Short Sea Shipping Feasibility Study for the Carriage of RoRo Cargo to Northern European Ports

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ABSTRACT: This paper aims to assess the competitiveness of Short Sea Shipping (SSS) by comparing the total amount of cargo between Portugal and Northern Europe that may be attracted by SSS (using RoRo ships) and by road. The total amount of cargo is evaluated according to a transportation demand evaluation model, which calculates transit times and costs between different regions in Europe. A decision-making process between transport modes is also included. The model also calculates external costs implied by both transport solutions and evaluates the effects of integrating these costs in the SSS potential demand. The model is tested for four alternative sea routes from Portugal to the Northern Europe, considering different destination ports: Le Havre, Rotterdam, Hamburg and Szczecin. The results allow the identification of the regions for which an intermodal solution (including SSS) is more competitive and quantifies its demand. SSS potential demand increases with lower freight rates, higher sailing speeds and external costs internalization. In all routes, apart from Le Havre, demand is more sensible to time than to costs. Rotterdam is the most interesting route due to its overall potential demand as well as its enlarged hinterland region. The results may be applied in determining the required cargo capacity of RoRo ships to be deployed in the different routes.

Keywords: Short Sea Shipping; Intermodality; Road Transport; RoRo Shipping; Time-Cost Model; External Costs.

1 INTRODUCTION

Seaborne trades contribute to the economic development by transporting goods and passengers, facilitate intercultural exchanges, to spread knowledge and ideas and being a source of economic growth itself. Short Sea Shipping (SSS) has been in European Union (EU) agenda since the early 1990's. It's considered the only mode capable of mitigate road congestion, increase sustainability and develop the efficiency of logistic chains. Despite strong financial subsidies to upgrade infrastructures and to improve fully integrated supply chain, as well as regulatory instruments to discourage international road haulage, the SSS potential has never been unleashed. SSS market share has stagnated, while road transport has expanded. Some authors pointed out that SSS has not been well defined by the EU, others that the market potential for shifting from road to sea has been overestimated and transport policy has been oriented to supply side instead of demand.

One of the requirements to ensure intermodality is a fully integrated linking connection between different base modes allowing smoothly operations without delays. The suggestion is to use RoRO ships. RoRo ships can transfer trailers, trucks and cargo units on top of wheeled platforms without using cargo handling gear. RoRo shipping is organized as liner services (regular, scheduled and advertised) providing continuous services of transporting vehicles, passengers, containers and general cargoes. The ability to use RoRo ships for numerous point-to-point operations and their flexibility contributes to improve port performance by reducing both waiting (dwell time) and handling times, when compared to regular container ships.

In some European countries, particularly those located in the center and north of Europe, the utilization of road haulage to facilitate intra-European trades is the most natural solution due to short road distances and consequently achieving the European single market. However, for countries outside the Center of Europe road haulage doesn't seem to be the best transport solution. Using a Heavy Good Vehicle (HGV) for moving goods from peripheral countries like Portugal to North and Center Europe requires crossing distinct countries contributing to road congestion, degradation of infrastructure and increasing of air pollution. In the end, both maintenance and social costs increase as consequence.

Although SSS increases environmental sustainability and energy efficiency, external costs are still not fully internalized. Transport activity is responsible for environmental damages that are not being borne to transport users. The internalization of external costs means making such effects part of the decision-making process of users. When transports fails to price both social and environmental harmful effects they will distort free competition as well as shipping companies will fail to find solutions to reduce emissions and mitigate environmental externalities. External costs are fundamental for policy-makers develop strategies for their internalization, and thus for making progress towards sustainable transport.

This article aims to develop a model able to assess the SSS potential demand when maritime transport, which is fully integrated in intermodal network, is in direct competition with the unimodal transport solution (road haulage). The intention is not to forecast SSS demand for containerized cargo. The freight already being transported in maritime transport is fixed. The motivation is understand if freights currently moved by road transport are available to be carried out more efficiently, faster and more cost-efficient by the intermodal solution. The goal of this thesis is to assess the reliability of the SSS for a given route and determining which combinations of freight and speed could be charged or performed for capturing enough demand to fulfill a ship. This purpose requires the development of a generic mathematical model capable of simulating transit time and transports costs calculated on a door-to-door basis for both modal solutions. After computing times and costs for all routes, a decision-making process is responsible for comparing costs and time. The criteria always selects the transport mode with higher efficiency (lower costs and time). The summation of all cargo volumes able to be performed by intermodal mode represent the SSS potential demand. The model will be tested in the route that links Portugal to Northern-Europe. NUTS2 regions are used as origin and destination points. The model considers port of

Leixões as the Portuguese terminal and four alternative ports in Northern-Europe are under study: Le Havre, Rotterdam, Hamburg and Szczecin. RoRo ships are assumed to be used. Moreover, the internalization of external costs on cost of transports is also to be integrated in the time-cost model.

The paper is organized as follows. In the first section, a literature review surveys and summarizes published papers, studies and other works about these themes. Then, a detailed and step-by-step description of the time-cost method is carried out. The decision-making process is explained at this stage too. In the Numerical Results section the results for four different routes are analyzed and discussed, with and without external costs, allowing conclusions to be drawn.

2 LITERATURE REVIEW

2.1 EU Transport Policies

European Commission acknowledges short sea shipping as the most feasible option for shifting cargo from road to sea. It's a more environmentally friendly and safer solution than road transport. This offers to European Commission a realistic prospect to reduce environmental hazards and improve transport sustainability. Furthermore, short sea shipping promotes connection not only between member states as well as it improves the accessibility with peripheral and island regions. And besides that, European Commission believes that short sea shipping is able to boost up transport efficiency by absorbing expected increase in road traffic arising from economic growth (EU., 1999). Under its common transport policy, European Commission has actively supported the promotion and development of European short sea networks by financing various programs as TEN-T, MoS PACT or Marco Polo.

In addition to all economic instruments above mentioned, regulatory instruments are also used by the European Commission to restrict European road freight transport. Those policy actions intend for an indirect increase on both time and costs of intermodal solution such as limiting maximum speed allowance, driving hours' reduction, lorry ban on weekends, fuel taxes harmonization, road haulage contract standardization and introducing new charges based on distance (Baindur & Viegas, 2011).

Despite all transport policy instruments to promote Short Sea Shipping, Eurostat reveal the unsuccess of European modal shift policies. In 2017, the Statistical Pocketbook (EC., 2017) published statistical data about the performance of freight transport from 1995 to 2015. According with the data available, although there has been a significant increase in volumes of freight transported within the EU (expressed in tonne-kilometer), most of the additional freight has been moved by road haulage. During 20 years of funding programs, road transport has had a modal share of nearly 50% and maritime transport has maintained a share nearby 31%. So, there is an imbalance situation which will persist every year while demand for freight is increasing. Road transport is still the prevailing mode of transportation.

With such poor numbers, two questions arise: how large is the real potential of Short Sea Shipping and which factors are affecting the modal shifting. Looking at Eurostat's statistics, once more, in 2016 liquid and dry bulk cargoes accounted together for 65% of the total of goods moved by short sea shipping (EU., 2018).

Due to bulk cargo specificities, it requires specialized ships traded on spot market with no fixed schedules. These type of cargo is usually used as feedstock to industrial process, so its final destination is limited to industrial facilities frequently located nearby specialized terminals. Due to economies of scale the probability of bulk cargo shift from sea to other modes is very low. For all those reasons, bulk cargo is a captive traffic for short sea shipping. On the other hand, container and roll-on roll-off cargo are commonly used to transport goods that require a door-to-door service with a restricted schedule. Reason why they are more suitable for feeder services and domestic traffic which makes them competing with road haulage.

Some authors (Grosso, Lynce, & K. Vaggelas, 2010) indicate four groups of factors as the main influencers of modal shift: price/cost relation, transit time, service frequency and reliability. Stakeholders (ship-owners, ports, shippers and cargo-owners) don't believe that Short Sea Shipping is a viable alternative to road transport and they have listed as set of critical factors affecting the development of European short sea networks

It was learned from the past experience that long term maintenance of SSS cannot be done by funding new SSS services. The European transport policy should be oriented to the demand side instead of the supply side. More attention to demand policies are more likely to increasing SSS competitiveness by virtue of ship's capacity utilization improvement and average costs reduction. Other policy action recommendation is the focus on shipping sector, especially in RoRo/RoPax ships for the reason that it's the maritime segment with more potential. Finally, new initiatives to benefit the relation between carriers (truck companies) and cargo-owners will stimulate scale economies, reducing customers' price and make sure that multimodal supply chain if fully integrated (COWI, 2015).

2.2 Supply Chain

A Portuguese study (Soares, 2003) has estimated both time and cost for a wide range of liner services linking Portugal to North and South Europe and compared to road haulage alternative. The intermodal advantage depends on distance, loading/unloading port and type of cargo (type of containers used). Intermodal solution can benefit from RoRo ships. Higher rates of cargo rotation and cargo selectivity (when compared to container ships) enables a decrease in port operating time. Dedicated terminal are also desirable, but they might not need large investments: high cargo rotation means that no significant parking areas are required, while intra-community trades reduce safety requirements. The study contributes with typical freight rates for Portugal-Rotterdam route.

Other authors (Ng, 2009) have performed an economic feasibility analysis investigating the potential competitiveness of SSS in the Baltic Region. The model tests the transport of containerized cargo for a set of routes connecting Western Europe (Antwerp) to Baltic Region (Tallinn, Riga, Klaipeda e Gdynia). The methodology differs from others because it combines a variable of monetary value of time for computing the generalized transport costs. Short Sea Shipping would become more competitive when sea leg occupies a higher proportion of intermodal chain. It means SSS should serve coastal regions, while road transport is likely to continue to be the best option for inland regions. Port efficiency is also pointed out as influencing cargo catchment.

Others cost-time models (Martínez-López, Kronbak, & Jiang, 2013) assess the transport of perishable cargo in Rosyth - Zeebrugge route. The model incorporates variables such as ship's gross tonnage, utilization rate, service frequency, fleet size, service speed and distance between transport nodes. Currently operating conditions running out for this route don't allow the intermodal transport of food related goods successfully, but changes on speed, service frequency and enough demand can create competitive intermodal networks (however very close to road haulage conditions).

A multi-criteria decision method computes detailed costs and time for both intermodal and unimodal solutions and Monte Carlo probability distributions performs sensitivity analysis (Martínez-López, Munín-Doce, & García-Alonso, 2015). The model is built form the cargo-owner point of view and is tested in the case study of traded goods between France and Spain by the Atlantic Coast. The authors conclude that the advantage of intermodal services is noticeable in terms of service costs, but it's more restrictive in time criterion. It's not advisable settling road distances range to evaluate intermodal competitiveness over road haulage. The most negative uncontrollable variable for Short Sea Shipping is truck speed (limited by legislation) and haulage costs (limited by fuel price on market). Just like other studies, port efficiency (loading/unloading rates) plays a relevant role in intermodal chains with shorter sea legs.

Some authors (Tsamboulas, Lekka, & Rentziou, 2015) focused on the development of financial viability analysis for Short Sea Shipping networks. The main goal is to provide technical support to maritime operators, port authorities and stakeholders before the development and implementation of a new liner service. The model is tested for a RoPax ship in Adriatic Sea.

Supply chain models considering both internal and external costs have been tested in a Greek case of study: Athens - Lavrio (Tzanatos, Papadimitriou, & Katsouli, 2014) and Patra – Eleusis (Sambracos & Maniati, 2012). These studies conclude that internal costs of Short Sea Shipping are more competitive than road transport, but not for external costs. The reasons behind are superior truck engines and their restricted fuel specifications as well as longer road distances on intermodal chains. Internal and external costs of RoRo ships are not so affected by the ship's capacity utilization (Tzanatos, Papadimitriou, & Katsouli, 2014). Shorter transit times seems to be more important than transport costs. Once more, upgrading port infrastructures will decrease congestion in ports (lower waiting and handling times) and improve intermodal competitiveness. Until then, road transport will remain the favorite mode of transport due to its flexibility and network connections (Tzanatos, Papadimitriou, & Katsouli, 2014).

Santos & Soares (2016) developed a generic time-cost model, fitted with decision-making criteria, for evaluating the potential demand for a new liner service. The model considers RoRo cargo ships and is tested in Leixões-Rotterdam route. Besides the potential demand, the model is also able to provide the port's hinterland region. From the point of view of the authors, transit time is more relevant than costs, but speeds above 14-15 knots don't lead to significant increases on cargo volumes. In the opposite direction, lower freight rates increases demand in regular way. Hinterlands regions are concentrated nearby the ports.

2.3 External Costs

The economists named external costs as the social costs upon society that result from the side effects of an activity. Therefore, all the external costs caused by transport activity should be paid by the users themselves due to the use of transport infrastructures, congestion, accident and environmental impacts (noise pollution, air pollution and climate change). When we hear about the internalization of those costs, it means not only making transport users responsible for paying such side effects but also making such effects part of their transport decision making process. This might be done by policy intervention through tighter regulation or through market-based instruments like new taxes and new charges.

The EU policy for internalizing the cost of externalities is one of the outlined measures to end up with the distortion between Short Sea Shipping and road haulage in Europe. Transport external costs calculations have been commissioned by both EU and member states under several studies such as CAFE, HEATCO or IMPACT. All of them have similarities, but also have different strengths and weakness.

As a result of the IMPACT study, it was published "The Handbook on External Costs" (see Maibach et. al., 2008), which describes the best methodologies into different categories to calculate external costs. The development of this Handbook was mainly based on the scientific facts already existing until 2007, and mostly supported by the European Union. In 2014, this handbook was revised and updated with new developments in research and policy. This updated version is an improvement and more accurate one, since it includes impact categories such congestion, accidents, noise, air pollution, climate change, infrastructure wear and tear (Korzhenevych et al., 2014).

The above mentioned studies instruct about the best scientific practices for estimating transport external costs. One of the European Union transport policy flags for the promotion of modal shift is that Short Sea Shipping is greener than road transport. Nevertheless, there is lack of published studies to prove it. Academics have been seeking for real evidences that maritime transport is in fact more sustainable, and some such as Hjelle (2010) and Kim & Van Wee (2011) claim that it isn't.

Different voyage-based models have been used to evaluate external costs for both maritime and road transport and all have achieved very similar conclusions. Short Sea Shipping has lower environmental costs, but its advantage is residual. It depends on speed and distance (López-Navarro, 2014), as well as the ships' type and port performance (Lee, Hu, & Chen, 2010). Ship engines and speed directly affect fuel consumption, air pollution and CO2 emissions. Reason why optimal speed is a function of fuel prices and shipping market situation. If ship speeds vary over time, external costs will also vary over time. So, sea transport emission factors should be continuously updated (Vierth, Sowa, & Cullinane, 2018). Another critical issue is higher freight rates, due to investments in emission reduction technologies, can distort the competition in favor of road transport (Jiang, Kronbak, & Christensen, Unknown) or more restricted regulation on road transport emissions (de Osés & Castells, 2008). The simple internalization of external costs does not lead to environmental benefits if not followed by improvements in port infrastructures and a fully integrated supply chain (Lee, Hu, & Chen, 2010).

3 METHODOLOGY AND NUMERICAL METHODS

Figure 1 represents the transportation problem under study. A cargo with origin in Portugal has two different options to reach its final destination in Northern Europe: unimodal or intermodal transport. In the first one the final destination is reached with the exclusive use a fully land-based route (road haulage). The intermodal solution is a combination of sea and land transport. The cargo unit is moved by a truck from the supplier to the port of Leixões where it is loaded into a RoRo ship. Then, the ship sails to a port in North-Europe where the unit of cargo is unloaded from the ship and transported once more by road truck to the final destination. The modal shifting between road and sea can be performed by two ways. The unit of cargo (container) can be unloaded from the road truck and loaded on a wheeled platform (mafi trailer or cassette) and the process is repeated in the discharge port. Another option is to drive the full truck or smi-trailer into the ship and when the ship arrives at the discharge port a new driver comes to pick up the truck and drive it to the final destination.

Figure 1 – Supply chain general formulation.

3.1 Modeling Transit Time

The transit time is the planned travelling time from origin to destination regions. It is based on several assumptions made and figures collected, to end up with two simple mathematical expression able to characterize each one of the modal solutions. In practice, travelling time cannot be taken as a fact, because it may de deviated from in unforeseen circumstances.

Unimodal solution has to concern about road time (time to cover the distance between origin and destination by road), while intermodal solution regards road time, sea time (time taken to sail from port to port) and time at port (time spent in port operations).

$$TTotUni = Troad,\ TTotInt = Troad + Tsea + Tport \quad (1)$$

Road time frequently depends on distance, vehicle speed, maximum driving hours allowed, weather conditions, traffic congestion and infrastructures condition. Understanding how hard is to compute the last three features, the transit time for a unimodal solution can be simplified as the time spent on voyage in a specific route plus the driver resting time:

$$Troad = Tdrive + Trest \quad (2)$$

The voyage time is measured dividing the road distance for the average speed (considered as 65 km/h for Portuguese and Northern Europe roads). Regulation (EC) No 561/2006 provides a common set of EU rules for maximum daily and fortnightly driving times, as well as daily and weekly minimum rest periods for all drivers of road haulage. The aim of this set of rules is to avoid distortion of competition, improve road safety and ensure drivers' good working conditions within the European Union. These rules establish that daily driving period shall not exceed 9 hours, daily rest period shall be at least 11 hours and breaks of at least 45 minutes. Meaning, for each 9 hours daily driven a rest period of 15h must be done.

Taking into consideration the above, transit time for unimodal solution transit time, linking Portuguese NUTS2 regions and North-European NUTS2 regions, is modeled by:

$$TTotUni_{i,j} = \frac{Drd_{i,j}}{SpRd} + int\left(\frac{Drd_{i,j}}{SpRd*TRdDri}\right) * TRdRest \quad (3)$$

The road time in the intermodal solution has two road legs: from the starting point to the loading port and from the unloading port to the final destination. In other words, a Portuguese leg and a North European leg. Both road segments are calculated just the same way as unimodal solution’s road time, considering driving time and resting time for each leg.

The time needed by a ship to sail between the port of Leixões and each one of the route alternatives (Le Havre, Rotterdam, Hamburg or Szczecin) at a constant speed is known as sea time. Just as driving time, sea time is a function of sea distance and sailing speed. A different set of ship speeds are studied to understand its influence on cargo demand.

The time at port concerns the time dedicated to port operations. The most significant operations, in terms of time, are cargo handling and dwell time. Cargo handling is the time used by the terminal to load/unload a container. It depends on the terminal equipment’s performance (equipment available and loading/unloading rates), and amount of cargo to be loaded (between zero, when no cargo exists, and fully loaded, when the amount of cargo to be handled is equal to ship’s maximum capacity). Typically, RoRo ship’s handling time are not as longer as containerships. A fixed value of 7h per container in Leixões terminal and 2h per container in North European terminals were assumed. In reality, handling time is variable and is equal to the time needed to load the ship.

Dwell time is the time spent by a container waiting in port for loading or unloading. In container ships this time could easily get to 6 days, unlike RoRo ships which decreases to a few hours. Dwell time impacts overall transit time, so achieving shorter dwell times will be fundamental to increase demand. The dwell time considered was 6h per container at loading and at discharge.

However, port operations are not limited to cargo handling and dwell time. There are other operations taking place inside port area such as waiting time for a free berth, ship maneuvering (time to come alongside and left berth), and idle time (time spent by the ship, when moored at a safe berth, in operations not related with cargo handling. For instance to open cargo holds, to perform surveys or to issue documents). Container ships as well as RoRo ships usually work as liner service. This type of service operates within a regularly schedule and has a fixed port rotation with published date of calls at dedicated SSS terminals. It means that waiting times will be shorter or almost zero. Nevertheless, a time tolerance is introduced in the model to cover any kind of extra-time that might happen.

Summarizing, the intermodal solution transit time between two NUTS2 regions can be modelled by the following formula:

$$TTotInt_{i,j} = TrdPT_{i,k} + TdwlPT + ThdlPT + Tnav_{k.l} + ThdlNE + TdwlNE + TrdNE_{l,j} \quad (4)$$

$i = Portuguese\ NUTS2\ Regions,$

$j = North - European\ NUTS2\ regions,$

$k = port\ of\ Leixões,$

$l = North - European's\ port$

3.2 Modelling Transport Costs

Transport costs arise from the physical moving of goods between two points and depend on the distance covered as well as the speed of delivery. Just as transit time, there is a diverse range of transport costs such as inventory costs, haulage costs, ship costs and external costs.

Inventory Costs are related to storing and maintaining a certain amount of cargo in stock over transit time. Apart from the time taken to move it, inventory costs are a function of cargo type too. Whatever may be the transport solution adopted, the total inventory cost for a specific route is calculated using the transit time and total amount of cargo traded by commercial transaction (import or export):

A freight rate, per unit of cargo, is charged by shipping companies to transport users to cover all ship costs, including fuel and port dues. A different range of freight rates are introduced in the model to evaluate how it can affect the demand for intermodal solutions. Ship surcharges that might occur are paid apart. Bunker adjustment factor (BAF) is an additional charge added to the base freight rate reflecting the price fluctuation of fuel. Another type of surcharge, but much more unlikely to happen, is demurrage. It refers to the period of time when charterer remains in possession of the ship beyond the agreed laytime. By extension, demurrage charges are paid by the charterer to ship owner for delays in loading/unloading operations. There are no reasons to accommodate any kind of delay since the probability of such thing might occur is very low because the supply chain model simulation adopts liner services, dedicated terminals and constant operating times as assumptions.

Similar to maritime freight rates, haulage rates aim to cover all costs that arise from the road transport. In the unimodal solution, it refers to the entire road journey, but in the intermodal solution, the fares paid to the haulage company regards the leg to take the cargo from the origin point to the loading port and the leg to carry out the cargo from the unloading port to its final destination. Haulage rates can be affected by various factors like vehicle speed, type of vehicle, cargo weight, road charges or fuel price.

Finally, external costs are the social costs caused on third parties by the harmful effects of transport activity. External marginal costs have been picked up from “Update of Handbook on External Costs of Transport” (Korzhenevych, et al., 2014). Summing up, both road and sea external marginal costs depend on the performing vehicle or ship and the features of each route. This means that each segment, either be a road or a sea leg, has its own marginal cots. At this stage, the external cost by route is the sum of the external costs for all legs:

The transport costs for each route concerning unimodal and intermodal solution are modelled by the following formula:

$$CTotUni_{ij} = TTotUni_{i,j} * SInvCost + Drd_{i,j} * RdCostUni + \sum MCext_{i,j} * Drd \quad (5)$$

$$CTotInt_{ij} = TTotInt_{i,j} * SInvCost + Fr + BAF$$
$$+ DrdPT_{i,k} * RdCostPT + DrdNE_{l,j} * RdCostNE$$
$$+ MCextPT * DrdPT_{i,k} + \sum MCext_{k,l} * Dsea_{k,l}$$
$$+ \sum MCext_{l,j} * DrdNE_{l,j} \quad (6)$$

$i = Portuguese\ NUTS2\ Regions,$

$j = North - European\ NUTS2\ regions,$

$k = port\ of\ Leixões,$

$l = North - European's\ port$

3.3 Decision-Making Process

The supply chain model evaluates times and costs by unimodal solution for the same pair of regions. Comparing costs and times of both solutions allows identifying the SSS potential demand. All cargoes moved between two regions by intermodal solution with lower cost and time than the unimodal solution are added to the total amount of cargo able to be shipped by short sea shipping. The summation of all cargoes across all pairs or regions, under the above conditions, represents the transportation demand for the SSS for a specific combination of freight and speed. If both intermodal transportation parameters are equal or lower than the unimodal solution, the cargo is shifted to intermodal solution. Any other combination of results is favorable to the conventional unimodal transportation solution. All cargo elements complying with the previous conditions are added to the total amount of cargo shipped by unimodal solution (Figure 2).

Moreover, the supply chain model encloses tolerances on time (per hour) and cost (per cent). Tolerances are an interesting tool to perform sensitivity tests and to measure with higher accuracy the influence of time and costs on potential demand. Another advantage provided by tolerances is to enable the user to make operational adjustments on the model based on user’s experience such as modelling time delays or extra costs. Sum it all up, the decision-making process for each unit of cargo moved from region of origin i to region of destination j, including arbitrary cost and time tolerances, is modelled as:

$$If\ TTotInt_{i,j} \leq TTotUni_{i,j} * (1 + CTol)\ and$$
$$CTotInt_{i,j} \leq CTotUni_{i,j} + TTol\ then\ Qot_{i,j} = QInt_{i,j} \quad (7)$$

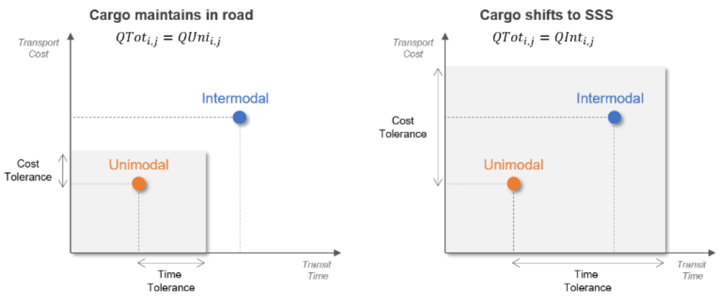

Figure 2 - Decision-making process.

4 NUMERICAL RESULTS

4.1 Time and Cost Results

Table 1 reports detailed time and costs for a given route. The route from Amarante to Amsterdam links the Portuguese NUTS2 region of North to the Dutch region of North Holland. For this route the intermodal transit time is 14h longer than unimodal solution. The intermodal transport costs are almost half of the unimodal costs due to lower haulage costs (short Portuguese and North-European road legs). Intermodal external costs are lower than unimodal.

Table 1 - Transit times and transport costs for both intermodal and unimodal solutions (freight rate €350/TEU, sailing speed 14 knots).

Route	Amarante - Amsterdam by Rotterdam	
Transport Solution	Unimodal	Intermodal
Road Distance (km)	2.032	138
Sea Distance (nm)	-	942
Road Time (h)	76,3	2,1
Sea Time (h)	-	67,3
Time at Port (h)	-	21,0
Transit Time (h)	**76,3**	**90,4**
Haulage Costs (€/TEU)	1.015,95	154,56
Inventory Costs (€/TEU)	76,26	90,41
Ship Costs (€/TEU)	-	377,50
External Costs (€/TEU)	183,88	69,08
Transport Costs (€/TEU)	**1.276,09**	**691,56**

4.2 Base Scenario with External Costs

The baseline was set as no tolerance cost and 12h hours' tolerance time. Additionally, transport external costs are also considered, besides they still don't be part of user's decision. Figure 3 and 4 illustrate the number of cargo units per year feasible to be moved between Portugal and Northeast Europe by the intermodal. The remaining containers from the overall demand, which are not suitable for shifting from road to sea, are assigned to unimodal solution. The demand for short sea shipping is encouraged by lower freight rates and higher sailing speeds.

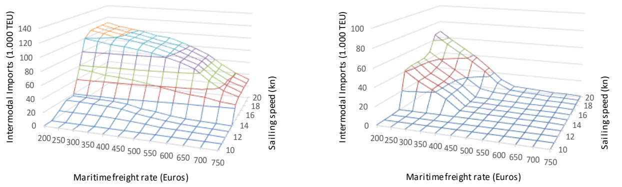

Figure 3 - Intermodal cargo handled (per TEU) by Rotterdam (at left) and by Le Havre (at right) as a function of freight rate (euros) and ship sailing speed (knots) for base scenario.

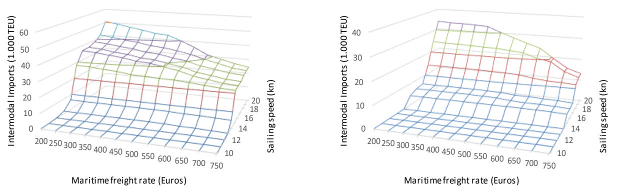

Figure 4 - Intermodal cargo handled (per TEU) by Hamburg (at left) and by Szczecin (at right) as a function of freight rate (euros) and ship sailing speed (knots) for base scenario.

Rotterdam presents interesting numbers of demand from 16 to 20 knots of speed, but there is no cargo handled at lower speeds (10 and 11 knots). From 12 to 14 knots the demand is lower and fairly regular, even for lower freight rates. When 15 kn upwards to 16 kn cargo volume takes a leap. It seems that time's break-even is somehow spotted in this gap. Concerning freight rates, the cargo volume decreases significantly with the increase in freight rates, especially when combined with speeds above the 15/16 knots. In the range set 200-600 euros and 16-20 knots more than 25% of the overall demand is carried out by the intermodal solution.

For the port of Le Havre the demand is approximately concentrated in the range set between 200–450 euros and 14-20 knots. It can also be seen that the amount of cargo that is suitable for short sea shipping increases undoubtedly more by decreasing the freight rate than by increasing speed. Under the 13 knots there aren't any cargo handled and the remaining pairs of freight and speed reveals low capacity to capture cargo volumes. Taking in consideration the above, it seems that Le Havre is more sensible to costs than time.

The intermodal cargo handled by Hamburg can be split into two different behaviors: the higher demand and lower demand. The first one, up to 14 knots of speed, the potential demand is zero, or almost zero, not being able to overcome more than 3% for both imports and export. Moreover, it looks like freight rates don't have any influence on demand. The second one, with higher sailing speeds, has got considerable amounts of cargo suitable for maritime transport and is more clear the influence of freight on demand. Just like the example of Rotterdam, the cleavage of cargo from 14 to 15 knots suggests that times' break-even is located in between both sailing speed.

Szczecin proves to be the weakest sea route alternative. Sailing through Kiel Canal reveals as a great disadvantage: zero cargo volume handled under 15 knots. To overtake this drawback, the ship has to compensate the average sailing speed. Increasing speed above 15 knots will raise the demand for short sea shipping naturally. Downwards freight rates leads to a noticeable increase in potential cargo volumes.

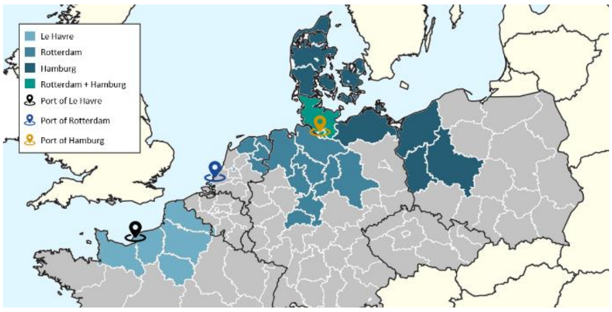

Figure 5 - Hinterland region for base scenario - North European Nuts2 regions for wich the intermodal solution are more feasible than unimodal solution for both imports and exports (freight rate €350/TEU, sailing speed 14 knots).

Figure 5 shows hinterland regions for each route alternative. From the picture verifies that port's hinterland are served by the surround regions except for Rotterdam, which hinterland is far north. There isn't any differentiation between import and export regions, they are all the same ones. While Le Havre's hinterland is focused on Northeastern France, Rotterdam's hinterland is spread thorughtout Northern Netherlands and a considerable area of Germany (northern regions and some more regions in the center). Hamburg presents a large hinterland area spread thorughtout Northern Germany, Denmark and some Polish regions near the border. Rotterdam and Hamburg have in commom two Germany regions: Schleswig-Holstein (most relevant city is Kiel) and Hamburg. Szczecin don't present any hinterland for the specified conditions.

4.3 Base Scenario without External Costs

The results reveal a decrease on demand for all pairs of freight and speed when external cost are disregarded. From Figure 6, Rotterdam and Le Havre imports have increased. Rotterdam have growth 70% in imports, while Le Havre has got 6 times more imports. It's a signficant raise for both routes. On the other hand, Hamburg and Szczecin didn't reveal any variation on maritime transport potential demand.

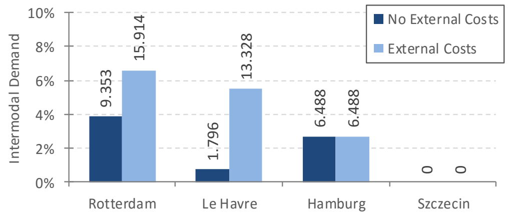

Figure 6 - Intermodal cargo imported by different ports for both base scenario and disregarding external costs.

Hamburg and Szczecin maintain their hinterland regions, since there were no changes in cargo volumes. Rotterdam' hinterland has lost two Germany regions: Schleswig-Holstein, at north, and Saxony-Anhalt (most relevant city is Magdeburg), at center. In the case of Le Havre, two of the most important regions have dropped: Île-de-France (Paris is the most relevant city) and Nord/Pas-de-Calais (Lille).

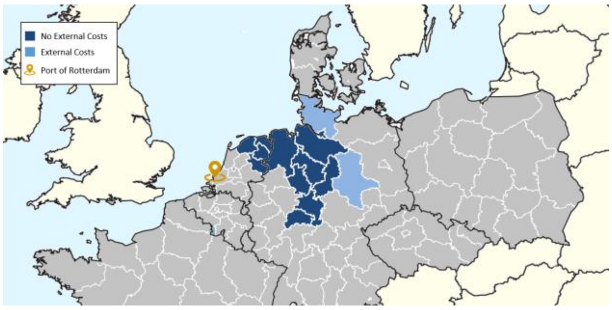

Figure 7 - Rotterdam's hinterland with and without external costs (freight rate €350/TEU, sailing speed 14 knots).

4.4 Sailing Speed Variation

Cargo volumes handled by Rotterdam don't reveal any variation for sailing speeds below service speed Although, for upward sailing speeds there is a clear increasing on demand for both import and export cargoes (Figure 8). Rotterdam's hinterland region is expanded to all German state, apart from southern regions, Netherlands and almost all Belgian regions (Figure 9).

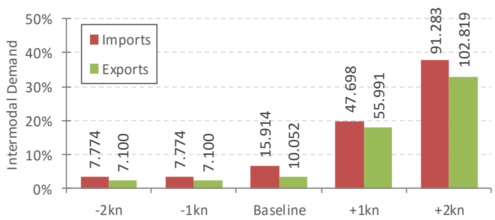

Figure 8 - Intermodal cargo handled by Rotterdam for different sailing speeds (freight rate fixed at €350/TEU, sailing speed set at 14 knots).

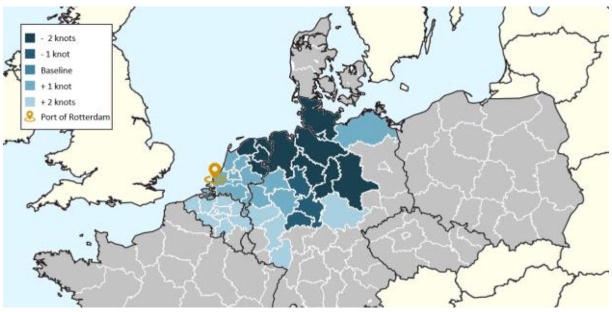

Figure 9 - Rotterdam's hinterland considering speed tolerance (fixed freight rate €350/TEU).

Le Havre behaves curiously. The demand for speed equal or greater than service speed is very regular, close to 6% and Le Havre' hinterland is located in the northeast of France. But when the the speed is decreased there is no demand at all (at -2 knots) or the port is only able to serve its own region (at -1 knots).

The port of Hamburg handles lower cargo volumes when the service speed is decreased. Under these conditions the hinterland region is remote from the port, namely Denmark and a few Polish regions nearby Germany's border. As speed increases, short sea shipping potential demand is over 10% and presents a relevant geographical dispersion, reaching states as Denmark, Germany, Netherlands, Poland and Czech Republic. Szczecin proves to be the least interesting alternative in terms of cargo volumes handled, between 1% and 2.5%. When sailing speed increases, Szczecin is able to serve almost all Polish regions and even some Czech regions in East.

4.5 Freight Rate Variation

Cargo volumes handled by Rotterdam and Le Havre increases with the decrease of freight rates, although in the case of Le Havre the increasing on demand is more pronounced. On the other side, the fluctuation on potential demand presented by Hamburg and Szczecin is zero, with the last one not being able to attract not even a single container. Both Rotterdam and Le Havre enlarged their areas of influence, whereas Hamburg maintains the same regions.

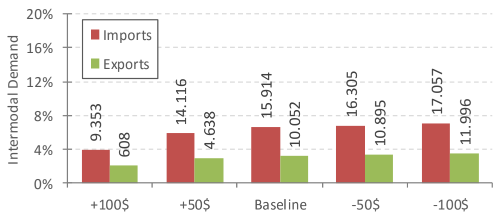

Figure 10- Intermodal cargo handled by Rotterdam for different freight rates (freight rate set at €350/TEU, sailing speed fixed at 14 knots).

4.6 Time Tolerance Variation

The outcome data shows that Rotterdam and Hamburg would only be able to meet minus 12 hours of tolerance at very high speeds (between 18 and 20 knots, depending on the route). Such conditions wouldn't be carried out by any ship-owner/shipping company due to the high operational costs that these speeds entail (it means raising bunkers consumption). For zero hours tolerance scenario the demand for maritime transport is higher than previous one. But the numbers aren't bright: short sea shipping potential demand remains concentrated on higher speeds (range 16-20 knots). Moreover, Le Havre is only able to promote short sea shipping when higher speeds are combined with lower freight rates (below 450 €/TEU). For time tolerances above the base scenario, as 24 and 36 hours, the potential demand is quite encouraging. This significant increase in intermodal cargo is explained by the shifting occurred in lower speeds (from 11 to 13 knots).

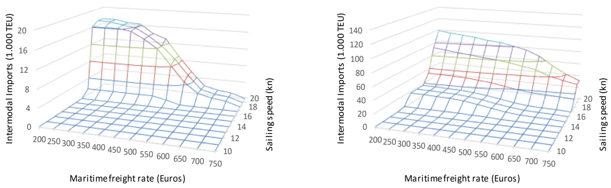

Figure 11- Intermodal cargo imported by Rotterdam when minus 12h tolerance (at right) and no time tolerance are allowed (at left).

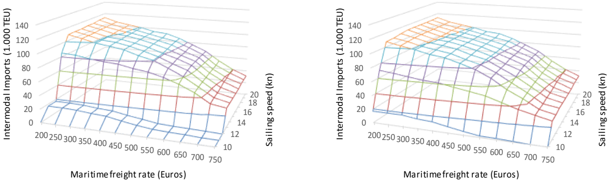

Figure 12 - Intermodal cargo imported by Rotterdam when 24h tolerance (at right) and 36h tolerance are allowed (at left).

Each port reveals a large hinterland area, apart from Le Havre which influence is focused on French Northeast. Another point to highlight is the inability revealed by all routes, even for higher tolerances, to serve the southern regions of Germany and Czech Republic, as well as the French territory uncovered by the port of Le Havre. An alternative route by the Mediterranean Sea could be more interesting for the first two states, but for France, the relatively short distance to Portugal could be the main challenge to increase maritime transport competitiveness over road transport.

SSS competitiveness is increased for positive time tolerances and decreases when no time tolerances, or negative tolerances are considered.

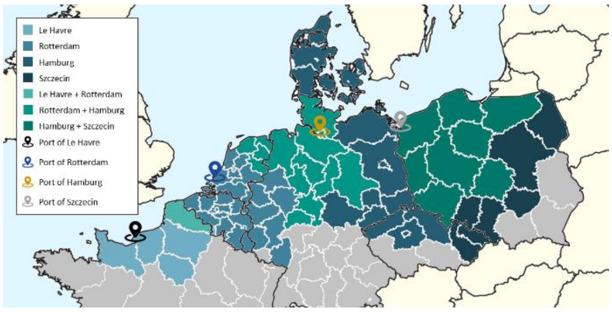

Figure 13 - Hinterland region for a 24h time tolerance (freight rate €350/TEU, sailing speed 14 knots).

4.7 Cost Tolerance Variation

For negative cost tolerances, higher speed ranges (16-20 knots) are holding the demand for maritime transport. Another point is the increasing demand from higher to lower freight rates. Le Havre's distribution profile distinguishes among the others: combinations of lower freight rates with higher sailing speeds stimulates short sea shipping potential demand. Positive tolerances behaves just like negative cost tolerances, except for Le Havre where demand clearly takes advantage from cost tolerances.

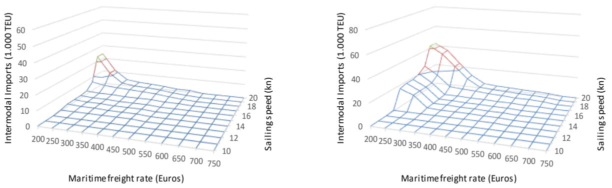

Figure 14 - Intermodal cargo imported by Le Havre when minus 20% tolerance (at right) and minus 10% tolerance are imposed (at left).

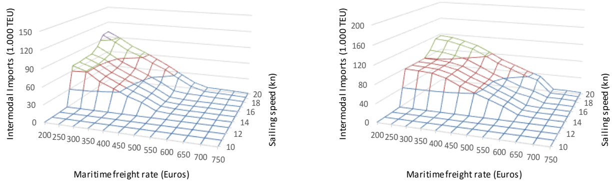

Figure 15 - Intermodal cargo imported by Le Havre when 20% tolerance (at right) and 10% tolerance are allowed (at left).

Le Havre's hinterland expands unquestionably. From the referenced pictures there is no doubts that the ports' hinterland regions have enlarged, but Le Havre's area of influence, for positive cost tolerances, extends to Belgian and Netherlands. In base scenario its hinterland is located in French Northeast. Szczecin hasn't got any demand under the specified conditions.

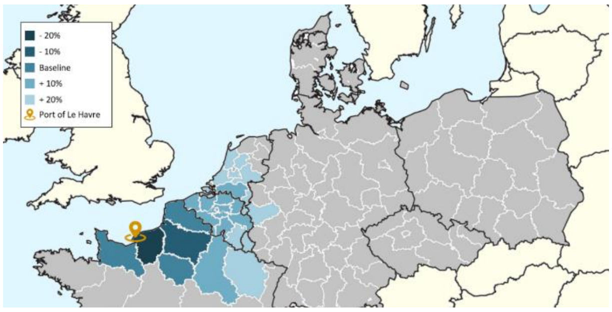

Figure 16 – Le Havre's hinterland considering cost tolerance (freight rate 350€/TEU, sailing speed 14 knots).

5 CONCLUSIONS

This paper presented a model of time and cost involved in unimodal and intermodal (using Short Sea Shipping) transportation between regions of the European Union. The model is written in a generic way and external costs of transport are also evaluated and added to other costs. The model disregards seasonal effects, considering regular demand over a year, which can be pointed out as a constraint. The model also considers that RoRo ships are used in intermodal transportation as these ships are able to load semi-trailers, full trucks and other wheeled cargo without the obligation of using lift-on lift-off cargo handling gear. This flexibility allows reducing dwell times typical of container ships. The time-cost model was tested for four alternative sea routes between Leixões and the North Sea and Baltic Sea regions, considering different destination ports: Le Havre, Rotterdam, Hamburg and Szczecin.

The numerical results show that there is enough demand for a new liner service, under specific operating conditions. This potential is built by shifting cargo from road to sea. Lower freight rates and higher sailing speeds stimulate maritime transport. Although it has been proven that all routes are influenced by these two variables, each route presents a different behavior. Even without a cost-benefit assessment, from the point of view of the shipowner, the route with best potential is Rotterdam. Taking into account the base scenario, the shifting potential is 7% for exports and 3% for imports when external costs are included, which means almost 25 thousand cargo units per year. The potential demand is stable for freight rates in the range of 250 – 450 euros and 1 knot more in sailing speed increases the potential demand up to 40%.

There isn't any intermodal route able to extend its hinterland region to all European NUTS2 regions. Each port has its region of influence. In the limit, two ports might share common regions, but one of them will be better for the user in terms of time and cost. Designing a route with several ports of call can be an attractive solution to reach an enlarged hinterland region and attract more cargo, but, on the other hand, will lead to increased transit times which erode cargo attraction.

The results obtained also show that the internalization of transport externalities in the transport price paid by the users could slightly enhance the Short Sea Shipping competitiveness (more cargo shifted from road transport to maritime transport). For typical operating conditions (considering freight rate of 350 euros per unit of cargo, and sailing speed of 14 knots), the numerical results reveal that cargo volumes handled by Rotterdam and Le Havre increase. Their hinterland regions expanded to the east, far away from Portuguese regions. However, Hamburg and Szczecin don't reveal any change on demand.

External costs depend on different variables such as distance, vehicle engine or speed. Intermodal networks with longer sea legs and shorter road legs could contribute to Short Sea Shipping competitiveness. Although, from the point of view of the users, intermodal transit times still need to be shorter than unimodal solution. Increasing sailing speeds is not a viable solution because it leads to higher emissions and higher fuel consumption. External costs will increase as well as operating costs leading to higher freight rates and SSS losing its short advantage.

Overall, road transport is more advantageous, for many pairs origin-destination, than short sea shipping because, mainly, it is faster and requires fewer regulations. SSS transit time has to be reduced by ways that do not imply stronger legislation on road haulage, but for the common interest of all stakeholders (shippers, owners and operators) to get together and finding practicable ways of increasing sailing speeds, decreasing waiting times and upgrading ports performance. Lower freight costs are also fundamental for SSS competitiveness. Maritime transport is the solution for road congestion and lower emissions. IMO 2020 regulation on new low-sulphur fuels content will decrease shipping pollutants, consequently leading to lower external costs, but on the other hand the price market of fuel will increase leading to higher freight rates.

Although a supply chain model was successfully developed, there is always room for improvements. Including sea channel crossing costs and seasonal effects are two examples. Even so, the time-cost model could be an interesting tool at the disposal of both shipowners and ship operators to evaluate the market demand for a new liner service. The model was designed in a generic way which allows the assessment for alternative routes by changing ports and regions' input conditions. In relation with North and Baltic Sea regions, it could be interesting to evaluate the SSS competitiveness for a liner service between Portugal and Belgium. The port of Antwerp is one of the most relevant Short Sea Shipping ports in Europe.

The most likely path for this work is the intermodal feasibility study for specific types of cargo, like perishable products. In recent years, better refrigeration technologies have been able to improve the shelf life of fresh products and consequently increasing the international trades of those products. With small adjustments to the model, such as the implementation of refrigerated costs or maximum allowable time and different input values for specific inventory costs or port handling times for perishable cargo will be able to upgrade the supply chain model.

The time-cost model allows the quantification of the capacity needed for a new liner service. The next step would be to assess the supply by applying a methodology capable of determining the ship or fleet's physical characteristics as well as computing its operating costs. From here, it's possible to calculate optimum points of operation. It has been proven that there is a potential demand for a new liner service, however, from the shipowners point of view, it's missing the service reliability evaluation and confirming if the operational conditions match those needed by shippers.

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