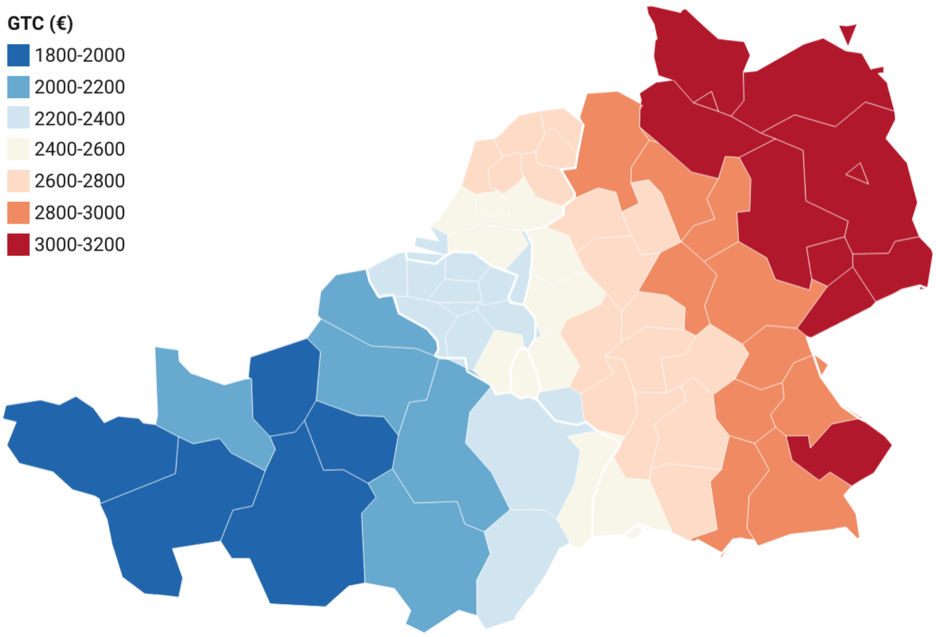


Figure B.5.3 Transport road GTC

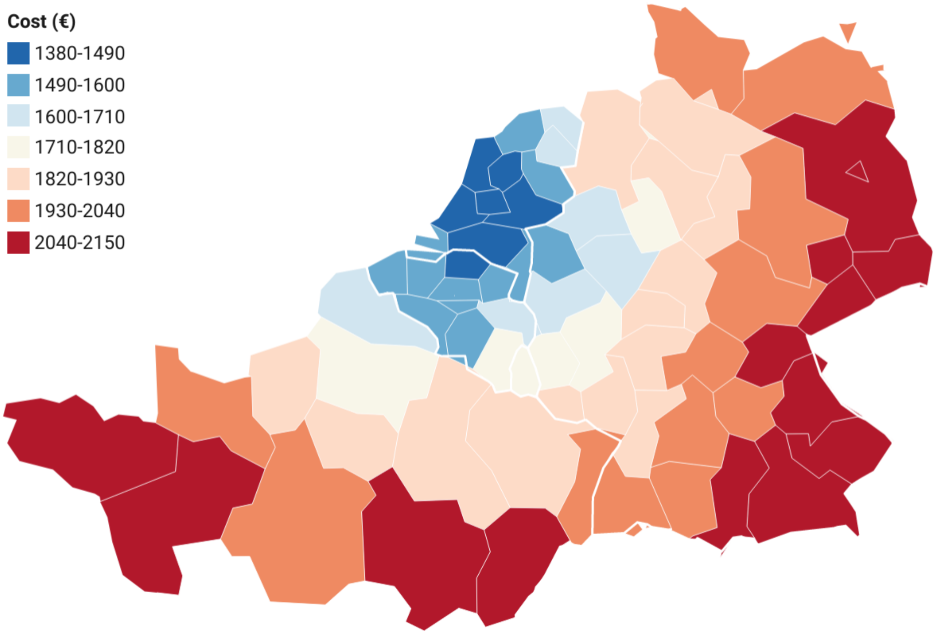


Figure B.5.4 Transport SSS+Road total cost

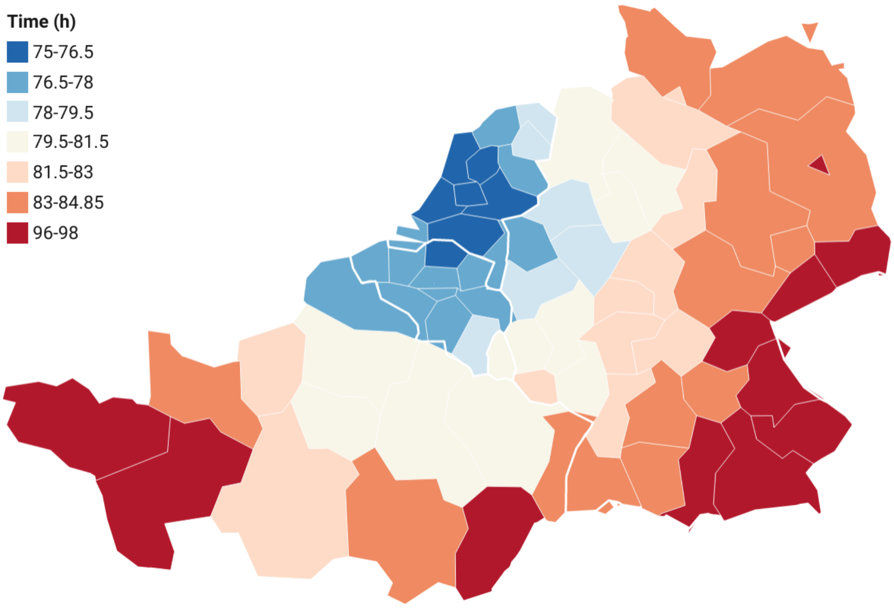


Figure B.5.5 Transport SSS+Road total time

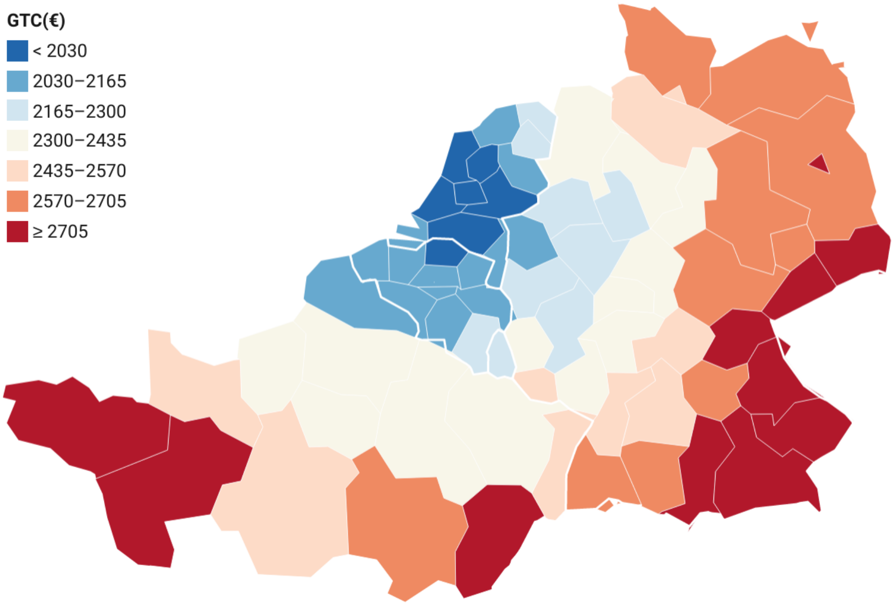


Figure B.5.6 Transport SSS+Road GTC

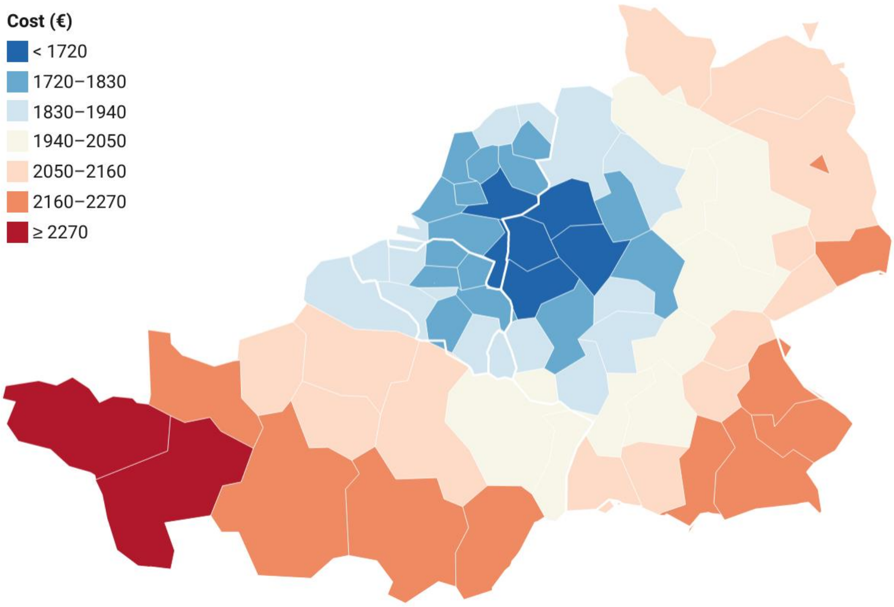


Figure B.5.7 Transport SSS+Rail+Road total cost

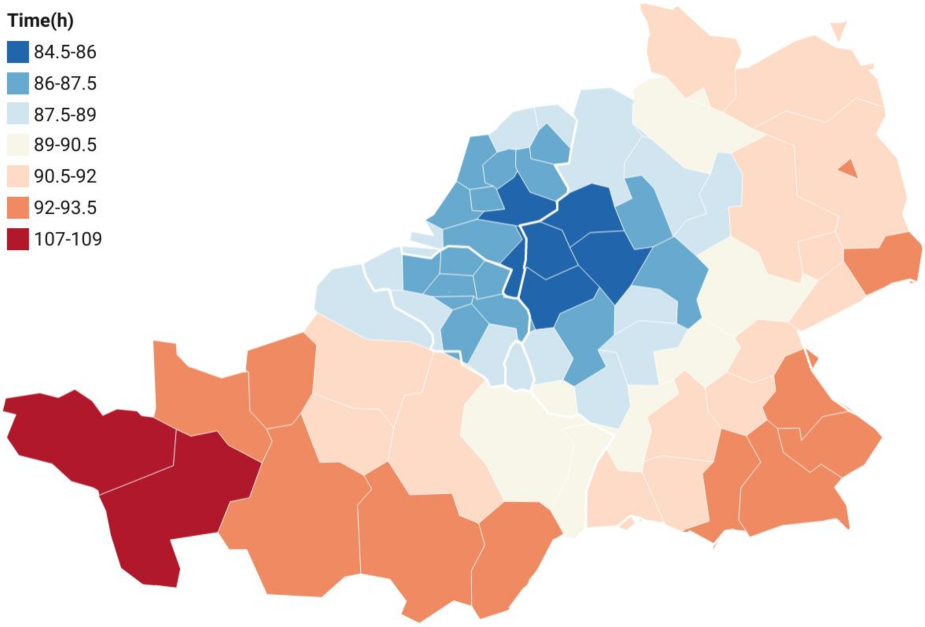


Figure B.5.8 Transport SSS+Rail+Road total time

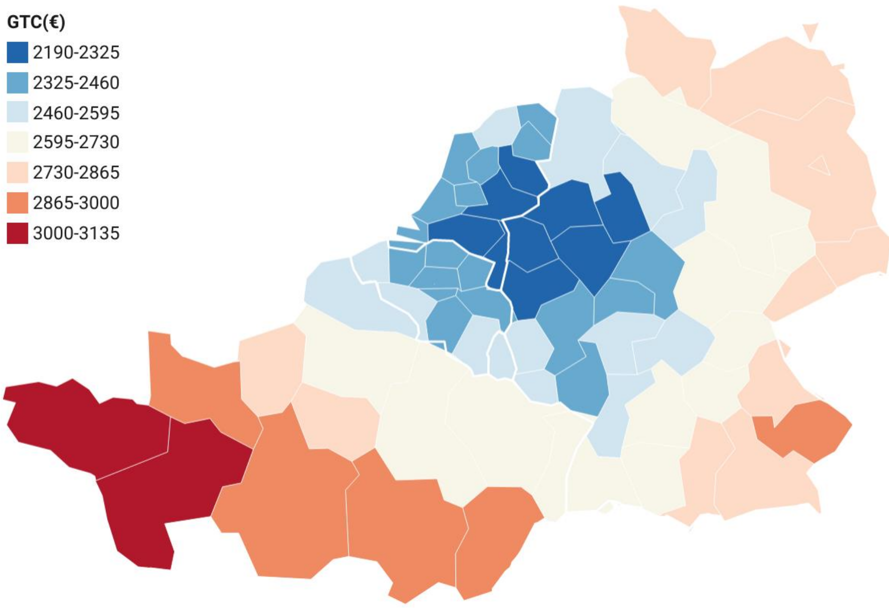


Figure B.5.9 Transport SSS+Rail+Road GTC

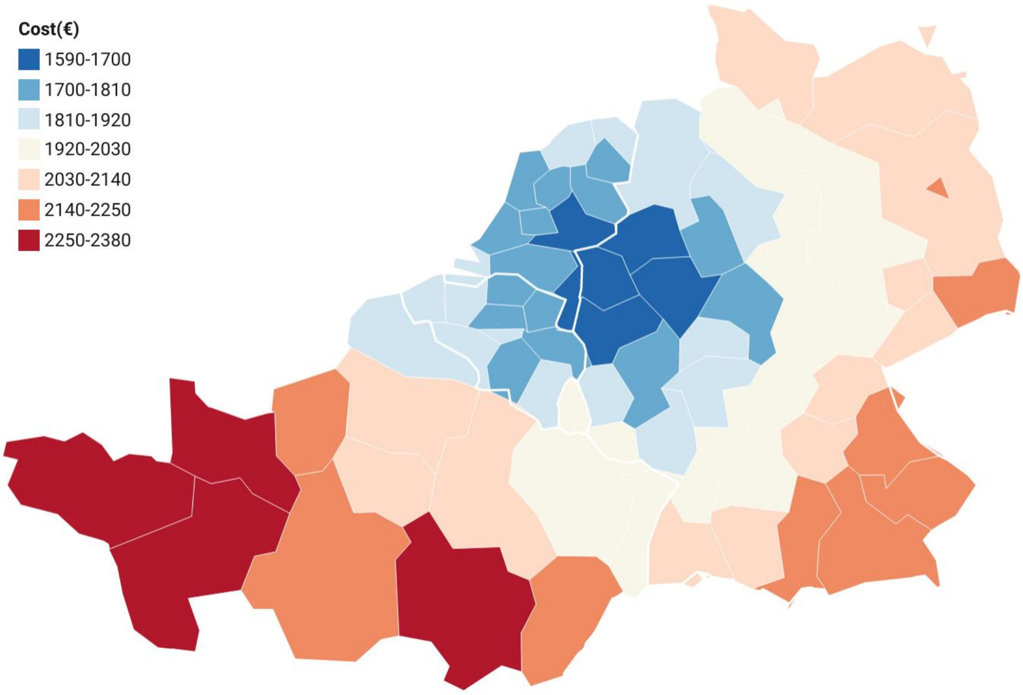


Figure B.5.10 Transport SSS+IWW+Road total cost

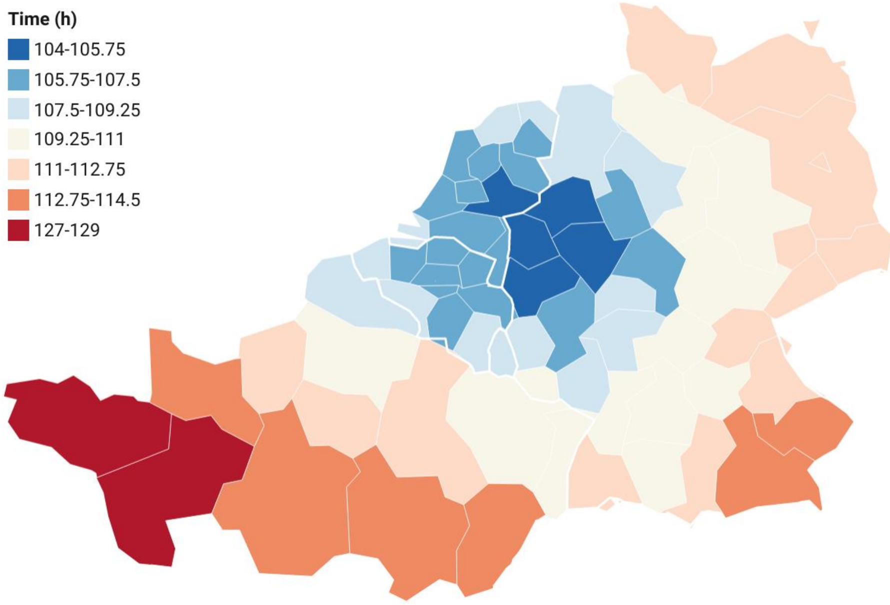


Figure B.5.11 Transport SSS+IWW+Road total time

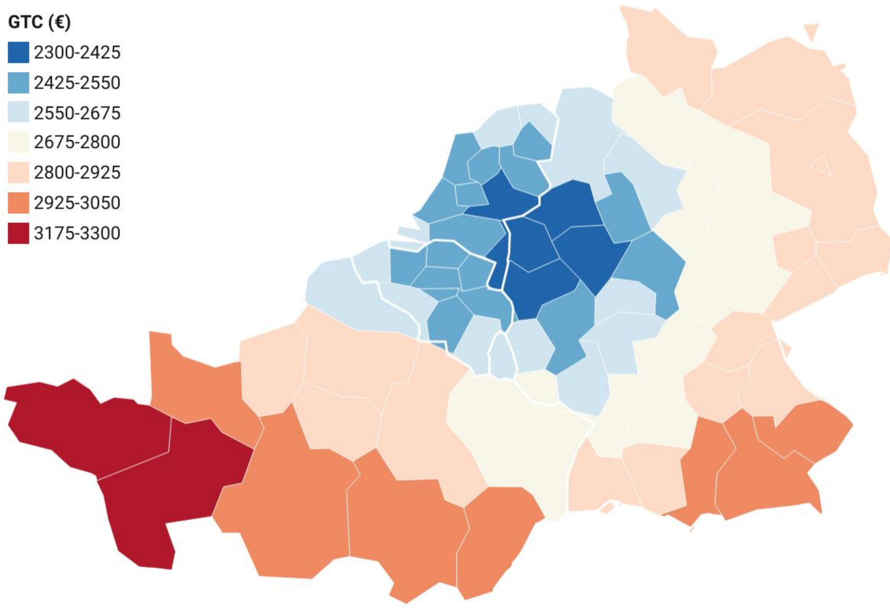


Figure B.5.12 Transport SSS+IWW+Road GTC

Appendix C - Numerical results for cargos with origin in Bragança

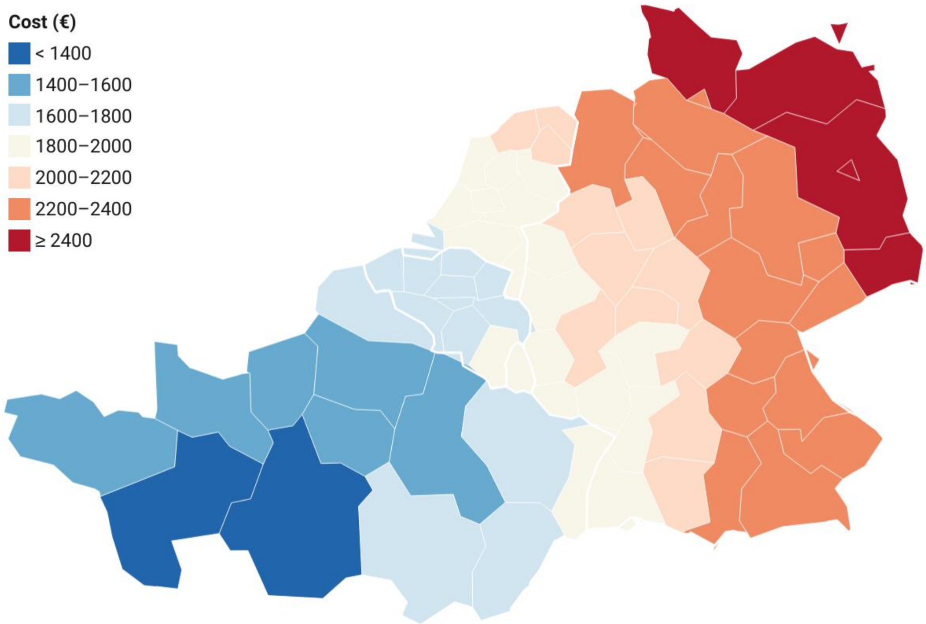


Figure C.5.1 Transport road total cost

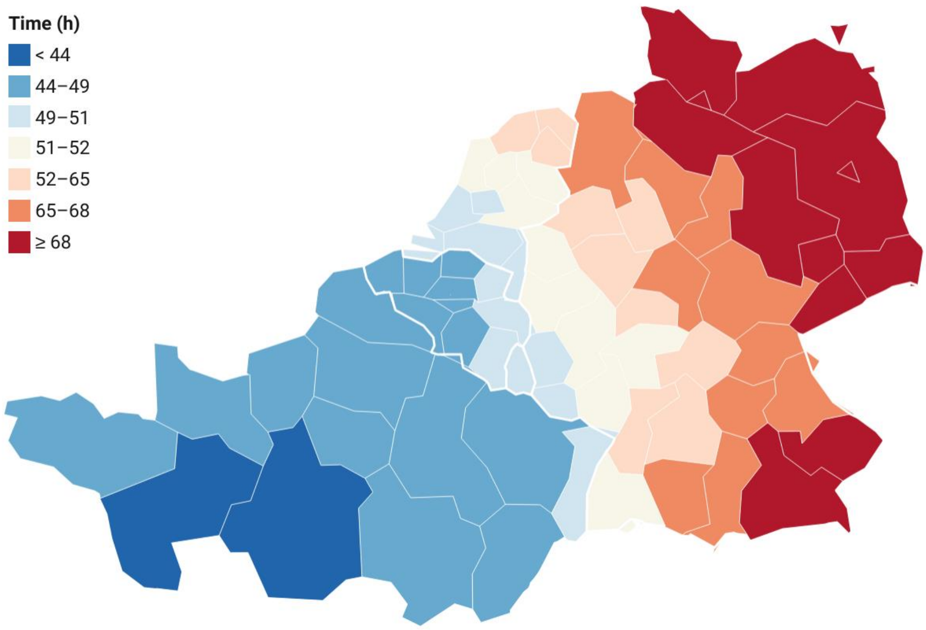


Figure C.5.2 Transport road total time

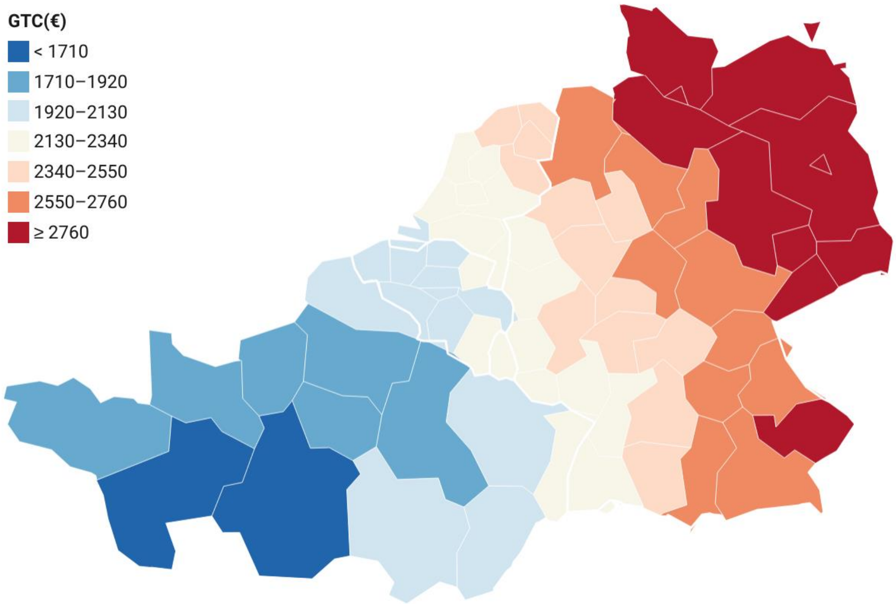


Figure C.5.3 Transport road GTC

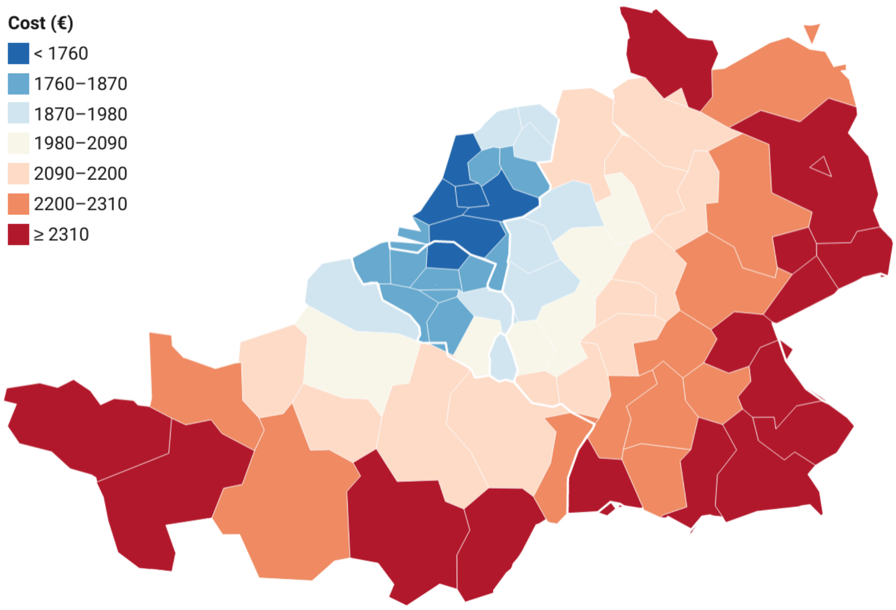


Figure C.5.4 Transport SSS+Road total cost

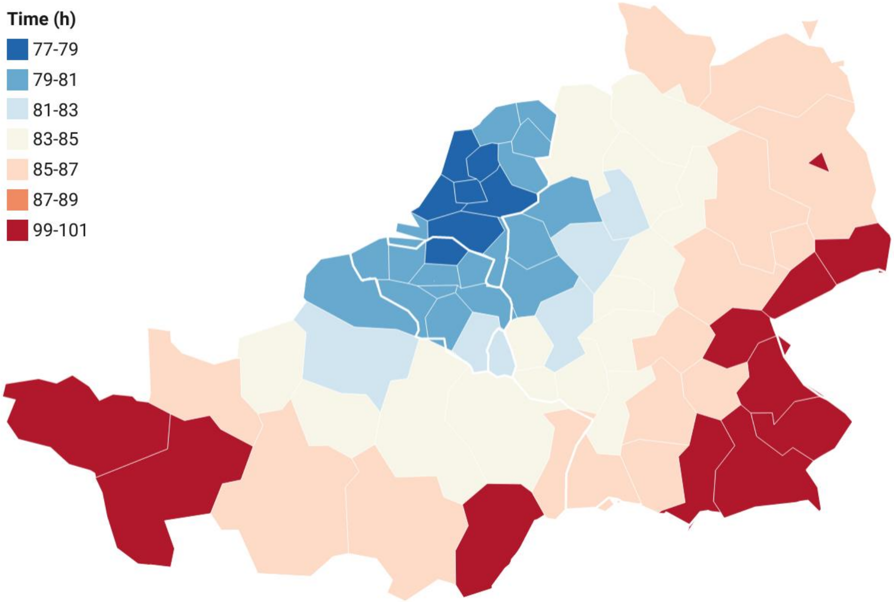


Figure C.5.5 Transport SSS+Road total time

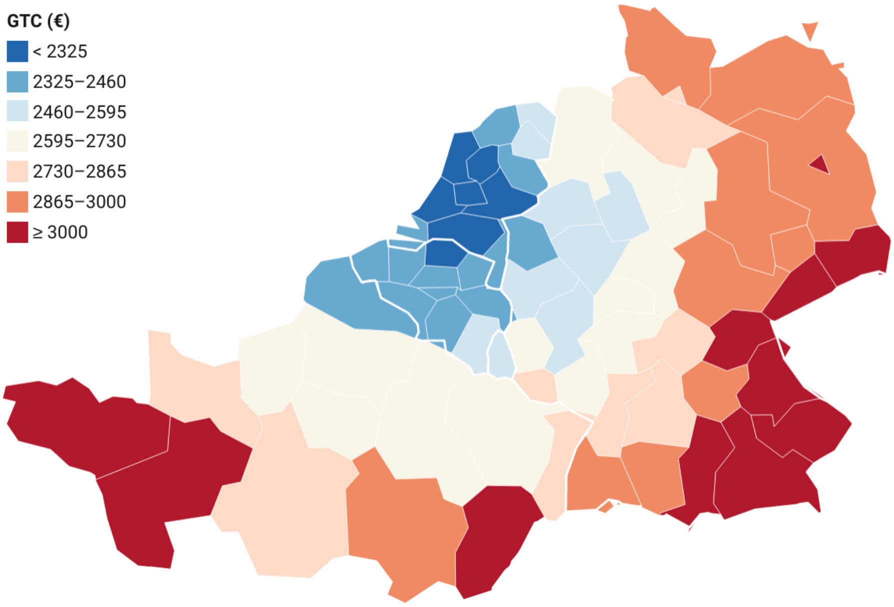


Figure C.5.6 Transport SSS+Road GTC

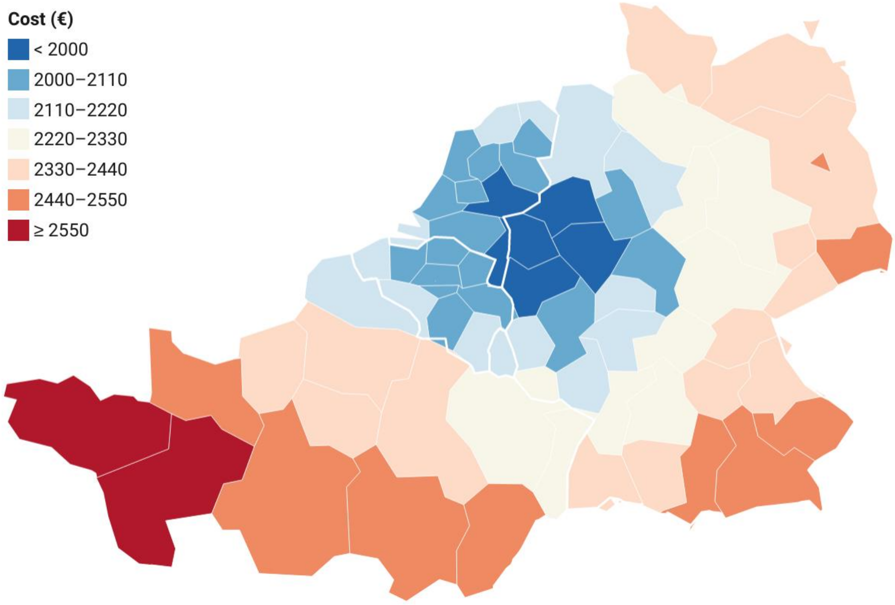


Figure C.5.7 Transport SSS+Rail+Road total cost

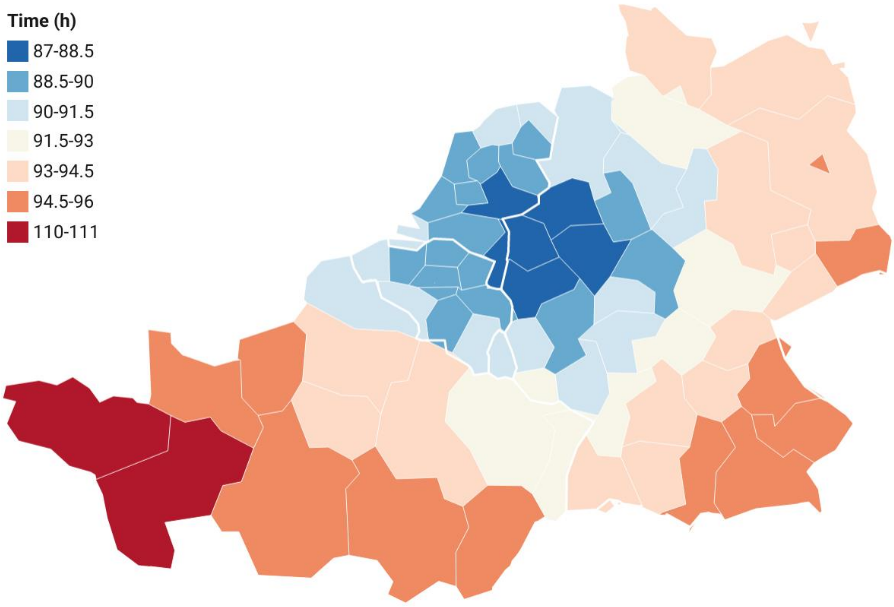


Figure C.5.8 Transport SSS+Rail+Road total time

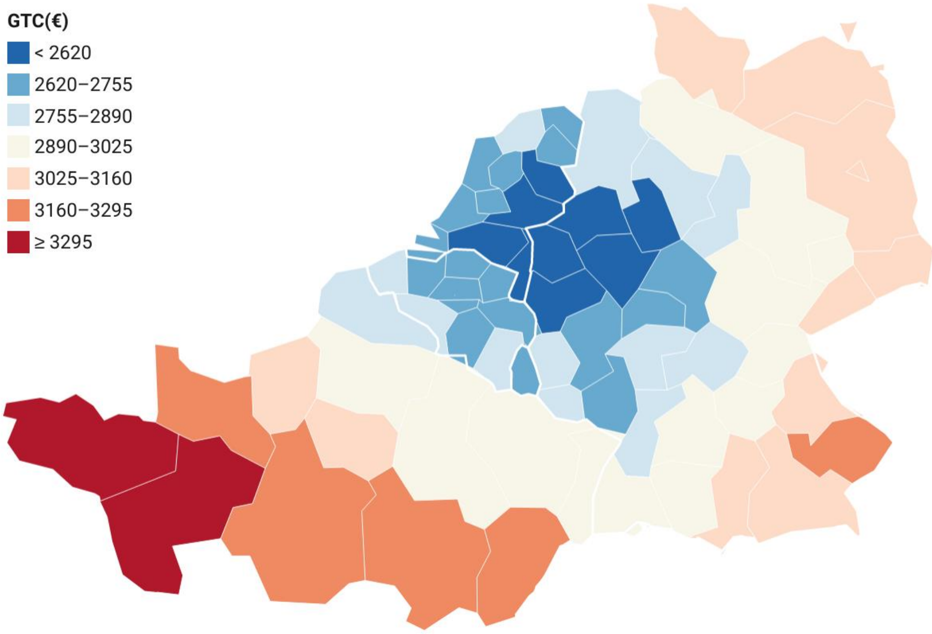


Figure C.5.9 Transport SSS+Rail+Road GTC

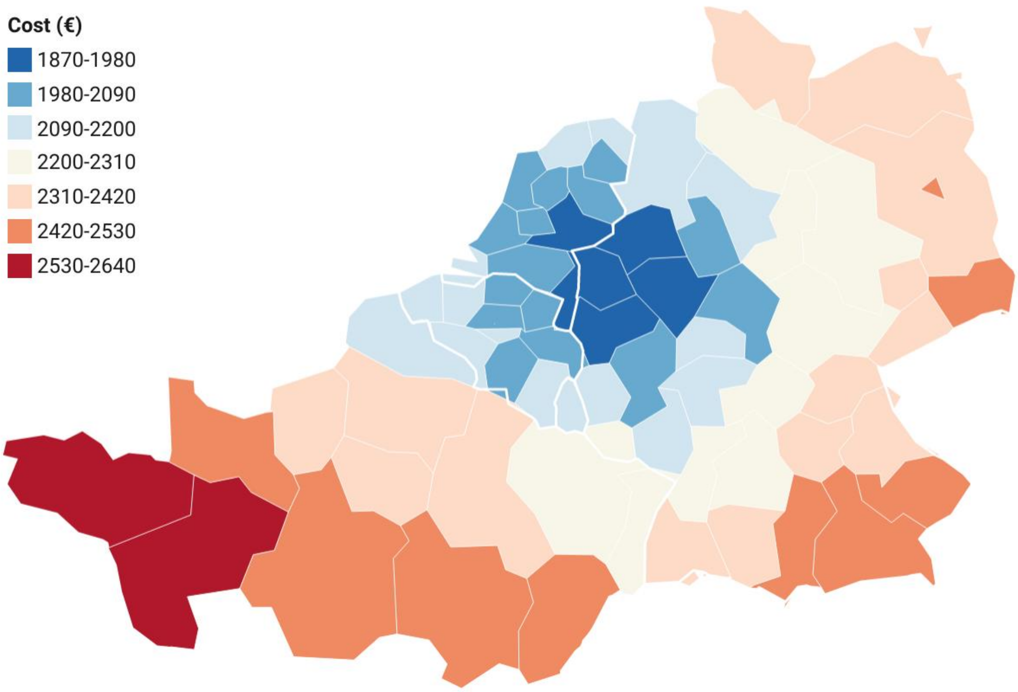


Figure C.5.10 Transport SSS+IWW+Road total cost

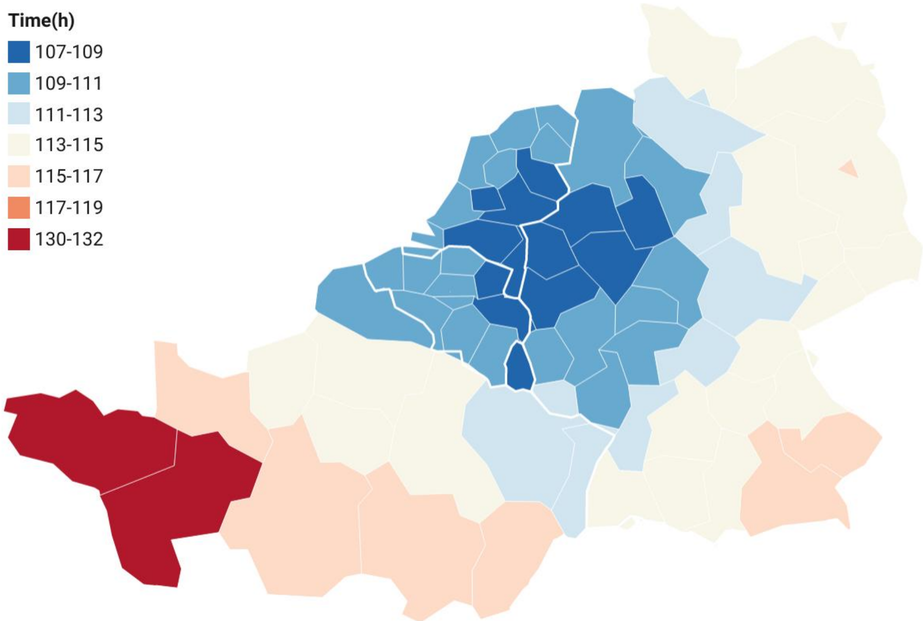


Figure C.5.11 Transport SSS+IWW+Road total time

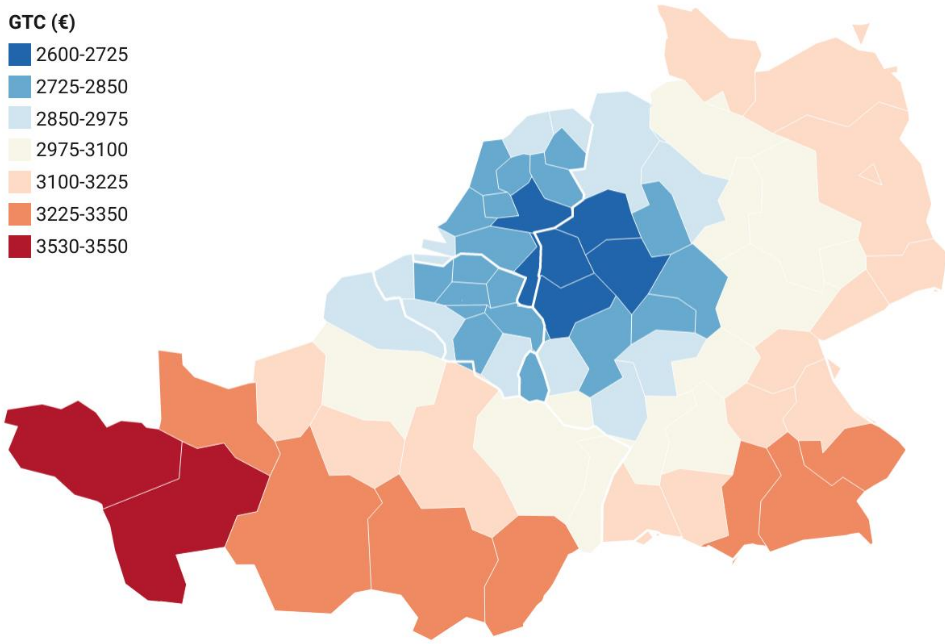


Figure C.5.12 Transport SSS+IWW+Road GTC