Article

Integrating Short Sea Shipping with Trans-European Transport Networks

Tiago A. Santos * , Miguel Â. Fonseca, Pedro Martins and C. Guedes Soares

Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico (IST), Universidade de Lisboa (UL), 1049-001 Lisbon, Portugal; miguel.a.fonseca@centec.tecnico.ulisboa.pt (M.Â.F.); pedro.martins@centec.tecnico.ulisboa.pt (P.M.); c.guedes.soares@centec.tecnico.ulisboa.pt (C.G.S.)

* Correspondence: tiago.santos@centec.tecnico.ulisboa.pt

Abstract: This paper studies the possibilities of closer integration of short sea shipping, with other components of the Trans-European Transport Networks, shifting a significant share of road freight onto rail corridors and inland waterways. A numerical model of transport networks is used to support the calculation of the main parameters driving transport decisions, for multiple pairs of origin/destination representing statistical regions of the European Union, and for different, alternative intermodal and unimodal transport chains. Results are presented using a geographic information system. This approach is applied in a case study dedicated to the evaluation of the competitiveness of transport chains based on short sea shipping between Portugal and The Netherlands, integrated with other components of Trans-European Transport Networks (rail freight corridors and inland waterways), compared to road haulage-based transport chains. Conclusions are drawn regarding the geographical scope of the relative competitiveness of these transport chains and policy investment insights are presented.

Citation: Santos, T.A.; Fonseca, M.Â.; Martins, P.; Soares, C.G. Integrating Short Sea Shipping with Trans-European Transport Networks. *J. Mar. Sci. Eng.* **2022**, *10*, 218. <https://doi.org/10.3390/jmse10020218>

Academic Editor: Mihalis Golias

Received: 21 January 2022

Accepted: 3 February 2022

Published: 7 February 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: short sea shipping; intermodality; Trans-European Transport Networks; rail freight corridors; inland waterways; logistics

1. Introduction

Short sea shipping (SSS) has not gained a significant market share in the European Union (EU) in recent decades even though substantial funding has been allocated to its promotion [1]. In general, SSS is cost competitive in comparison with road but it involves longer transit times, it is not door-to-door, and it is less flexible [2]. Overall, SSS has sustained a consistently strong competition from road haulage, spurred also by the influx of lower-wage drivers, who have even allowed some improvement of road haulage cost competitiveness. The position of SSS could benefit from increased utilization of Roll-on/Roll-off (Ro-Ro) ships [3], which facilitate cargo handling and integrate better with road haulage, thus allowing savings in door-to-door transit time (important considering current just-in-time logistics, as reported in [4]), albeit at the cost of somewhat increased costs [2]. In the Portuguese case, maritime freight transportation to Northern Europe resorts mainly to container ships, but the advantages of Ro-Ro could be better explored, as it was only a few years ago that the first SSS Ro-Ro liner service came into operation¹.

SSS services of any type are, however, still inevitably dependent on road haulage for pre-carriage or on-carriage of cargo from ports to origins/destinations (O/D). Therefore, when distributing cargo throughout northern Europe, substantial distances still have to be covered by road from the ports to the final destinations, and in many cases, this will contradict important European Commission policy objectives [5], namely that “a substantial part of the 75% of inland freight carried today by road should shift onto rail and inland waterways”. This objective is in line with the White Paper [6] target of achieving “a modal shift of 30% of road freight over 300 km by 2030, and more than 50% by 2050”. It is thus essential that SSS

integrates efficiently with railway lines and inland waterways if it is to assist effectively the EU policies of shifting cargo away from the road and promoting multimodal transport.

In order to promote this integration it is essential to know the main service attributes ensuring the competitiveness of SSS in intermodal transport chains (TC). This has been studied by different authors using questionnaires issued to logistic operators, shippers, and intermodal operators [7]. Furthermore, the Portuguese Industry Confederation (CIP) [4] has conducted a study of the competitiveness of transport modes in freight transportation between Portugal and Northern Europe. This organization reports that almost 70% of Portuguese foreign trade occurs with the European Union and that out of this trade, about two thirds of the physical goods are carried by road with the remaining part being carried by sea (container lines). Awareness of the existing or possible multimodal or intermodal alternatives for delivery of cargo throughout Europe is limited among shippers and forwarders in Portugal [4]. This situation is even more true for the scope of geographical competitiveness of unimodal and multimodal transport chains, as studies [4] and [7] are purely qualitative. The present paper contributes to the literature by delimiting and quantifying the scope of SSS (intermodal transport) competitiveness, shedding light on the common qualitative assertion that SSS remains primarily a transportation option for coastal regions [4] and for cargo that is not urgent, all other cargo being carried by road across long distances.

When one looks at land-based modes, the situation in this corridor concerning the utilization of the TEN-T network (other than the road network) remains very unsatisfactory. In fact, the use of railway lines to move freight directly from Portugal to Northern Europe has been repeatedly proposed [4] but the fact is that no direct rail service operates in the Rail Freight Corridor 4 (RFC 4) from Portuguese ports to Mannheim (Germany). There were attempts in the past to establish rail freight services in Portugal-Germany² but these have been short-lived as long transit time (3 days only for rail), differences in rail gauge, difficulties in finding available slots in congested railway lines and dependence on road haulage for pre-carriage and on-carriage compromised the attractiveness of these services. This situation is evidenced by the modal distribution of trade between Portugal and Spain and the European Union in 2017, showing that the railroad has percentages of 1% and 2%, while the road holds 68% and 64% and, finally, maritime transport is responsible for 31% and 34% [8]. In this context, it is important to note that the history of the modal split, between 2008 and 2017, despite observing growth rates in commercial trades, maintained the railroad at very low rates, with a predominance in road transport and maritime transport.

This paper presents research that supports that SSS, preferably using Ro-Ro ships, if cleverly combined with rail freight corridors or inland waterways from Northern European ports to locations deep within the continental mass, could offer a cost-competitive intermodal alternative solution, thus assisting the EU in increasing the modal shift from road to other more environmentally friendly transport modes. The infrastructure required for supporting intermodality is already well developed in Northern Europe so that theoretically intermodal transport in this corridor has conditions to develop itself. In fact, the infrastructure in major northern European ports (Rotterdam and Antwerp, for example) is well developed, with good connections to rail freight corridors and inland waterways, both forming part of Trans-European Transport Networks (TEN-T) [9], and this could be better explored. However, few integrated services exist in the so-called Western Europe Motorway of the Seas that group SSS, rail and inland waterways to reach locations remote from the coastline, implying that this concept is far from materialising and yielding its long-promised advantages. The findings of this paper, albeit related to this specific corridor, are relevant for many other peripheral regions in the EU which could use SSS to reach EU's core continental regions.

The research presented in this paper is based on a model of transport networks connecting European regions situated along the Atlantic Ocean. This network model supports a numerical model that examines the relative cost competitiveness of alternative transport chains, using an approach that resembles simulation techniques, albeit simplified.

The numerical model is capable of performing systematic calculations of costs and transit time for pairs O/D, where origins and destinations are taken to be the capitals of NUTS 2 regions (NUTS-Nomenclature des unités territoriales statistiques). The numerical results are displayed using maps developed in a geographic information system (GIS) tool. The paper is organized in the following manner. Section 2 presents a literature review on the relevant themes. Section 3 presents the numerical model for assessing intermodal transport chains. Section 4 presents a numerical application of the model in a case study dealing with intermodal freight transportation between Portugal and Northern Europe, allowing conclusions to be drawn in Section 5.

2. Literature Review

2.1. Cost and Time Competitiveness of Intermodal Transport

There is a substantial body of literature that considers the modelling of costs in road and intermodal freight transportation. Several studies [10,11] assessed internal and external costs in transportation, concluding that the break-even distance for intermodal transportation (rail-based) is about 1050 km and that internalising external costs may not necessarily promote a shift of cargo to intermodal transportation. Other authors [12,13] indicate, however, that intermodal transport solutions become attractive at distances above only 500 km or even 400 km. Internal and external costs of intermodal transport that use SSS instead of rail lead to the conclusion that SSS benefits from the use of low sulphur fuels and from an increase in ship's capacity utilization, which may make it competitive even at much shorter distances than 1050 km [14,15]. Overall, the threshold distance for the competitiveness of SSS or rail in comparison with road appears to vary significantly according to the particular conditions of the transport chains under study.

Most of the literature concentrates on the cost side (internal, external, or full costs) of intermodal transport, but very few consider in detail the time factor, which is crucial in just-in-time logistic strategies. This factor has been highlighted in a study [16] dedicated to the case of Portuguese cargo exported or imported from the EU. Companies indicate that the transit time of SSS is unsatisfactory and that the low frequency of departures further degrades the performance of SSS. The inappropriate door-to-door capability of SSS contributes additionally to the problem of excessive transit time due to changes of transport mode across the transport chain. This may also produce extra costs, but these in most cases are not critical [17]. In general, respondents agreed that SSS-based intermodal transport chains were certainly cheaper than road-based transportation, which is not surprising given that the distance from Portugal to Germany is generally above 2000 km, thus well beyond the above-mentioned thresholds. In general, the time factor now appears to be more important than transportation cost.

Accordingly, the time and cost particularities of intermodal transport chains based on SSS in the corridor from the Iberian Peninsula to Northern Europe have been studied [18,19]. The first paper includes a methodology for modelling demand in SSS (using Ro-Ro ships), which allowed the estimation of cargo volumes in the route Leixões-Rotterdam, while the second presents a multicriteria approach to select the most convenient ports for establishing SSS services in the same corridor. The methodology in [18] involved the evaluation of preferences for SSS or road transportation over a set of pairs O/D, considering both time and cost as decision parameters. These results were later used to size the required Ro-Ro ship for this route and estimated cargo volume [20]. In these papers, the transport network was modelled only employing road distances between main cities representative of each NUTS 2 region without regard for such parameters as, for example, type of road, impact in the average speed of heavy goods vehicles (HGV) and type of environment where the road is located. Therefore, to enable a more realistic calculation of the various transport parameters frequently considered in transport decision making, a comprehensive model of the transport network (including road, rail, SSS and inland waterways) covering the main parts of Western Europe was developed.

The network model developed by the authors has already allowed the study of the competitiveness of different intermodal transport solutions, some including SSS services (Ro-Ro or container services), in terms of transit time and transportation cost, as shown for a corridor from Northern Portugal to Northern France [21]. This paper only considered a pair O/D (Porto/Paris) but the work was later extended to cover multiple pairs O/D across Northern France and Belgium [22]. This allowed a geographic delimitation of the potential hinterland and foreland of a SSS route, using as a criterion the GTC. In these two studies, the maritime route linked the ports of Leixões and Le Havre. The same approach had been used to determine the external costs of intermodal transportation using the Marco Polo approach [23] and also the EU handbook [24]. The present paper seeks to apply the same approach to assess the cost competitiveness of different intermodal transport chains based on SSS, for transporting cargo from Portugal to wide set of Northern European NUTS 2 regions, covering Germany, Netherlands, Belgium, Luxembourg, and part of France.

Considering that both time and cost have a high impact on the relative competitiveness of different transport chains, it seems useful to resort to the concept of generalized transportation cost (GTC), which sums to the transport cost the product of time and value of time (VoT) for cargo. This latter variable is a difficult parameter to estimate in a precise manner. A substantial body of literature exists on this topic, but the general conclusion is that values vary significantly. Values for VoT may be found in many papers and studies and a summary is provided in comprehensive reviews such as those of [25–27]. A significant number of VoT values were identified in these studies, with a variation between €2 and €47 per hour and trailer. Particular studies [28] focused on SSS-based chains indicate suitable values of €6.82 per hour, which will be considered in this paper.

2.2. Geographical Delimitation of Transport Chains Competitiveness

The cost and time considerations above, coupled to models of transport networks, allow the geographical delimitation of the scope of competitiveness of SSS solutions (integrated in intermodal transport), in the wake of a considerable literature on this topic. In fact, such geographical studies can be subdivided into three broad categories: studies dedicated to the characterization of port hinterlands; studies dedicated to the characterization of which transport solutions are employed to reach different locations within the port's hinterland; studies dedicated to the characterization of the competitiveness of full transport chains (from origin to destination) across vast geographical regions.

The first category includes studies on the characterization of port's hinterlands and accessibility to the different port ranges. This approach stems from the considerable literature on transportation networks [29–31] and has allowed, for example, the study of the accessibility of locations across the US from and to different port ranges [32,33]. This category includes also studies carried out using empirical data on the geographical distribution of cargos flowing through a certain port. If such information is available for several ports (from Customs for example), the hinterlands of the different competing ports may be identified. The literature is rich on such studies and many port authorities also regularly conduct studies in this field. The hinterland of Ligurian ports across Northern Italy and a few NUTS 1 regions of neighbouring countries was studied in [34], which also examined the effectiveness of gravity models to explain the share of the different ports in this contested environment. In [35], an optimization model for evaluating the location of potential inland ports within the same geographical area is proposed. An empirical analysis of the port hinterland and the catchment area of Adriatic ports (in Italy), but still with no definition of the geographical scope of different ports, has been presented in [36]. Based on customs data, in [37], an analysis of the spatial development of Spanish ports hinterlands between 2000 and 2010 is carried out, considering both the Mediterranean and Atlantic coast. Similar studies have been carried out to determine the hinterland boundaries of major ports in France, namely the boundary between Le Havre (and other Northern range ports) and Marseille [38]. The findings of this study are actually in line with those of [39] on the delimitation of the boundary of northern and southern European port ranges. Market

shares and volumes of the main Northern Range ports in NUTS 2 regions have also been studied in [40].

The second category of studies, rather than focusing on the competitiveness of ports across the hinterland, considers the competitiveness of different transport solutions to reach locations situated within the hinterland. The competitiveness of combined transport versus road based transport in freight transportation from Le Havre to multiple locations across the Ile de France region is studied in [41]. A very interesting and complete model has been developed in Belgium [42] and used to determine the scope of competitiveness of intermodal solutions (rail or inland waterways based) in the distribution of containers originating in Antwerp throughout this country. That paper presents a very complete geographic information system (GIS) based model that comprises road, rail and barge networks in Belgium, as well as existing intermodal terminals, and it has been used to study the effects of fuel price increases, the internalization of external costs, the value of time in modal choice, and the optimal location of barge terminals [43–46]. In connection with this model, empirical studies have also been conducted on the preferences of modal choice decision makers in Belgium in the short distance inland container transport [47]. The competitiveness of intermodal transport solutions versus road solutions and its impact in the competitiveness of ports has also been studied for the Portuguese case in [48].

The third category of studies, which are relatively rare, strives to analyse the competitiveness of full transport chains, in which short sea shipping integrates with other modes in complex combinations, to reach wide geographical areas. The catchment area of SSS-based transport solutions from Belgium to the Baltic countries and Russia has been studied in [49], using various ports in the Baltic Sea as possible gateways. Regarding the competitiveness of SSS in the corridor from Western Iberian Peninsula to Northern Europe, very few studies have been carried out. One example is [19], where a number of transport chains from Spain to France are studied, combining different ports in Spain and France to reach specific destinations in France, while in [21] the route between Leixões (Portugal) and Rotterdam was studied to reach NUTS 2 regions spread throughout Germany, Netherlands, Belgium, and France. A similar study [22] has been conducted for the port of Le Havre. However, these studies have only considered road distribution of containerized cargo from the destination ports to final destinations. This paper seeks to expand the analysis to cover a diversity of SSS-based intermodal transport solutions across a vast geographical region.

3. Numerical Model

Numerical calculations of decision parameters for the selection of the most competitive intermodal transport chains are based on a model of the transport networks. Let L be the number of links in the transport network. A sequence of links between an origin and a destination forms a path. Paths with the same origin and destination are organized in a set k . All different paths in a set (eventually using different transport modes) represent alternatives for the transportation of cargo units between that pair O/D. Index p is used to denote a path within that group. Each link, i , is characterized by a mode of transport, a distance (length) D_{l_i} and an average speed S_{l_i} . The binary variable δ_{l_i} defines whether the link i is active (operational) or not, whereas the binary variable δ_{kp_i} defines whether link i is used in path p of set k . Finally, a third binary variable δ_{Rd_i} identifies whether the link i is of road type or not.

The transportation time taken by a cargo unit along a given path, using road type links, is given by the following summation over all links existing in the database:

$$T_{RD_{kp}} = \sum_{i=1}^L \delta_{l_i} \cdot \delta_{kp_i} \cdot \delta_{Rd_i} \cdot \frac{D_{l_i}}{S_{l_i}} \quad (1)$$

Similarly, it is possible to calculate the time taken in links of other types, namely rail, inland waterways, and maritime (using Ro-Ro or container ships), denoted as, respectively, T_{RL} , T_{IW} , T_{RR} , and T_{CC} . The transportation time taken along path p of set k is then given by:

$$T_{TRkp} = T_{RDkp} + T_{RLkp} + T_{IWkp} + T_{RRkp} + T_{CCkp} \quad (2)$$

In addition to the transportation time, there might be delays at certain nodes in the path. Let N be the number of nodes in the database representing the transport network. The nodes are user specified and can represent, for example, dwell time in a container terminal. This dwell time is assumed to represent the unloading time (from a truck, rail, or barge), the storage time in the container terminal stockyard and the loading time (in the ship). Therefore, Equation (3) defines the total time between an origin to a destination using a certain path as the sum of actual transportation time, given by Equation (2), with the time taken in nodes j along the path:

$$T_{kp} = T_{TRkp} + \sum_{j=1}^N \delta_{kpj} \cdot T_{Dwj} \quad (3)$$

where δ_{kpj} is a binary variable representing whether or not node j belongs to the path p of set k and T_{Dwj} represents the average dwell time in node j .

A similar procedure is used for calculating the total cost of freight transportation in each path. Firstly, the total distance travelled in path p of set k is determined. In the case of road transportation, the total distance travelled is given by:

$$D_{RDkp} = \sum_{i=1}^L \delta_{li} \cdot \delta_{kp_i} \cdot \delta_{Rd_i} \cdot D_{li} \quad (4)$$

The cost associated with such distance is then calculated by:

$$C_{RDkp} = D_{RDkp} \cdot c_{RD} \quad (5)$$

where the cost coefficient c_{RD} is, itself, a function of the distance travelled by road, that is:

$$c_{RD} = f(D_{RDkp}) \quad (6)$$

This coefficient is obtained by interpolation over a non-linear function of specific cost $f(D_{RDkp})$ (monetary units per km for a cargo unit), specified according to the applicable market conditions. The same principle is applied to calculate the costs of sub-paths that use other modes of transportation in the path, which are represented by C_{RLkp} , C_{IWkp} , C_{RRkp} , and C_{CCkp} . Each of these costs is a function of the respective cost coefficient which, in turn, is a non-linear function of the total distance travelled using the relevant transport mode. The total transportation cost in a given path is then the sum of the costs associated with each mode of transport:

$$C_{TRkp} = C_{RDkp} + C_{RLkp} + C_{IWkp} + C_{RRkp} + C_{CCkp} \quad (7)$$

The total transportation cost is the summation of the cost incurred in the transportation operations plus costs associated with transfers (handling and storage) between transport modes occurring in nodes of the network:

$$C_{kp} = C_{TRkp} + \sum_{j=1}^N \delta_{nj} \delta_{kpj} \cdot (C_{uj} + C_{lj} + C_{sj}) \quad (8)$$

where C_{u_j} , C_{l_j} , and C_{s_j} represent the unloading, loading, and storage costs in node j , δ_{nj} is a binary variable which indicates whether or not node j is active, and δ_{kpj} is a binary variable that indicates if node j is used in path p of the set of paths k .

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

$$GTC_{kp} = C_{kp} + VoT \cdot T_{kp} \quad (9)$$

where VoT represents the value of time for the cargo in monetary units per hour. Finally, numerical results obtained with this model for transportation cost, transportation time, and generalized transportation cost will be displayed in maps built in a geographic information system (QGIS), using a uniform distribution and classification system.

4. Case Study Definition

The results of the numerical model presented in the previous section will be illustrated in the framework of a case study dealing with freight transportation between northern Portugal (origin in the city of Porto) and different locations (destinations) spread across continental Northern Europe (shaded area in Figure 1). These locations correspond to cities that are the capitals of NUTS 2 regions in Germany, Netherlands, Belgium, Luxembourg, and part of France. This geographical scope corresponds to the major Portuguese commercial partners in the European Union, apart from Spain. Freight bound for these countries may be reached using road haulage, maritime services (container ships or roll-on/roll-off ships), or railway services. The southern half of France and Spain has not been included in this case study as these regions/countries are too close to Portugal to be served using other transport modes than road haulage.

Figure 1. Intermodal routes supporting transport chains between Porto and Stuttgart.

The ports considered in this case study are Leixões (Portugal) and Rotterdam (Netherlands). The geographical scope of this study in Northern Europe was also chosen to match the area that realistically can be served from Rotterdam. Figure 1 shows also an example of the supporting infrastructure, allowing freight transportation to be carried out between

Porto and Stuttgart, comprising railways, inland waterways, maritime routes, and roads. These are included in a comprehensive model of the transport networks containing all the necessary infrastructure for supporting freight transportation to multiple destinations across the area under study.

The intermodal transport chains considered in this study combine SSS with EU Rail Freight Corridors and inland waterways (IWW), seeking to improve the integration of transport modes without compromising transit time, thus promoting a modal shift away from the road. Table 1 shows the alternative transport chains specified for this case study (most comprise also, in addition to the transport modes indicated below, road haulage in Portugal and Northern Europe, respectively pre-carriage and on-carriage).

Table 1. Definition of the alternative transport chains in the case study.

Transport Chain	Transport Modes and TEN-T Components
TC1	Road haulage Portugal-Northern Europe
TC2	SSS (Ro-Ro ship) Leixões-Rotterdam
TC3	SSS (Container ship) Leixões-Rotterdam
TC4	SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Oberhausen)
TC5	SSS (Ro-Ro ship) Leixões-Rotterdam + IWW (Rhine to Duisburg)
TC8	SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Mannheim)

Table 2 shows the cargo handling costs, storage costs, and dwell time in seaport terminals and intermodal terminals. Information regarding handling and storage costs (including principles regulating free time) is taken from terminal tariff regulations, which are generally available for seaport terminals and, in some cases, for intermodal terminals. Where not available, the general principle adopted is that handling containers is much more expensive in seaports than in intermodal terminals and, particularly, loading/unloading from ships is the most expensive operation. Costs applicable to intermodal terminals have been taken from [50] and when not available, taken in line with the values shown in [51,52].

Table 2. Costs and average dwell times in seaport and intermodal terminals (Sources: [53–55]).

Terminal	Cost Unload (€)	Cost Load (€)	Dwell Time (h)	Free Time (h)	Time Cost (€/day)
Rail Terminal (Oberhausen)	25.0	25.0	6.0	48.0	2.0
Rail Terminal (Mannheim)	25.0	25.0	12.0	48.0	2.0
Container Terminal (Leixões)	0.0	142.7	48.0	120.0	1.8
Container Terminal (Rotterdam)	25.0	120.0	48.0	96.0	2.0
Ro-Ro Terminal (Leixões)	25.0	25.0	6.0	48.0	2.0
Ro-Ro Terminal (Rotterdam)	50.0	50.0	6.0	96.0	2.0
IWW Terminal (Duisburg)	25.0	25.0	9.0	96.0	2.0

Regarding dwell time, there is limited information on this parameter in the literature as terminal operators avoid disclosing this information. Consequently, the general principle adopted is that dwell time in seaport container terminals is much larger than in Ro-Ro terminals and in intermodal terminals. This is in line with the fact that dwell time in container terminals very rarely is smaller than 2 days (48 h) and in Ro-Ro terminals very rarely is smaller than 6 h. However, in [53] it is indicated that dwell time for full containers may range from 5 to 10 days but large modern terminals may offer lower numbers. The same reference advises 1 to 2 days for Ro-Ro freight terminals. This is even though terminal regulations often mention that containers or Ro-Ro cargo may be accepted up to 6 h before ship arrival (container ships) and 2 h before ship departure (Ro-Ro freight). As may be seen in Table 2, dwell times in seaports have been specified at low values. Dwell times in intermodal terminals have been specified as larger than dwell time in Ro-Ro terminals, particularly when located in Portugal rather than in Northern Europe.

Regarding road transportation costs, ref. [51] 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 [56,57]. In the case of maritime transportation, the values for this specific route (Leixões to Rotterdam) have been used following information from shipping companies: 1050 €/FEU (forty feet equivalent unit) for the Ro-Ro ship and 740 €/FEU for the containership. Regarding rail cost, ref. [58] indicates that a freight train from Portugal to Germany (distance of about 2700 km) costs about €41,000 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 an 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.

5. Numerical Results for a Specific Transport Chain

This section presents the detailed results of the numerical model for a specific pair O/D that corresponds to transport operations between Porto (Portugal) and Stuttgart (Germany), using approximately the routes shown in Figure 1. All the transport chains detailed in Table 1 are considered to be active and the terminal parameters are as shown in Table 2. These results illustrate the output of the numerical model for a single pair O/D, while Section 6 will present an analysis of similar results obtained systematically for a wide range of 75 pairs O/D covering the shaded area in Figure 1.

Figure 2 shows, for this O/D pair, the distances calculated using the numerical model (minimum distances for each transport mode), as well as the transport cost and the transport time (door-to-door). Road haulage (TC1) is the fastest chain while the container ship-based chain (TC3) is the one with the largest transport time. TC2 and TC4, both based on Ro-Ro ship, are also very time effective. Rail directly from Portugal (TC7) could be the cheapest transport chain, but the necessary infrastructure for a seamless operation is not yet available. On the opposite extreme, TC1 is the most expensive transport chain but also the fastest one. TC3 (container ship and road) and TC8 (rail Rotterdam-Mannheim) are the most cost-effective chains after rail direct (TC7).

Figure 2. Distance per mode of transportation, transport cost (€) and time (h) for the transport chains Porto-Stuttgart: (a) Distance per transport chain; (b) Transport cost (€) and time (h) per transport chain.

Figures 3 and 4 show examples of the split of transport time and cost for specific transport chains between the same pair O/D. Regarding transport time, it may be seen in Figure 3 that in TC1 there are only two components, time taken driving on the road and time taken in pauses. The pauses include small breaks and night breaks (assumed at 12 h, slightly more than the legal minimum), as specified in applicable EU regulations [59]. If the night pauses are decreased to the minimum value, the time spent pausing will come down to about half the total transport time. The numerical model also allows the operation to

include two drivers and, in this case, the time taken in pauses would become negligible. TC2 shows that most time is taken on board the ship (average ship speed was specified at a modest 15 knots) but pauses in ports still take about 14% of the total time. Road pauses are almost non-existent as no night rest is required between Rotterdam and Stuttgart (~630 km) and the driving time represents 10% of the total.

Figure 3. Split of transport time in transport chains TC1 and TC2: (a) Transport time in transport chains TC1; (b) Transport time in transport chains TC2.

Figure 4. Split of transport cost on chains TC2 and TC6: (a) Transport cost in TC2; (b) Transport cost in chain TC8.

Regarding transport cost, it may be seen in Figure 4 that SSS represents over half of the total cost, for chains TC2 and TC8, but still much less than 75% of the time in TC2, implying that it is cost effective. Road costs are in any case significant: in TC2 it represents 42% of the total cost (for about 630 km); in TC8 it represents 19% of the total cost (for only about 140 km). These percentages result from the fact that road haulage at short distances is proportionally more expensive than at long distances. Comparatively, in TC8, rail represents 14% of the total cost, but the distance from Rotterdam to Mannheim is approximately 550 km. Another important observation is that in these two chains 8–11% of the total cost consists of cargo handling costs.

To summarise, any actions taken to decrease Ro-Ro time at sea and decreasing its costs (maritime freight rates) would greatly benefit intermodal solutions. However, these actions are contradictory, as decreasing sailing time implies higher speeds and this leads necessarily to higher freight rates. Decreasing road haulage costs in Northern Europe would also improve the performance of intermodal transport chains.

6. Numerical Results for Transport Chains between Multiple Pairs Origin/Destination

6.1. Competition between Road Haulage and SSS (Using Lo-Lo)

This section presents results for the specific case of the competition between road haulage (TC1) and SSS based on container ships (Lift-on/Lift-off cargo handling method) using the port of Rotterdam, in this case complemented by road haulage (TC3). Therefore, only transport chains TC1 and TC3 will be considered to compete. This situation corresponds largely to the current situation, as only one SSS Ro-Ro service is in operation between Portugal and Northern Europe. Competition in this corridor will be evaluated for 75 pairs O/D as the numerical model presented above allows the systematic calculation of door-to-door transport costs for multiple pairs. In this case, the origin is kept fixed in the city of Porto (capital of a major manufacturing region and also a major population centre) and the destinations are the main cities representing NUTS 2 regions in Northern Europe, as shown in Figure 3 (the locations of capitals of NUTS 2 regions are shown by small circles). The transport cost in each alternative transport chain is defined as the result of the summation of the freight costs of the different modes of transportation with the cargo handling costs (and storage costs if applicable) that are incurred in seaports and intermodal terminals.

Figure 5 shows the results of the numerical model for transport chain TC1 (road haulage from Porto to Northern Europe). It may be seen that such cost increases gradually with the distance from Portugal. Values are lower for the region of Paris (€1600) and increase gradually to almost €2707 for Eastern and Northern Germany. Similar results are shown in Figure 6 for transport chain TC3, evidencing a similar gradual increase in transport cost from the port of Rotterdam (where the cargo is unloaded) to the most distant regions from the coast. Note that transport cost until Rotterdam is constant for all NUTS 2 regions as the transport operations until Rotterdam are the same. The difference in total transport cost arises from the differences in road haulage costs, which depend largely on the distance of the NUTS region from the coast. It may be seen that total transport costs range from €1300 (regions surrounding Rotterdam) to almost €2000 for regions further away from Rotterdam.

Figure 5. Total transport cost (door-to-door, in euros) for TC1: Road haulage Portugal-Northern Europe.

Figure 6. Total transport cost (door-to-door, in euros) for TC3: SSS (Ro-Ro ship) Leixões-Rotterdam.

Table 3 shows the maximum and minimum values and the range, which are €1207 and €791 for TC1 and TC3, respectively. Although it appears that the TC3 is at an advantage in the context of the values presented and, with this, the variation of costs is significantly lower, it is important to position these values in the regional territories being studied to analyze the effective competitiveness between TC1 and TC3. The importance of this positioning stems from the difference between the focus of competitiveness found on each chain: whereas in TC1 competitiveness decreases as it moves eastward, in TC3 competitiveness decreases as it moves away from the centre, located in Rotterdam. This difference results from the road haulage distances in each of the two transport chains.

Table 3. Minimum, maximum, and range of transport cost (TC1 and TC3).

Transport Chain	Minimum (€)	Maximum (€)	Range (€)
TC1: Road haulage Portugal-Northern Europe	1500	2707	1207
TC3: SSS (Container ship) Leixões-Rotterdam	1230	2021	791

Figure 7 shows the relative competitiveness of the TC1 and TC3 chains, and in the context of transport cost, TC3 chain stands out in the territories of Northern Europe. This transport chain is the most competitive in most of the geographical areas under study, including all of Germany, Netherlands, Belgium, and Luxembourg. Regarding France, road haulage from Portugal (TC1) is the most cost competitive for all regions up to the Seine valley (including Paris). This situation could be expected as these regions are located closest to Portugal and the use of the port of Rotterdam is not cost competitive enough because of the need to still cover a significant distance by road when heading south. In any case, transport using container ships to Rotterdam and further on-carriage using road haulage is shown to be very cost competitive for the vast majority of NUTS 2 regions.

Figure 7. Preferred transport chain (TC1 or TC3) considering transport cost.

When TC1 and TC3 are analyzed in the context of the transport time, it is clear that TC1 has shorter times, with the particularity that the maximum transport time verified in TC1 (73.3 h) is less than the minimum transport time verified in TC3 (153.9 h), as shown in Table 4. It should be noted that this difference is motivated by several factors, most notably, in TC3, the dwell time for containerized cargo in both port terminals (48 h each). However, even if this dwell time would be largely reduced, the time competitiveness of TC3 would still be small when compared with TC1. Figure 8 shows that the transport time afforded by TC1 is always smaller than that of TC3, establishing it as superior to TC3 for all NUTS 2.

Table 4. Minimum, maximum, and range of transport time (TC1 and TC3).

Transport Chain	Minimum (h)	Maximum (h)	Range (h)
TC1: Road haulage Portugal-Northern Europe	44.7	73.3	28.6
TC3: SSS (Container ship) Leixões-Rotterdam	159.1	182.3	23.3

Figure 8. Preferred transport chain (TC1 or TC3) considering transport time.

The competition between transport chains may also be seen from the point of view of Generalized Transportation Cost (GTC). This parameter combines transport cost with the product of transport time and VoT, thus combining both previously analyzed parameters. In this case, by changing the variable of the VoT according to the type of cargo, it is possible to observe the dynamics of competition between TC1 and TC3. Figure 9 shows the regional competition, based on the GTC, between TC1 and TC3, for a VoT of € 6.82. It is evident that TC1 (road haulage) is more competitive for all the territories of Central Europe and France. For this VoT and the resulting GTC, TC3 maintains its competitiveness only in Rotterdam and in the regions to the east of this port. This limited competitiveness of TC3 is due to the high transit time, which multiplied by the VoT adds substantially to the GTC.

Figure 9. Preferred transport chain (TC1 or TC3) considering GTC (with VoT at €6.82).

6.2. Competition between SSS Coupled to TEN-T (Using Ro-Ro) and Road Haulage

This section presents the results of the specific case of the competition between SSS (using Ro-Ro and coupled to various components of TEN-T) and road haulage (TC1). Therefore, transport chains TC3 (container ships), TC6, and TC7 are not included in this analysis. The results in this section aim at analysing the competition in this scenario, allowing conclusions on the relative improvements achievable when compared to the situation analysed in the previous section.

Table 5 shows a summary of transport costs implied by the different chains. The maximum difference obtained between maximum and minimum transport cost values occurs in TC1 (€1207), whereas in the remaining chains this variation is between €771 and €787. Again, this is a consequence of distances covered by road in each case.

Table 5. Minimum, maximum, and range of transport cost (TC1, TC2, TC4, TC5, and TC8).

Transport Chain	Minimum (h)	Maximum (h)	Range (h)
TC1: Road haulage Portugal-Northern Europe	1500	2707	1207
TC2: SSS (Ro-Ro ship) Leixões-Rotterdam	1380	2165	785
TC4: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Oberhausen)	1612	2399	787
TC5: SSS (Ro-Ro ship) Leixões-Rotterdam + IWW (Rhine to Duisburg)	1596	2379	783
TC8: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Mannheim)	1710	2481	771

Figures 10–13 represent the transport cost for chains TC2, TC4, TC5, and TC8. There is a common principle: greater regional competitiveness is observed around the intermodal platform of destination (Rotterdam, Oberhausen, Duisburg, or Mannheim), with different minimum transport costs, losing competitiveness as the travelled distance to final destination increases. However, it should be noted that the minimum transport cost is found in TC2, with TC4, TC5, and TC8 having a minimum transport cost higher than TC1. On the other hand, it is also observable that the maximum transport cost is verified in TC1, with TC4, TC5, and TC8 having maximum values higher than TC2, since a part of these chains is shared with TC2 to Rotterdam.

Figure 10. Total transport cost (door-to-door, in euros) for TC2: SSS (Ro-Ro ship) Leixões-Rotterdam + Road.

Figure 11. Total transport cost (door-to-door, in euros) for TC4: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Oberhausen).

Figure 12. Total transport cost (door-to-door, in euros) for transport chain TC5: SSS (Ro-Ro ship) Leixões-Rotterdam + IWW (Rhine to Duisburg).

Figure 13. Total transport cost (door-to-door, in euros) for transport chain TC8: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Mannheim).

Figure 14 shows the results regarding the most competitive transport chain, in the context of the total transport cost, between TC1, TC2, TC4, TC5, and TC8. It is important to note, firstly, that TC4 is not competitive for any NUTS 2 region. Indeed, TC4 does not present any added value in the context of the total cost of transport when compared to the other transport chains, as the rail distance from Rotterdam is only about 216 km. Once again, TC1 reveals greater competitiveness in the French regions, closer to the origin of the cargo. However, it is observed that the rest of the territory benefits, in addition to TC2, from the existence of the solutions provided by TC5 and TC8 (IWW to Duisburg and RFC 1 to Mannheim). In this latter case, it is worth noting that the distance along RFC 1 to Mannheim is about 550 km.

Figure 14. Preferred transport chain (among TC1, TC2, TC4, TC5, and TC8) considering transport cost.

The greater dispersion between the different solutions TC1, TC2, TC5, and TC8 suggests different observations. First, there is a division of regional competitiveness between TC1 and TC2 in French territory with a significant predominance for TC1. For Germany, Holland, Belgium, and Luxembourg TC2 is mainly competitive in coastal regions, while eastern and southern areas benefit the most from transport chains that include IWW and rail. Regarding the latter, it should also be noted that TC5 and TC8 chains are the most competitive in regions located to the east of, respectively, Duisburg and Mannheim platforms, being limited to the west by the TC2 solution.

When observing the regional competitiveness of the TC1, TC2, TC4, TC5, and TC8 chains expressed by the transport time variable, there is, once again, larger competitiveness offered by the TC1 solution, being seconded by TC2, where the minimum value of transport time is higher than the maximum transport time value offered by TC1, as shown in Table 6.

Table 6. Minimum, maximum, and range of transport time (TC1, TC2, TC4, TC5, and TC8).

Transport Chain	Minimum (h)	Maximum (h)	Range (h)
TC1: Road haulage Portugal-Northern Europe	44.7	73.3	28.6
TC2: SSS (Ro-Ro ship) Leixões-Rotterdam	75.2	98.5	23.3
TC4: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Oberhausen)	84.8	108.1	23.3
TC5: SSS (Ro-Ro ship) Leixões-Rotterdam + IWW (Rhine to Duisburg)	104.8	128.2	23.3
TC8: SSS (Ro-Ro ship) Leixões-Rotterdam + RFC 1 (to Mannheim)	100	123.3	23.2

Figure 15 identifies the most competitive transport chain, considering transport time. It may be seen that TC1 is the most competitive chain in all the analyzed regions. However, excluding TC1 from the analysis based on the transport time variable, it can be seen in Figure 16 that TC2 (road haulage from Rotterdam) is the second most competitive chain for most of the Northern European area under study. TC4 is represented only in some regions to the south, which represents greater distances to Oberhausen.

Figure 15. Preferred transport chain (among TC1, TC2, TC4, TC5, and TC8) considering transport time.

Figure 16. Preferred transport chain (among TC2, TC4, TC5, and TC8) considering transport time.

When the GTC variable is considered, there are significant changes compared to previous analyses. It can be seen in Figure 17 that the TC5 solution is now replaced by TC4, as a result of the negative impact of the VoT on the transport solution with IWW. It may be seen that intermodal solutions based on SSS to Rotterdam coupled to Rail Freight Corridor N°1 are competitive in comparison to road haulage for most of Germany and all of Belgium, Netherlands and Luxembourg. When comparing to results previously shown in Figure 9 (competition between TC1 and TC3, road versus container ship), where it was evident that the containership solution (TC3) was only competitive for Northern Germany and Netherlands, it may be seen that the utilization of Ro-Ro ships in SSS shows a significant advantage compared to more traditional container ships. This is due, mainly, to the significantly decreased transport time offered by this type of cargo handling and its typically lower dwell time in port. As a result of this decrease in transport time, SSS based on Ro-Ro ships can hold its ground when competing with road haulage and, in doing so,

provides integrated solutions with TEN-T for a significant number of regions away from the coastline, not resorting in these cases to road haulage from Rotterdam, which is an additional benefit.

Figure 17. Preferred transport chain (among TC1, TC2, TC4, TC5, and TC8) considering GTC (with VoT of €6.82 per hour).

6.3. Comparison with Statistics of SSS Modal Share

It has been shown that this numerical model may produce a number of different results, allowing a valuable insight into the geographical scope of competitiveness of different transport chains. However, it is relevant to compare and validate these results, in so far as possible, with the existing evidence regarding the modal share of SSS in Portuguese freight transportation for those countries. In this respect, valuable data was gathered from transport statistics of the Portuguese Statistics Bureau [60]. These reports contain the tonnage of cargo exported and imported from Portugal to all European countries, but focus in this paper is on Germany, Netherlands, Belgium, and France (in the numerical study above, only the northern half of the latter country is covered). The tonnage of cargo is reported per mode of transportation: road, maritime, rail, and airplane. In the case of these countries only road and maritime modes are significant. It is important also to take into account that a large part of maritime cargo transported to/from these countries consists of solid bulks, liquid bulks and general cargo, and these types of cargo could hardly be carried by road. Therefore, it was possible to deduct these cargo types from the tonnage of cargo carried by sea, thus finally producing more realistic modal shares.

Figure 18 (left) shows the final results of the analysis for exports from Portugal. It may be seen that road dominates in transportation to/from Germany and, especially, to/from France, while the situation is quite balanced for The Netherlands and Belgium. Figure 18 (right) shows the modal share of SSS for the same countries and for export cargo. It may be seen that for The Netherlands and Belgium the modal share of SSS slightly exceeds 50%, while for Germany it is 34% and for France a mere 6%. This same figure shows some numerical results of the model described above. It may be seen that average road haulage costs from Rotterdam are almost 800 € for both Germany and France while for The Netherlands and Belgium they are slightly less than 400 €. This implies that for countries further away from Rotterdam, other intermodal solutions present lower cost than road haulage (see Figure 14). However, as intermodality still implies delays, bureaucracy, and coordination issues, in the end these solutions are deemed too complicated and road haulage ends up dominating the transportation of cargo to Germany. Finally, there is a significant gap in modal share of SSS between Germany and France, but the results of this

model show that the average road haulage cost to Germany is 2400 € while for France it is only 1600 €. The modal share of SSS for Germany is, nonetheless, 34% (in spite of long distance) because for many western and northern regions in Germany, as seen in Figure 14, SSS through Rotterdam is very competitive.

Figure 18. (a) Export cargo from Portugal using SSS and road haulage; (b) Modal share of SSS and road haulage costs (€) from Rotterdam and Porto.

7. Conclusions

This paper presents a systematic evaluation of the competitiveness of alternative intermodal transport chains in the Atlantic Corridor. These chains generally combine short sea shipping with other Trans-European Transport Networks (TEN-T) components such as inland waterways (Rhine river) and railway lines (Rail Freight Corridor 1), while using a suitable seaport. It should be noted that SSS competitiveness assessment in this paper is based only on the destination port of Rotterdam, but this port is deemed to represent the much wider set of port infrastructures located elsewhere in this port range.

Numerical results allow the conclusion that depending on the variable under consideration (time, cost, or GTC), the different transport chains perform differently. Considering only the time variable, road haulage from Portugal is the one that offers greater competitiveness in relation to all other solutions for all the areas under study. However, considering the cost variable, SSS-based solutions offer greater competitiveness for regions located in Belgium, Luxembourg, Holland, and Germany, while road is more competitive for French NUTS 2 regions up to the Seine valley, including Paris.

On the other hand, it is important to highlight the importance of intermodal chains (using terminals in Oberhausen, Duisburg, and Mannheim) which are the most competitive for regions located immediately east of these infrastructures, competing directly with road haulage from Rotterdam. Containerships are very time ineffective due to typically larger dwell times in ports but are very cost competitive. However, they prove to be very sensitive to VoT as even for moderate values they are competitive only for northern Germany, all other regions finding it preferable to use road.

In the analysis of the competitiveness of transport chains when considering GTC, significant reconfigurations are observed. It is worth noting, for example, that using IWW from Rotterdam to Duisburg loses relevance when considering GTC, as IWW is typically slow. It is thus replaced by a rail solution from Rotterdam to Oberhausen. For a moderate VoT, intermodal chains based on Ro-Ro ships manage to remain competitive throughout Belgium, Luxembourg, The Netherlands, and Germany. Consequently, SSS based on Ro-Ro ships appears more competitive than services based on containerships.

This paper has also presented statistical evidence for SSS and road modal shares for transportation to each country in Northern Europe and these shares are well explained

considering the numerical results presented in this paper. Nevertheless, the numerical results on the relative competitiveness of different modes and chains will be validated in future research by requesting expert opinion from forwarders, shippers, and shipping companies involved in SSS.

These results support the more general transport policy implication that integrated transport chains, combining short sea shipping (with Ro-Ro ships) and other components of TEN-T (rail freight corridors and inland waterways), should be promoted by EU and national authorities, as these transport chains show good competitiveness for a wide range of NUTS 2 regions in Northern Europe, up to approximately 300 km from the coastline. This finding is thus fully in line with the Commission objective of severely shifting long distance inland freight away from European roads. This is especially true for cargos with low to moderate values of VoT and raising the shipper's awareness of this competitiveness could significantly assist EU authorities in achieving its transport policy goals.

A further policy implication of this paper is that costly investments in railway lines all the way from the Atlantic façade of the Iberian Peninsula to Northern Europe could be largely avoided by using the already well developed TEN-T infrastructure in Northern Europe and combining it with Ro-Ro based SSS, thus assisting in providing cheaper but still efficient door-to-door transportation. Finally, the utilization of such intermodal combination would also greatly decrease the number of drivers required (this paper deals with unaccompanied Ro-Ro transport), an aspect that is of the utmost importance given the current scarcity of truck drivers in the EU logistics industry.

Author Contributions: Conceptualization, T.A.S.; methodology, T.A.S.; software, T.A.S.; validation, T.A.S. and P.M.; formal analysis, M.Â.F. and P.M.; investigation, M.Â.F. and P.M.; resources, P.M.; data curation, P.M. and T.A.S.; writing—review and editing, T.A.S., M.Â.F. and C.G.S.; visualization, M.Â.F.; supervision, T.A.S. and C.G.S.; project administration, T.A.S. and C.G.S.; funding acquisition, T.A.S. and C.G.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundação para a Ciência e a Tecnologia (FCT), grant number PTDC/ECI-TRA/28754/2017 and contributes to the Strategic Research Plan of the Centre for Marine Technology and Ocean Engineering (CENTEC), which is financed by FCT under contract UIDB/UIDP/00134/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The research presented in this paper was conducted within the research project “Evaluation of short sea shipping services integrated in supply chains”, financed by the Portuguese Foundation for Science and Technology (Fundação para a Ciência e Tecnologia - FCT), under contract PTDC/ECI-TRA/28754/2017. This work contributes to the Strategic Research Plan of the Centre for Marine Technology and Ocean Engineering (CENTEC), which is financed by FCT under contract UIDB/UIDP/00134/2020. The authors would like to thank the European Commission, DG MOVE, TENtec Information System, for the permission to use the representation of the TEN-T network in the maps presented in this paper.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Notes

1. <https://www.transportesenegocios.pt/cobelfret-anuncia-servico-semanal-leixoes-ro-terdao/> (in Portuguese, accessed on 1 March 2021).
2. <https://www.publico.pt/2012/06/17/jornal/db-schenker-realiza-comboios-de-mercadorias-directos-entre-portugal-e-a-alemanha-24733921> (in Portuguese, accessed on 1 March 2021).

References

- European Court of Auditors. *Have the Marco Polo Programmes Been Effective in Shifting Traffic off the Road?* Special Report No 3; European Court of Auditors: Luxembourg, 2013.
- Paixão Casaca, A.C.; Marlow, P. The Impact of the Trans-European Transport Networks on the Development of Short Sea Shipping. *Marit. Econ. Logist.* **2007**, *9*, 302–323. [\[CrossRef\]](#)
- Christodoulou, A.; Raza, Z.; Woxenius, J. The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service. *Sustainability* **2019**, *11*, 2422. [\[CrossRef\]](#)
- CIP. *Logistics in Portugal (in Portuguese)*; CIP: Lisbon, Portugal, 2015.
- European Commission. *The European Green Deal, COM (2019) 640 Final*; European Union: Brussels, Belgium, 2019.
- European Commission. *White Paper Roadmap to a Single European Transport Area—Towards a Competitive and Resource Efficient Transport System, COM (2011) 0144*; European Union: Brussels, Belgium, 2011.
- Paixão Casaca, A.C.; Marlow, P.B. The competitiveness of short sea shipping in multimodal logistics supply chains: Service attributes. *Marit. Policy Manag.* **2005**, *32*, 363–382. [\[CrossRef\]](#)
- OTEP. 9th Report of the Cross-Border Observatory Spain/Portugal. 2018. Available online: <https://www.gee.gov.pt/pt/publicacoes/observatorio-transfronteirico-espanha-portugal/> (accessed on 1 June 2021). (In Portuguese)
- European Parliament. *Regulation (EU) No 1315/2013 on Union Guidelines for the Development of the Trans-European Transport Network and Repealing Decision No 661/2010/EU*; European Union: Strasbourg, France, 2013.
- Janić, M. Modelling the full costs of an intermodal and road freight transport network. *Transp. Res. Part D Transp. Environ.* **2006**, *12*, 33–44. [\[CrossRef\]](#)
- Janic, M.; Vleugel, J. Estimating potential reductions in externalities from rail-road substitution in Trans-European freight transport corridors. *Transp. Res. Part D* **2012**, *17*, 154–160. [\[CrossRef\]](#)
- Van Klink, H.; Berg, G.C.V.D. Gateways and intermodalism. *J. Transp. Geogr.* **1998**, *6*, 1–9. [\[CrossRef\]](#)
- Tsamboulas, D.; Vrenken, H.; Lekka, A.-M. Assessment of a transport policy potential for intermodal mode shift on a European scale. *Transp. Res. Part A Policy Pr.* **2007**, *41*, 715–733. [\[CrossRef\]](#)
- Tzannatos, E.; Papadimitriou, S.; Katsouli, A. The cost of modal shift: A short sea shipping service compared to its road alternative in Greece. *Eur. Transp. Transp. Eur.* **2014**, *56*, 2. [\[CrossRef\]](#)
- Sambracos, E.; Maniati, M. Competitiveness between short sea shipping and road freight transport in mainland port connections; the case of two Greek ports. *Marit. Policy Manag.* **2012**, *39*, 321–337. [\[CrossRef\]](#)
- CIP. *Survey into International Goods Transportation*; Report Ref-106; CIP: Lisbon, Portugal, 2016. (In Portuguese)
- Kim, N.S.; Van Wee, B. The relative importance of factors that influence the break-even distance of intermodal freight transport systems. *J. Transp. Geogr.* **2011**, *19*, 859–875. [\[CrossRef\]](#)
- Santos, T.A.; Soares, C.G.; A Santos, C.G.S.T. Modeling transportation demand in short sea shipping. *Marit. Econ. Logist.* **2017**, *19*, 695–722. [\[CrossRef\]](#)
- Martínez-López, A.; Munín-Doce, A.; Alonso, L.G. A multi-criteria decision method for the analysis of the Motorways of the Sea: The application to the case of France and Spain on the Atlantic Coast. *Marit. Policy Manag.* **2015**, *42*, 608–631. [\[CrossRef\]](#)
- Santos, T.A.; Soares, C.G. Methodology for ro-ro ship and fleet sizing with application to short sea shipping. *Marit. Policy Manag.* **2017**, *44*, 859–881. [\[CrossRef\]](#)
- Santos, T.A.; Guedes Soares, C. Short Sea Shipping and the Promotion of Multimodality in the European Atlantic Area. In *Proceedings of the 27th Annual Conference of the International Association of Maritime Economists*, Athens, Greece, 25–27 June 2019.
- Santos, T.A.; Escabelado, J.; Martins, P.; Soares, C.G. Short Sea Shipping Routes Hinterland Delimitation in the European Atlantic Area. In *Developments in Maritime Technology and Engineering*; Guedes Soares, C., Santos, T.A., Eds.; Taylor and Francis: London, UK, 2021; Volume 1, pp. 81–90.
- Santos, T.A.; Guedes Soares, C. Assessment of Transportation Demand on Alternative Short Sea Shipping Services Considering External Costs. In *Integration of the Maritime Supply Chain: Evolving from Collaboration Processed to Maritime Supply Chain Network*; Vanelander, T., Sys, C., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 13–45. [\[CrossRef\]](#)
- Santos, T.A.; Ramalho, M.; Guedes Soares, C. Sustainability in Short Sea Shipping—Based Intermodal Transport Chains. In *Short Sea Shipping in the Age of Sustainable Development and Information Technology*; Santos, T.A., Guedes Soares, C., Eds.; Routledge, Taylor & Francis Group: London, UK, 2020; pp. 89–115. [\[CrossRef\]](#)
- Zamparini, L.; Reggiani, A. Freight Transport and the Value of Travel Time Savings: A Meta-analysis of Empirical Studies. *Transp. Rev.* **2007**, *27*, 621–636. [\[CrossRef\]](#)
- Feo-Valero, M.; García-Menéndez, L.; Garrido-Hidalgo, R. Valuing Freight Transport Time using Transport Demand Modelling: A Bibliographical Review. *Transp. Rev.* **2011**, *31*, 625–651. [\[CrossRef\]](#)
- Hintjens, J.; Van Hassel, E.; Vanelander, T.; Van De Voorde, E. Port Cooperation and Bundling: A Way to Reduce the External Costs of Hinterland Transport. *Sustainability* **2020**, *12*, 9983. [\[CrossRef\]](#)
- Lupi, M.; Farina, A.; Orsi, D.; Pratelli, A. The capability of Motorways of the Sea of being competitive against road transport. The case of the Italian mainland and Sicily. *J. Transp. Geogr.* **2017**, *58*, 9–21. [\[CrossRef\]](#)
- Morris, J.; Dumble, P.; Wigan, M. Accessibility indicators for transport planning. *Transp. Res. Part A Gen.* **1979**, *13*, 91–109. [\[CrossRef\]](#)

30. Southworth, F.; E Peterson, B. Intermodal and international freight network modeling. *Transp. Res. Part C Emerg. Technol.* **2000**, *8*, 147–166. [CrossRef]
31. Thill, J.-C. Geographic information systems for transportation in perspective. *Transp. Res. Part C Emerg. Technol.* **2000**, *8*, 3–12. [CrossRef]
32. Lim, H.; Thill, J.-C. Intermodal Freight Transportation and Regional Accessibility in the United States. *Environ. Plan. A Econ. Space* **2008**, *40*, 2006–2025. [CrossRef]
33. Thill, J.-C.; Lim, H. Intermodal containerized shipping in foreign trade and regional accessibility advantages. *J. Transp. Geogr.* **2010**, *18*, 530–547. [CrossRef]
34. Ferrari, C.; Parola, F.; Gattorna, E. Measuring the quality of port hinterland accessibility: The Ligurian case. *Transp. Policy* **2011**, *18*, 382–391. [CrossRef]
35. Ambrosino, D.; Ferrari, C.; Sciomachen, A.; Tei, A. Intermodal nodes and external costs: Re-thinking the current network organization. *Res. Transp. Bus. Manag.* **2016**, *19*, 106–117. [CrossRef]
36. Acciaro, M.; Bardi, A.; Cusano, M.I.; Ferrari, C.; Tei, A. Contested port hinterlands: An empirical survey on Adriatic seaports. *Case Stud. Transp. Policy* **2017**, *5*, 342–350. [CrossRef]
37. Alonso, L.G.; Martínez-Pardo, A.; Pinto, J.A.V. Analysis of the spatial development of the hinterland of ports: A case study. *Int. J. Shipp. Transp. Logist.* **2016**, *8*, 111. [CrossRef]
38. Guerrero, D. Deep-sea hinterlands: Some empirical evidence of the spatial impact of containerization. *J. Transp. Geogr.* **2014**, *35*, 84–94. [CrossRef]
39. Hassel, E.V.; Meersman, H.; Voorde, E.V.; Vanelslander, T. Impact of scale increase of container ships on the generalized chain cost. *Marit. Policy Manag.* **2016**, *43*, 192–208. [CrossRef]
40. Zondag, B.; Bucci, P.; Gützkow, P.; De Jong, G. Port competition modeling including maritime, port, and hinterland characteristics. *Marit. Policy Manag.* **2010**, *37*, 179–194. [CrossRef]
41. Frémont, A.; Franc, P. Hinterland transportation in Europe: Combined transport versus road transport. *J. Transp. Geogr.* **2010**, *18*, 548–556. [CrossRef]
42. Macharis, C.; Pekin, E. Assessing policy measures for the stimulation of intermodal transport: A GIS-based policy analysis. *J. Transp. Geogr.* **2009**, *17*, 500–508. [CrossRef]
43. Macharis, C.; Pekin, E.; Van Lier, T. A Decision Analysis Framework for Intermodal Transport: Evaluating Different Policy Measures to Stimulate the Market. In *Integrated Transport: From Policy to Practice*; Givoni, M., Banister, D., Eds.; Routledge: Oxfordshire, UK, 2010; pp. 223–240.
44. Macharis, C.; Van Hoeck, E.; Pekin, E.; Van Lier, T. A decision analysis framework for intermodal transport: Comparing fuel price increases and the internalization of external costs. *Transp. Res. Part A* **2010**, *44*, 550–561. [CrossRef]
45. Pekin, E.; Macharis, C.; Meers, D.; Rietveld, P. Location Analysis Model for Belgian Intermodal Terminals: Importance of the value of time in the intermodal transport chain. *Comput. Ind.* **2013**, *64*, 113–120. [CrossRef]
46. Macharis, C. The Optimal Location of an Intermodal Barge Terminal. In *Transport Developments and Innovations in an Evolving World*; Beuthe, M., Himanen, V., Reggiani, A., Zamparini, L., Eds.; Springer: Berlin/Heidelberg, Germany, 2004; pp. 211–234.
47. Meers, D.; Macharis, C.; Vermeiren, T.; van Lier, T. Modal choice preferences in short-distance hinterland container transport. *Res. Transp. Bus. Manag.* **2017**, *23*, 46–53. [CrossRef]
48. Santos, T.; Soares, C.G. Container terminal potential hinterland delimitation in a multi-port system subject to a regionalization process. *J. Transp. Geogr.* **2019**, *75*, 132–146. [CrossRef]
49. Ng, A.K.Y. Competitiveness of short sea shipping and the role of port: The case of North Europe. *Marit. Policy Manag.* **2009**, *36*, 337–352. [CrossRef]
50. Infraestruturas de Portugal. *Regulation on Access and Tariffs of the Rail Freight Terminals of Leixões and Bobadela*; Infraestruturas de Portugal: Lisbon, Portugal, 2017. (In Portuguese)
51. Black, I.; Seaton, R.; Ricci, A.; Enei, R. *Final Report: Actions to Promote Intermodal Transport*; Final Report of EU Project RECORDIT (Real Cost Reduction of Door-To-Door Intermodal Transport); TRT Transporti I Territorio: Milano, Italy, 2003.
52. Martins, P. Road Freight Transportation: The Dilemma Railway versus Road in Portugal. Master's Thesis, Faculty of Economics, University of Porto, Porto, Portugal, 2015. (In Portuguese).
53. PIANC. *Masterplans for the Development of Existing Ports*; Report n° 158; PIANC: Brussels, Belgium, 2014.
54. Yilport. Tariff Regulations, Yilport-TCL, Leixões, Portugal. 2021. Available online: <http://www.tcl-leixoes.pt/en/regulations/tariff-regulations/> (accessed on 22 February 2021).
55. TRT; MDS. *Gathering Additional Data on EU Combined Transport*; Report for Directorate-General for Mobility and Transport, Unit D1-Maritime Transport & Logistics; European Commission: Brussels, Belgium, 2017.
56. CEGE. *Container Terminals in the Region of Lisbon-Setúbal—a Comparative Analysis*; Technical Study; ISEG—School of Economics and Management: Lisbon, Portugal, 2014.
57. Reis, V. Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model. *Transp. Res. Part A Policy Pr.* **2014**, *61*, 100–120. [CrossRef]
58. Martins, S. Economic Evaluation of the Project “Rail Freight Corridor Lisbon-Germany” Developed by DB Schenker. Master's Thesis, Faculty of Sciences, University of Lisbon, Lisbon, Portugal, 2013. (In Portuguese).

-
59. European Parliament. *Harmonisation of Certain Social Legislation Relating to Road Transport and Amending Council Regulations (EEC) No 3821/85 and (EC) No 2135/98 and Repealing Council Regulation (EEC) No 3820/85; Regulation (EC) No 561/2006*; European Union: Strasbourg, France, 2006.
 60. INE. *Transport and Communications Statistics*; Instituto Nacional de Estatística: Lisbon, Portugal, 2019. (In Portuguese)