Container terminal hinterland characterization in the Portuguese port system

Lucas Blunck Salazar Santos

Instituto Superior Técnico, Universidade de Lisboa, Portugal

ABSTRACT: The economic influence of a seaport depends not only on the distance, but also on the effectiveness of connections to different inland locations. In order to improve the competitiveness of a seaport in a geographical region, intermodal transport is being used to make the best of the transportation infrastructure. This paper presents a potential hinterland characterization for the Portuguese port system, as regards containerized cargo. The hinterland of these terminals were analyzed using a software developed in CENTEC (Intermodal Analyst), with regard to the transportation cost, transportation time and generalized transportation cost considering two scenarios, the first one with road only transportation and the second one adding an intermodal option to the port of Sines. The numerical results are shown using a Geographic Information System (GIS) tool, which allows a good visualization of the impact that intermodal transport has in the inland influence of a port. The results of this study show that intermodal transportation can help improve the inland influence of a seaport only in locations far from the container terminal, as the combination of rail and road transport is more competitive for longer distances in terms of cost, but at the same time transportation time is higher for intermodal options when compared to road only transportation.

1 INTRODUCTION

As intermodal freight transport gains importance over the last decades because of the containerization process that the world economy went through, distance is no longer considered the parameter that better reflects the economic influence of a seaport on land and became only one of the factors to be analyzed. The effectiveness of the port's inland connections is now of great importance and intermodalism is an alternative to enhance this characteristic (Ferrari et al., 2011).

Intermodal transportation is described as the combination of at least two modes of transport (mainly road, rail and water) to move goods in the same loading unit and it gets growing recognition from policy makers, practionners and academics as an important alternative to solve the congestion and it is also, in most cases, more environmentally friendly than unimodal road transportation for the carriage of goods. In this sense, the European Commission encourages through their latest White Paper the efficient use of co-modality, shifting road freight to more environmentally friendly modes such as rail and waterborne transport in order to reduce transport-related greenhouse emissions. An important objective of the Commission therefore is to increase the share of intermodal rail and barge transport through an efficient use of co-modality. Regarding long distance transport, more than 50% of road freight should shift to more environmentally friendly modes such as rail and waterborne transport. But also on shorter distances intermodal transport can prove to be cheaper in certain cases, decreasing the external effects caused by freight transport (Meers et al., 2014).

Intermodalism is a tool of inestimable value to shippers which has given them greater choice of routings and a technique to lower costs by enabling them to select carrier combination and vehicles which offer most efficient service at least expense (Chanda, 2004). However, combined transport must still demonstrate that it can compete with road transport and this option might be successful because of reliability and the possibility to massify flows. Despite being an option to enhance the port's hinterland connections and also more sustainable than road-only transport, it can be argued that the price remains, quite often, the critical factor to be studied before adopting intermodal hinterland transport (Frémont et al., 2010). Also, successful intermodal transport also requires a conducive administrative and legal environment, and interchange of information. Also, one of the main keys to intermodalism in a transfer between modes is coordination amongst multiple freight transportation providers (Chanda, 2004).

In the context of modal change, Geographic Information System (GIS), as a spatial information system, can represent realistically the geometry of transportation networks and is used to model hinterland intermodal transportation (Deloukas et al., 1997). GIS tools are intended to support policy makers in evaluating the impact of technological, infrastructural or legislative actions as well as freight transportation during the choice of paths and transport modes, by analyzing and comparing the adoption of the aforementioned actions in different scenarios (Gianpiero et al., 2015).

Nowadays GIS applications are used by transportation analysts and decision makers in order to evaluate the adoption of measures at different levels of the logistic chain: infrastructure planning, traffic analysis, transportation safety analysis, environmental impacts assessment, etc. One of the main advantages that GIS provides is to offer a platform for managing information sharing among various actors in the transport decision making process. GIS enables a continuous analysis and revision of plans, at any point in the process: the inputs received by different stakeholders pertaining to the process can be easily integrated by also providing an advantage for analysis and presentation of the results (Gianpiero et al., 2015).

Traditionally, GIS has been applied to two-dimensional analysis on strictly spatial data. Such applications include traditional urban planning and mapping, particularly demographic data, marketing, and real estate analysis. In additional, usage in natural sciences and water and environmental engineering has become norm (Standifer et al., 2000). As for transport planning, the main use of GIS is data collection, management and display of model inputs and outputs and it requires high quality of the data (Berglund, 2001).

In order to reduce the use of road-only transport, the location of intermodal terminals, where the transshipment of goods take place, and the density of the terminal network are crucial factors to be analyzed. This location analysis can be efficiently done using GIS tools, which are composed of different transport networks, locations of terminals and their associated costs, and allows the user to make ex-ante and ex-post analysis of policy measures to stimulate the intermodal transport market. This way, GIS and transport modelling are closely related, as it is capable of capturing, management, analysis and visualization of spatial data (Macharis et al., 2009).

An important application of GIS in Europe is the location analysis model for Belgian intermodal terminals (LAMBIT), which is scaled on the Belgian intermodal network and analyzes the potential market area of a new terminal and assesses the impacts on existing terminals. The LAMBIT also compares barge/road and rail/road intermodal chains to unimodal road transport within Belgium (Macharis et al., 2011).

Considering the increasing relevance of intermodalism in the port hinterland connections and the importance of Geographic Information Systems (GIS) tools to model transportation networks, this thesis will review the literature on container port and terminal delimitation, in which the Portuguese port system is to be analyzed and existing models of hinterlands for containerized cargo are to be described.

A software for calculating transportation costs, transit times and generalized cost of transportation, for containerized cargo in the Portuguese hinterland and cross border Spanish provinces, is to be used and its results analyzed. Finally, a GIS tool is to be used to display the results of the models (transit times, transportation costs, generalized cost, hinterland contestability, cost reductions offered by intermodalism) per Portuguese municipality and Spanish comarca.

The rest of this paper is structured as follows. Section 2 contains the literature review over intermodal freight transportation and geographic information systems. The logistic infrastructure in Portugal is discussed in section 3 and geographic information systems applied to hinterland analysis is introduced in section 4. The hinterland analysis in Portugal and all results obtained are shown in section 5 and conclusions are drawn in section 6.

2 LITERATURE REVIEW

2.1 Intermodal Freight Transportation

In the present competitive environment of ports, the key determinant in port competition is the ability of a port to be integrated into the local maritime and hinterland transportation chain. Creating effective integrated hinterland chains requires the coordination of several actors both in port and the hinterland (Franc et al., 2010). The term hinterland often refers to the effective market or the geo-economic space in which the seaport sells its services (Bergqvist et al., 2015).

The concept of port hinterland deeply evolved over the years following the transformations that occurred in the maritime transport industry. A hinterland is the inland area from where a port produces the majority of its businesses. Concretely, the catchment area of a port is the scatter of inland points of cargo origin/destination generating the traffic flows passing through a specific port. In abstract terms, the traditional concept of hinterland conceives it as the area whose contour is a continuous line bounding the port economic influence on shore (Ferrari et al., 2011). On the other hand, the containerization process and the development of intermodal transport networks have led to a competitive scenario in the port sector and have modified their hinterlands all over the world. Those hinterlands are no longer captive areas of one port but competitive areas among two or more ports. The hinterlands of the port of Rio Grande, in Brazil, is shown in Figure 1 (Pizzolato et al., 2010).

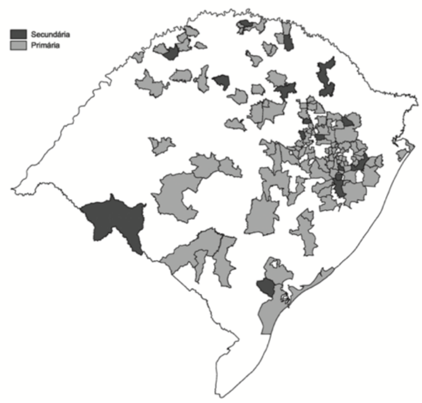

Figure 1: Hinterlands of the port of Rio Grande, Brazil – Pizzolato et al., 2010

A port hinterland is also interconnected to its foreland, which was first defined about 50 years ago, described as the land area which lied on the seaward side of a port, beyond maritime space, and with which the port was connected by ocean carriers. Also, later definitions treated foreland as overseas area with which the port carried out trade. The strong interdependency between a port's foreland and hinterland is very apparent when considering the rise of containerization and intermodality. Increased supply chain integration has made that the separation of foreland and hinterland relationships of a port into two neatly labeled packages representing dichotomy that is been questioned. The limits of the hinterland and the characteristics of the foreland are in effect interdependent variables which cannot be separated (Rodrigue et al., 2010).

Port hinterland services mostly rely on road transport in Europe. However, the enduring growth in port traffic is challenging the dominance of road for hinterland services because of costs, congestion and growing environmental constraints. For hinterland transportation high volumes are achieved by using rail-road or waterway-road transport. The ability of transport operators to attract freight from the hinterland at the lowest possible cost and with reliable and regular services is an essential condition for them to gain or maintain an advantage in a competitive environment (Frémont et al., 2010).

An increase in fuel price potentialize the market areas of intermodal terminals. An interesting situation for intermodal transport is created when the fuel price increases, making the break-even distance smaller due to the stronger price advantage for intermodal transport on the long haul (Macharis et al., 2010). When the value of time is taken into consideration to compare intermodal transport and road transport costs, it is possible to see that the types of goods in the containers have an important impact. If we have lower values of time for lower value goods, intermodal transport is more competitive than road only transport (Pekin et al., 2013).

In order to increase intermodal transport in short-distance hinterland container transport, it is necessary to provide daily services at a competitive price, providing more reliable services than road transport. Additional efforts should be made to correctly inform decision-makers on the available intermodal services (Meers et al., 2017). The variables used in the selection of the optimal terminal locations will severely impact the location choice. This way, depending on the perspective that is central in the decision making, different variables should be used and different terminal locations shall be given (Meers et al., 2014).

2.2 Geographic Information Systems

The Geographic Information Systems (GIS) were first invented in the decade of 1950, and since then has become an essential computational tool to represent geographic realities, manipulate and store a great amount of data and simulate different scenarios. GIS is an information system prevenient from other systems, as the Computer Aided Design (CAD), Data Base Management System (DBMS) and Remote Sensing Systems (RSS), and its functioning depends on the coordination between these systems, which will help obtain, manipulate and classify all data. It is possible to say that GIS is a spatial information system that aggregates technology elements (equipments and programs), data base (images, maps, statistical data), and personnel (trained users, maintenance and technical support). The capacity to process spatial analysis is what differentiates GIS from other information systems (Dantas et al., 1997).

In the transportation context, three classes of GIS models are relevant: Field models (representation of the continuous variation of a phenomenon over space), Discrete models (according to which discrete entities – points, lines or polygons – populate space) and Network models (represent topologically connected linear entities such as roads, rail lines or airlines (Thill, 2000). GIS is a product of increased computing power, improved database technology, and strengthened Computer Aided Design (CAD) capabilities. GIS represents the fusion of these technologies into one product designated to display, query, and manage, and manipulate spatial data (Standifer et al., 2000).

In transport planning using GIS, the inclusion of spatial effects in regression models is important, since the best results are obtained with alternative models (spatial regression models or the ones with spatial variables included) (Lopes et al., 2014). On the other hand, a simple GIS-based tool developed to allow rapid analysis of accessibility by different transport modes uses generalized cost to measure transport costs across networks including monetary and distance components. This tool allows many alternative scenarios of transport infrastructure and policies to be easily compared and tested (Ford et al., 2015).

The GIS network has two main tasks. First of all, it visualizes the real transportation network including the terminals. The second and vital characteristic of the network is its capability in serving as a database to include transport prices (Macharis et al., 2011). A GIS-based model can provide a comprehensive set of parameters dealing with policies, rail and road infrastructures, transport units, vehicles and loading systems. It also compares transport alternatives based on the current market prices for each transport mode and enables the definition of various scenarios such as the introduction of new policies/taxes or innovative hub infrastructures and policies. Another important characteristic is that GIS enables a continuous analysis and revision of plans, at any point in the process: the inputs received by different stakeholders pertaining to the process can be easily integrated by also providing an advantage for analysis and presentation of the results (Gianpiero et al., 2015).

3 LOGISTIC INFRASTRUCTURE IN PORTUGAL

3.1 Portuguese Ports

Portuguese ports have come to be known as the ‘Portuguese range’, comprising a set of ports located in the west coast of the Iberian Peninsula, currently serving primarily the Portuguese hinterland but also the cross-border regions of Spain and, to a lesser extent, the region of Madrid. This group of ports includes Leixões, Aveiro, Lisbon, Setúbal and Sines (main ports) but also two smaller commercial ports: Viana do Castelo and Figueira da Foz. Grouped in a multi-port gateway region, these ports are directly connected to one of the main European Union rail freight corridors and possess a natural competitive advantage as a gateway to foreland regions along the Atlantic Ocean, such as Latin America, North America and West Africa (Santos et al. 2017).

These ports include one or more container terminals per port, the most notable case being Lisbon. The main container terminals in the “Portuguese range” are Terminal XXI, located in the port of Sines; TCL, in the port of Leixões; Sadoport, located in the port of Setubal, and finally Sotagus and Liscont, located both in the port of Lisbon. The map represented in Figure 2 shows the geographical location of the ports and terminals in the “Portuguese range”.

Figure 2: Location of ports and container terminals in the “Portuguese range” – Santos et al. 2019

Figure 3 shows the number of TEU handled throughout the last 10 years, being noteworthy mentioning that Terminal XXI stands out because it is also a transshipment hub (80%) (Santos et al. 2019).

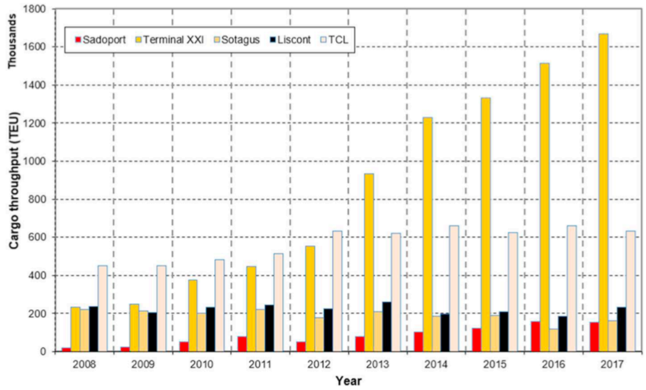

Figure 3: Container traffic in terminals 2008-2017 – Santos et al. 2019

3.2 Road and Rail Transport in Portugal

Over 235 million tons of goods were transported in Portugal in 2013, in which road transport represented 62,67% of this total, maritime transport 33,29%, rail transport 3,95% and air transport only 0,09% (Martins, 2015).

At the end of 2013, Portugal had 14310 Km of roads, 3065 Km of which were highways and 83% of all goods transported by road had as a final destination Spain, France, Germany, Italy and The Netherlands (Martins, 2015). The quantities of cargo transported by road in Portugal from 2015 to 2018 are represented in Table 1 (Anuário Estatístico da Mobilidade e dos Transportes, 2018).

Table 1: Quantity of cargo transported by road – Estatísticas dos Transportes e Comunicações (INE)

Cargo Transported	2015	2016	2017	2018
1000 TON	162956	148532	157590	156658

As for its rail transport, there were 3619,3 Km of railways in Portugal, 2544,4 Km of which were being used in 2013 (Martins, 2015). The quantities of cargo transported by rail in Portugal from 2015 to 2018 are represented in Table 2 (Anuário Estatístico da Mobilidade e dos Transportes, 2018). It is also important to mention that rail transport is the most operational efficient, economic, sustainable and less bureaucrat option in order to improve maritime flow through inland connections. Also, railways have the potential to optimize the whole transportation process by adopting new information and communication technologies, which impact directly container terminals operations (Tonga, 2018).

Table 2: Quantity of cargo transported by rail – Estatísticas dos Transportes e Comunicações (INE)

Cargo Transported	2015	2016	2017	2018
1000 TON	11094	10378	10632	10634

3.3 Multimodal Terminals

A multimodal terminal is usually directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport. Also known as dry ports, these multimodal terminals frequently use railways to move cargo.

4 GEOGRAPHIC INFORMATION SYSTEMS APPLIED TO HINTERLAND ANALYSIS

As mentioned in previous sections, the purpose of this thesis is to use a Geographic Information Tool in order to represent graphically the results of numerical models related to the transportation of general cargo (containerized or not) from locations across Portugal and in some regions of Spain, to Portuguese container terminals. The GIS software used in this thesis is QGIS and the inputs used were provided by the Intermodal Analyst software.

4.1 Geographic Region Model

Generally, cargos are considered to be concentrated in the main cities and towns corresponding to capitals of Portuguese municipalities or of Spanish comarcas (covering the cross-border provinces of Badajoz, Caceres, Salamanca and Zamora). The equivalent to Portuguese municipalities in Spain is the *ayuntamiento* but these were found to be too small in comparison with Portuguese municipalities. Therefore, a larger administrative unit, the comarca, was chosen to be used in this model.

The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the European Union and the United Kingdom for the purpose of the collection, development and harmonization of European regional statistics. This division is also important to do a socio-economic analysis of the regions, where NUTS-1 are major socio-economic regions, NUTS-2 are basic regions for the application of regional policies and NUTS-3 are small regions for specific diagnosis (Eurostat). Currently, Portugal has 308 municipalities which are divided in 25 NUTS-3 regions, 7 NUTS-2 regions and 3 NUTS-1 regions. As of Spain, the whole country has 7 NUTS-1 regions, 19 NUTS-2 regions and 59 NUTS-3 regions, with a total of 8124 municipalities.

4.2 Intermodal Analyst Software

The Intermodal Analyst is a Fortran coded software developed by Tiago Santos in the research unit CENTEC of IST, University of Lisbon. The objective of the software is to calculate the cost and time of transport between an origin and a destination. The origin is considered to be the 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. The voyage undertaken by the cargo may be unimodal or intermodal and the typical cargo considered is equivalent 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 inland waterway (barge) (Intermodal Analyst User Manual, 2020).

The software is controlled with a log file, which receives the input data files, in txt format, that contains the network database, cost database, path database and also the cargo database. This information allow the software to calculate the cost/time results, cargo distribution and the paths as links, which are the output data files given by the software, also in txt format.

In the transport network defined in the database, there are transportation nodes and links. Transportation nodes may represent road junctions, rail junctions, inland waterway junctions, seaport terminals, intermodal terminals or cities. Also, sea routes may have nodes inserted at suitable points and border between countries are also supposed to be represented by nodes. After the node definition, the links are defined, which may be roads, motorways, urban (streets), rails, inland waterways, container ship sea routes or Ro-Ro ship sea routes (Intermodal Analyst User Manual, 2020).

Assume a transportation network with N nodes L and links, with n and l representing individual nodes and links. Links are characterized by attributes such as the length of each link, d_l, and the average speed in the link, s_l. As for the nodes, they are characterized by the time spent in each node, which is zero unless for intermodal and seaport terminals, where this attribute is t_n and t_s, respectively. The time spent in terminals, t_n and t_s, are composed of the waiting time at the gate, time required to handle the containers and the dwell time in the storage yard (Santos et al., 2019).

Taking in consideration this, the total accumulated transit time through an individual path is given by equation 1, where δ_{rl} is a binary variable to consider whether the link is used in route r or not and δ_{rn} is a binary variable to consider whether the node is used in route r or not (Santos et al., 2019).

$$T_r = \sum_{l=1}^{L}(\delta_{rl}.d_l.s_l) + \sum_{n=1}^{N}(\delta_{rn}.d_n.s_n) + t_s \quad (1)$$

The cost model used in this software comprises separate costs associated to road and rail on a per TEU.km basis (c_{l-road} for specific transport cost by road and c_{l-rail} for specific transport cost by rail), which are user specified and correspond to average costs as perceived by the user of the transportation network. Also, costs are specified in certain nodes of the network where container handling occurs, such as intermodal terminals and seaport terminals. In the first case, the cost of unloading and loading the container from the truck or train to/from the container yard is C_{nu} and C_{nl}. As for seaport terminals, these same costs are defined by C_{su} and C_{sl} (Santos et al., 2019).

Finally, storage of containers in intermodal and seaport terminals may also have additional costs, depending on the number of free days, t_f, allowed by the terminal operator. The number of free days and the daily storage cost, c_{nSt} and c_{sSt}, are used to calculate the storage costs in intermodal terminal n and in seaport terminal s, as shown in equations 2 and 3 (Santos et al., 2019).

$$C_{nSt} = (t_n - t_f).c_{nSt} \quad (2)$$

$$C_{sSt} = (t_s - t_f).c_{sSt} \quad (3)$$

Considering the definitions presented so far, the total cost in a given path r may be calculated as follows in equation 4:

$$C_r = [\sum_{l=1}^{L}(\delta_{rl-road}.d_{l-road})].c_{l-road} + [\sum_{l=1}^{L}(\delta_{rl-rail}.d_{l-rail})].c_{l-rail} + \sum_{n=1}^{N}[\delta_{rn}(C_{nu} + C_{nl} + C_{nSt})] + C_{su} + C_{sl} + C_{sSt} \quad (4)$$

The generalized cost in path r, C_{gr}, is then calculated as a function of total cost C_r, transit time T_r and the value of time (VOT) for the cargo in the container:

$$C_{gr} = C_r + VOT.T_r \quad (5)$$

After calculating the generalized cost associated with each path r from a load centre, c, to a seaport, s, it is possible do determine which path has the lowest generalized cost, as shown in equation 6, where Rcs is the set of paths between the load centre and seaport analyzed.

$$C_{g\,min_{cs}} = min(C_{gr})_{r\in Rcs} \quad (6)$$

Similarly, the seaport s with the lowest generalized cost for each load centre c is determined in equation 7, where S is the set of all seaport terminals available. This result is important because it shows which load centers are part of the main hinterland of the terminal.

$$C_{g\,min_c} = min\left(C_{gr_{min_{cs}}}\right)_{s\in S} \quad (7)$$

At last, the level of competition between seaport terminals is measured using the hinterland contestability index, CI_c.This index is defined as the number of seaport terminals presenting a generalized cost not higher than 25% of the minimum generalized cost among the studied terminals. In other words, CI_c is the cardinal of the set of terminals whose generalized costs are within the 25% range described in equation 8:

$$CI_c = card\{s: C_{g\,min_{cs}} \in [C_{g\,min_c}; 1.25 \times C_{g\,min_c}]\} \quad (8)$$

4.3 QGIS Software

The Geographic Information System tool used in this thesis is QGIS, which is a free software that supports numerous vector, raster and database formats and functionalities.

All transportation nodes used in this thesis were provided by the Intermodal Analyst software in *txt* format. This file contains several information about the nodes, such as cargo handling costs, cargo handling time, the identification of the node, its name and latitude and longitude coordinates. In order to represent the nodes in the map as points, it is necessary first to convert the file to *csv* format using excel, and then add it in QGIS as a delimited text layer. Additionally, it must be checked if the coordinate reference system in this new layer is the same as the one used in the project, if not, it must be changed. Figure 5 shows all transportation nodes in Portugal and the ones in the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain.

The Intermodal Analyst also provides all data to be uploaded to the maps, also in txt format, which again had to be converted into a csv file in excel in order to be used in QGIS. As the objective in this paper is to do an analysis among Portuguese and Spanish regions, it was necessary to add layers with the administrative areas of these countries to the project, using shapefiles. These shapefiles containing the cities of Portugal and the counties of the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain, were downloaded from DIVA-GIS website, which provides free spatial data for the whole world, that can be used in all GIS related tools, and also from the website of the ministry of agriculture, fisheries and food from the government of Spain. After adding these layers, the Spanish counties outside the provinces of interest were deleted from the map, and both layers were merged using the merge vector layers option, under data management tools. Figure 4 and 5 shows the transportation nodes and the regions analyzed in this paper, respectively.

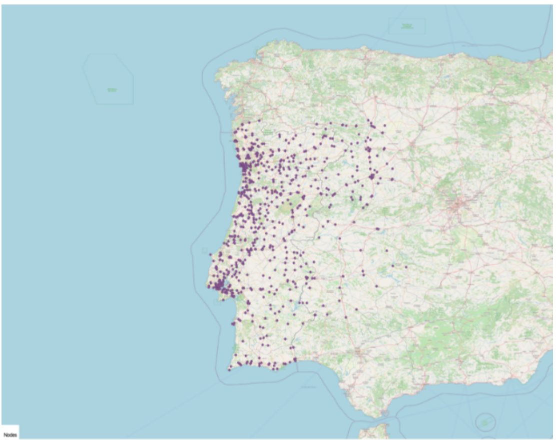

Figure 4: Transportation nodes in Portugal and in the provinces of Badajoz, Caceres, Salamanca and Zamora, in Spain

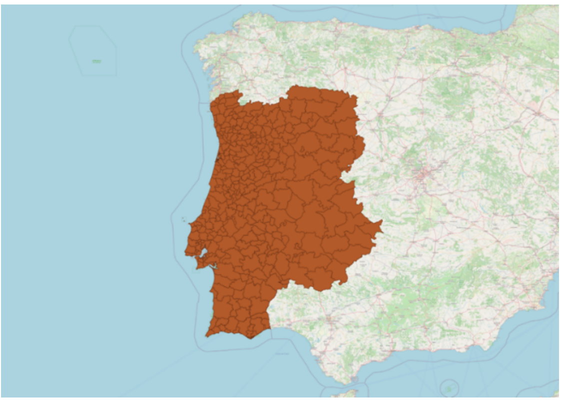

Figure 5: Portuguese cities and Spanish counties from the provinces of Badajoz, Caceres, Salamanca and Zamora

Once these layers were added to the map, their attribute table had to be checked in order to verify how the cities and counties were presented. As their names were used to identify each segment, and the data provided by Intermodal Analyst uses the nodes number, it was necessary to list all nodes and rename them using the exact identification shown in the attribute table of the layers.

Using this new identification, all data used must also be converted into a *csv* file before being able to add them to the project. After adding the *csv* files data to QGIS, they were joined to the administrative areas layer using the join command inside the layer properties. This new data, however, is recognized as a string by the software, and this way it is not possible to represent the data graphically. The conversion of the new data from string to real number is possible by using the toggle editing mode of the attribute table and writing a simple expression in the field calculator, using the *to_real* function.

5 APPLICATION TO HINTERLAND ANALYSIS IN PORTUGAL

The situation regarding containerized cargo in Portuguese ports is to be analyzed regarding the relative competitiveness of terminals. Container terminals to be considered are Leixões (TCL), Lisbon (Liscont and Sotagus), Setubal (Sadoport) and Sines (Terminal XXI).

In the first phase, only road transportation of containers will be considered from each municipality or comarca to every port terminal. In a second phase, rail transport of containers will be added as an option to certain port terminals: Sines Terminal XXI. Trains currently go to Sines from intermodal terminals in Leixões, São Martinho do Campo (Valongo), Entroncamento and Vale do Sado (Praias do Sado).

For the first phase, with no container rail transportation in operation, the transportation time, transportation cost and generalized transportation cost to a container terminal from all municipalities and comarcas will be analyzed. After this analysis, the minimum transportation cost, minimum transportation time and minimum generalized transportation cost from each municipality and comarca will be determined, making it possible to define the hinterlands of the analyzed terminals regarding these parameters. At last, it will also be determined the contestability index between terminals, which is the number of terminals for each municipality and comarca that have a generalized transportation cost within 25% of the most competitive terminal.

For the second phase, rail transportation will be included and the same analysis made in phase one will be done, but now only for Terminal XXI in the port of Sines. Also, it will be determined for which municipalities and comarcas it is better to use rail transportation based on the minimum transportation cost, minimum transportation time and minimum generalized transportation cost and in which cases the use of rail transport results in any savings when comparing to road only transportation.

Finally, the results from the first and second phases of analysis will be compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals.

5.1 Parameters Considered for each Terminal

The seaport terminals analyzed are defined by Intermodal Analyst using certain parameters, such as cargo unloading cost, cargo loading cost, average time in terminal, time of free storage, cost of storage and time of port call. The values considered for each terminal are described in Table 3.

Table 3: Parameters considered for each terminal

	Alcantara	Leixões	Santa Apolonia	Setubal	Sines
Cargo Unloading Cost (€)	30	0	23,2	29,5	27
Cargo Loading Cost (€)	118	142,2	110,4	152	115,5
Average Time in Terminal (h)	96	24	24	96	96
Time of Free Storage (h)	72	120	120	48	72
Cost of Storage (€)	1,09	1,79	1,45	0,5	2,68
Time of Port Call (h)	10	6	6	10	10

5.2 Road Only Transportation

First of all, it is important to mention that as regards the transportation cost, transportation time and generalized transportation cost from each municipality and comarca to the terminals, only the maps regarding the container terminal in Leixões will be presented in this section. The maps for the other analyzed terminals are available in the Annex C of this thesis. For the minimum transportation cost, minimum transportation time, minimum generalized transportation cost, the hinterlands of the terminals regarding these last parameters and also for the competition level, all maps will be presented in this section.

The results given by Intermodal Analyst from node 46 (Almada) to the analyzed terminals will be exemplified in Table 4.

Table 4: Results given by Intermodal Analyst from node 46 (Almada) to the analyzed terminals

Terminal	Transportation Cost	Transportation Time	Generalized Transportation Cost
	€	hours	€
Alcantara Terminal	64,00	1,06	540,47
Santa Apolonia Terminal	176,32	1,08	644,61
Setubal	178,20	0,76	692,26
Sines	267,20	2,25	752,41
Leixões	666,08	5,27	1176,66

5.2.1 Container Terminal Hinterland (as per transportation cost)

Figure 6 shows, for each municipality and comarca, the container terminal for which the transportation cost is lower. When the analyzed factor is the transportation cost, it is possible to see that the Port of Sines has a clear advantage in the municipalities in the region of Algarve, Alentejo Litoral, Baixo Alentejo, and for most municipalities in the center and north of the country, as well as comarcas in the provinces of Salamanca, Zamora and some comarcas in the province of Caceres, the port of choice would be Leixões if the decisive factor is the transportation cost only. The port of Setubal has lower transportation costs for Portuguese municipalities in located in Alentejo Central and some in Alto Alentejo and parts of the Lisbon metropolitan area, and also in comarcas in the province of Badajoz and some in the province of Caceres, in Spain. As for the terminals of Santa Apolonia and Alcantara, both located in the Lisbon metropolitan area, the first one has transportation costs advantages in most municipalities in Leiria, Médio Tejo, Leziria do Tejo, Oeste, and some in Alto Alentejo and in the Lisbon metropolitan area. Finally, Alcantara terminal is the one with the smallest hinterland in this scenario, being the best choice only for some municipalities in the Lisbon metropolitan area.

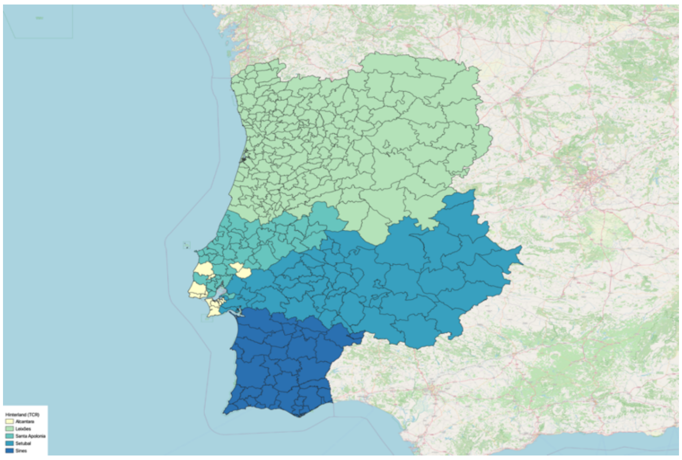

Figure 6: Hinterland (transportation cost – road only)

5.2.2 Container Terminal Hinterland (as per transportation time)

Figure 7 shows, for each municipality and comarca, the container terminal for which the transportation time is lower. The hinterlands of the analyzed terminals regarding the transportation time are almost the same as the hinterlands presented in the previous section, in which the transportation cost was the decisive factor.

When taking the transportation time into consideration, the terminal of Alcantara has a hinterland composed of only 5 Portuguese municipalities: Sintra, Cascais, Oeiras, Amadora and Barreiro in the Lisbon metropolitan area, and also the municipality of Batalha. Even though Batalha is located among other municipalities from the Santa Apolonia terminal hinterland, its transportation time to the terminal of Alcantara is 2,53 hours and to the terminal of Santa Apolonia is 2,54 hours. This result is understandable, as almost all municipalities in this range have similar transportation times to both terminals. This implies that the numerical results for the Alcantara and Santa Apolonia terminals are very close and any small variation may cause an "island" of hinterland such as this in Batalha to emerge. The conclusion is that as both terminals are in the same port, and are located not so distant from each other, their hinterlands are in fact very similar.

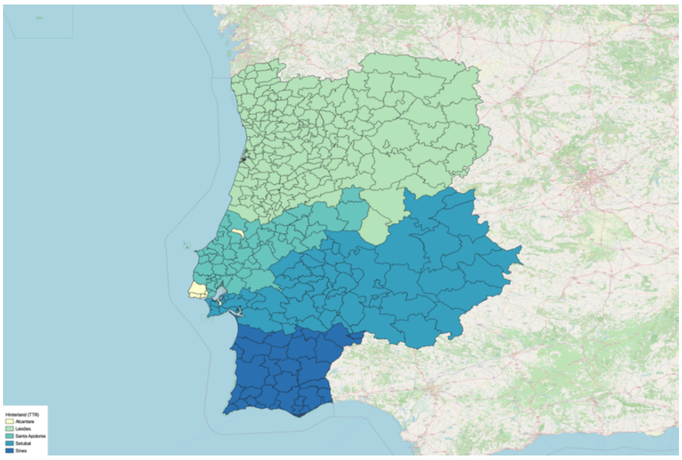

Figure 7: Hinterland (transportation time – road only)

5.2.3 Container Terminal Hinterland (as per GTC)

Figure 8 shows the minimum GTC for each municipality and comarca while Figure 9 shows, also for each municipality and comarca, the container terminal for which the generalized transportation cost is lower. As the GTC is calculated based on the transportation cost plus the dwell time in terminal, any inefficiency in terminal operation would reduce the hinterland of the terminal.

It is possible to observe that the hinterland of the Port of Sines and the hinterland of the Port of Leixões did not present any significant changes when compared to the hinterlands considering the transportation cost and transportation time. As for the Port of Setubal, it did lose part of its hinterland in Alentejo Central to the Santa Apolonia terminal, and Alcantara terminal continued to have a hinterland composed mainly of municipalities located in the Lisbon metropolitan area. In this scenario, in which the generalized transportation cost is the decisive criteria, the Port of Leixões has the largest hinterland, when compared to the other analyzed terminals. The Port of Sines, Setubal and the Santa Apolonia terminal present hinterlands with approximately the same area, and the terminal of Alcantara has a hinterland composed of only 7 municipalities in the Lisbon metropolitan area.

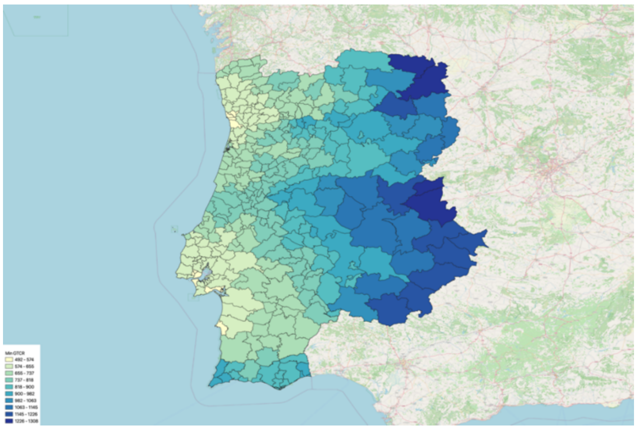

Figure 8: Minimum GTC (road only)

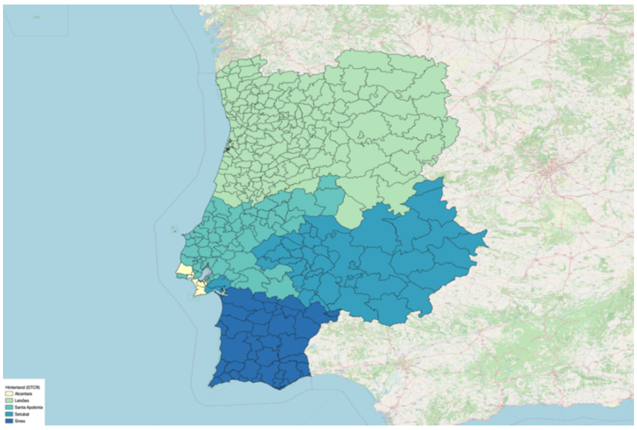

Figure 9: Hinterland (generalized transportation cost – road only)

5.2.4 Contestability Index

Figure 10 shows the contestability index per municipality and comarca. The contestability index is the number of terminals for each municipality and comarca that have a generalized transportation cost within 25% of the most competitive terminal. This was determined for each municipally and comarca, being possible to observe that the Port of Leixões has a clear generalized transportation cost advantage in the municipalities in the north of Portugal and in the comarcas of the provinces of Salamanca and Zamora in Spain.

As of the rest of the Portuguese municipalities and Spanish comarcas analyzed, most of them present between 2 and 4 terminals with the generalized transportation cost within 25% of the most competitive terminal, which means a significant competition between these terminals. In most comarcas of the province of Caceres and in some Portuguese municipalities close to the border between Portugal and Spain in the region of this same province, there is an even higher contestability index, indicating that any of the 5 terminals analyzed in this thesis are competitive in these locations. Finally, the Port of Sines has no significant competition in the municipalities of Sines and Odemira, in the south of Portugal, because of their proximity to the terminal.

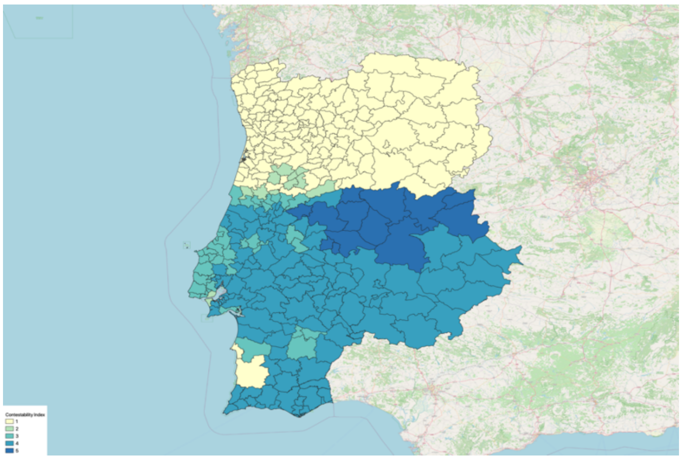

Figure 10: Contestability index

5.3 Rail and Road Transportation

In this second phase of analysis, 5 different road + rail paths were considered in order to analyze the influence of railways in the transportation cost, transportation time and generalized transportation cost to Terminal XXI in the port of Sines. Therefore, rail transport of containers will be added as an option to the port of Sines Terminal XXI. In any case, the containers are first carried to these intermodal terminals, loaded in the trains and carried by rail to Sines.

This scenario closely resembles the existing reality as trains currently go to Sines from intermodal terminals in Bobadela, Entroncamento, Leixões, São Martinho do Campo (Valongo) and Vale do Sado (Praias do Sado), ehich can be seen in Figure 11. Consequently, paths have been added in the data file, identified as 7, 7A, 7B, 7C and 7D.

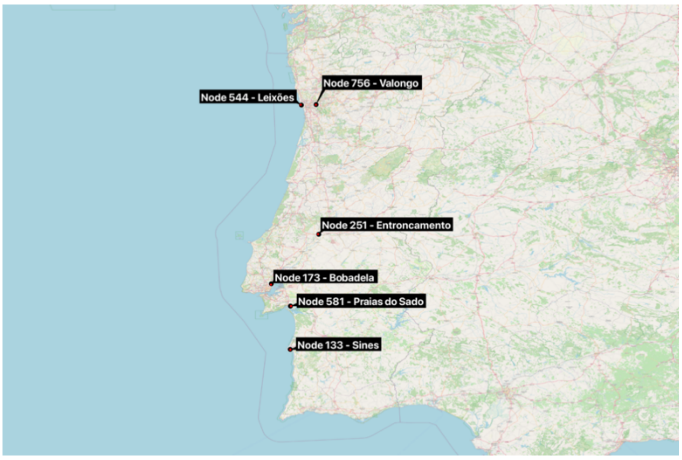

Figure 11: Intermodal terminals

5.4 Comparison Between Road Only and Road + Rail Transportation

The results from the first and second phases of analysis will be compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals.

5.4.1 Transportation Cost

Figure 12 shows the municipalities and comarcas for which it is preferable to use road only transportation or road + rail transportation, considering as criterion the transportation cost and Figure 13 shows the hinterlands considering the transportation cost. It can be seen that in this case, for some Portuguese municipalities in the center of the country, close to the border with Spain, as well as some comarcas in the provinces of Badajoz, Caceres and Salamanca, it is better to transport cargo to the port of Sines using a combination of road and rail modes. Also, the Portuguese municipalities of Entroncamento, Golegã in the Alentejo region, and Aljezur in Algarve should use this intermodal option to transport its cargo. Other than that, the hinterlands are similar to the ones when considering road only transportation.

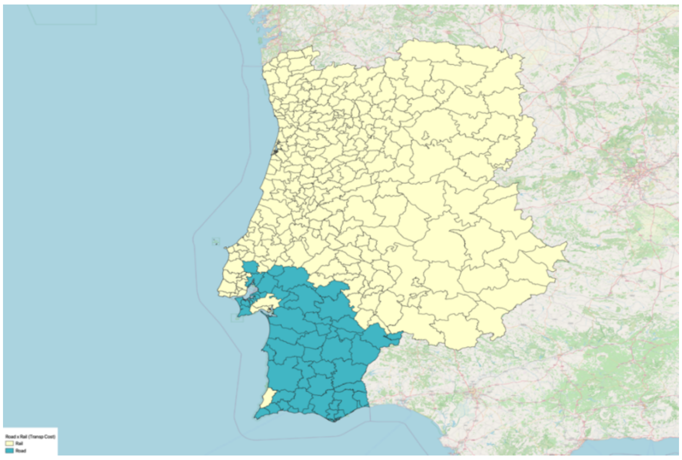

Figure 12: Road only transportation vs road + rail transportation hinterlands considering the transportation costs

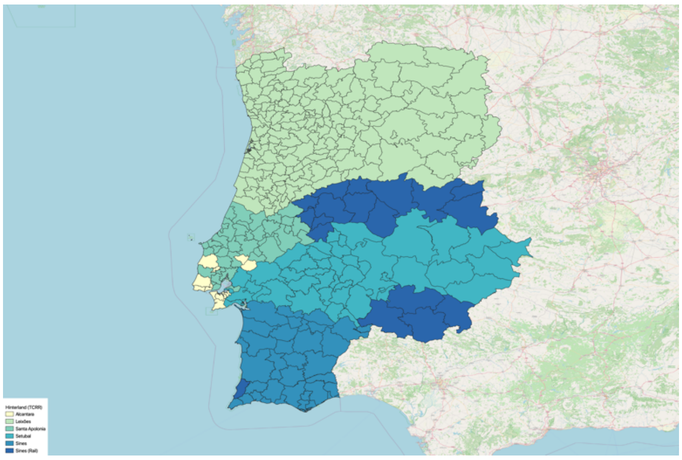

Figure 13: Hinterlands when considering road only and road + rail transportation (as per transportation cost)

5.4.2 Transportation Time

As for the transportation time, there are no changes in the hinterlands when considering road only transportation or when including the intermodal option, because the transportation times using railways are much higher than the ones using roads.

5.4.3 Generalized Transportation Cost

As for the GTC, there are also no changes in the hinterlands when considering road only transportation or when including the intermodal option. This occurs because transporting cargo by rail is economically viable for longer distances, which is not the case in the region analyzed. In this case, the distances between the Portuguese municipalities and Spanish comarcas to any of the analyzed terminals range from short to medium, in which road transportation is overall cheaper than rail transportation. Figure 14 shows the savings in GTC (in Euros) offered by having an intermodal transport option in operation (road + rail) and in competition with road based transportation. It is worth reminding that the rail option is always directed to the terminal in Sines. The minimum GTC for each municipality and comarca when considering both options of transport is shown in Figure 15.

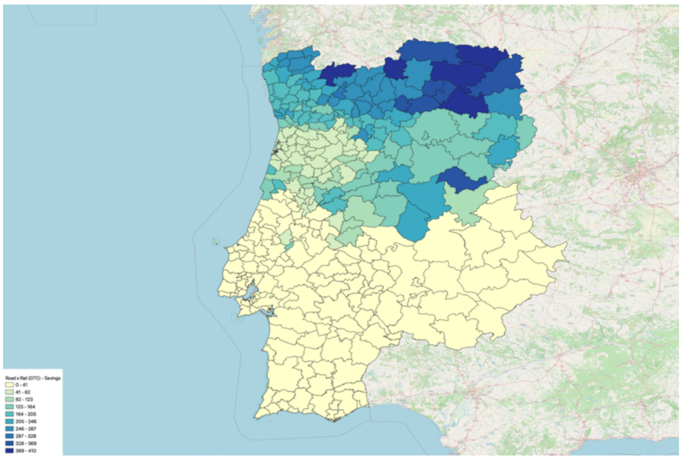

Figure 14: Road + rail generalized transportation cost savings compared to road only generalized transportation cost

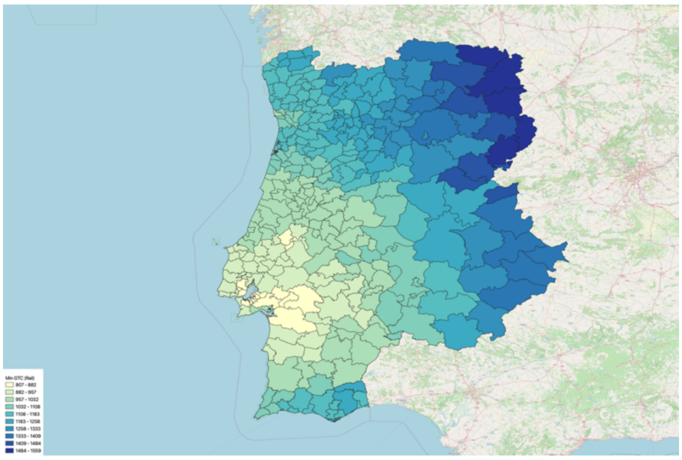

Figure 15: Minimum generalized transportation cost (road + rail)

6 CONCLUSIONS

In the first phase of analysis, in which intermodal transport was not considered, it was possible to observe that the hinterland of the terminal of Sines and the hinterland of the terminal of Leixões did not present any significant changes between the analyzed criteria. As for the terminal of Setúbal, when considering the GTC, it did lose part of its hinterland in Alentejo Central to the Santa Apolónia terminal when compared to its hinterland regarding the transportation time and transportation cost. The Alcântara terminal presents a hinterland composed mainly of municipalities located in the Lisbon metropolitan area in all cases. In a scenario in which the generalized transportation cost is the decisive criteria, the terminal of Leixões has the largest hinterland, while the terminals of Sines, Setúbal and the Santa Apolónia present hinterlands with approximately the same area, and the terminal of Alcântara has a hinterland composed of only 7 municipalities in the Lisbon metropolitan area. However, the numerical results for the Alcântara and Santa Apolónia (both in Lisbon) are very similar and their hinterlands largely overlap.

As for the second phase, considering an intermodal option along with road only transportation to the terminal of Sines, in regards of transportation cost the combination of road and rail is the best choice for all of the Spanish comarcas analyzed and also in all Portuguese municipalities located in the north of the country and most in the center and in the Lisbon metropolitan area. This happens because rail transportation gets more competitive over road only for transportation for longer distances. When the transportation time is taken into consideration, there is no doubt that intermodal transport is not an option, as cargo trains take longer than a truck to travel a same distance. Finally, when considering the GTC to the terminal of Sines, the combination of road and rail transportation is the best choice for most of the Spanish comarcas in the provinces of Caceres, Salamanca and Zamora, and also in all Portuguese municipalities located in the north of the country and some in the center of Portugal.

Finally, the results from the first and second phases of analysis were compared, in order to determine if having the option to transport cargo to the port of Sines using a combination of road and rail modes impacts the main inland hinterlands of the terminals. It was possible to observe that having an intermodal option resulted only in a small change in the terminals' hinterlands regarding the transportation cost. Other than that, when transportation time or GTC is to be considered, road transportation is still the best choice for the analyzed scenario. Notwithstanding these facts, it was observed that intermodal transport (road and rail) did reduce transport costs to Sines, even if not sufficiently to attract a significant number of municipalities to the hinterland of the Sines container terminal.

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