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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

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Despite European Union (EU) political support to identify the most feasible Motorways of the Sea, the final decision can only be made by Private Shipping Companies, which are operators of a unique stretch of the intermodal chain. This paper provides a multi-criteria decision method to identify the most suitable Motorways of the Sea taking into account the competitiveness of whole intermodal routes versus the alternative of road transport from the loader's perspective. The analysis is carried out assuming a 'many-to-many' transport model. Firstly indexes of time and cost were defined and evaluated for every available route in the model in accordance with a multi-criteria decision matrix. Secondly, through a Monte Carlo simulation a sensitivity analysis was carried out in order to evaluate the influence on the results of the forecast assumed to construct the matrix. The results obtained are not only quantitative, but also qualitative. The development of intermodal routes via Motorways of the Sea is especially relevant for the peripheral EU countries. Due to the relevance of the freight flow between France and Spain and the congestion of their connections through the Pyrenees, the method proposed was applied to the analysis of this particular case

Keywords: Motorways of the Sea; selection of maritime routes; Monte Carlo simulation; sensitivity analysis; multi-criteria decision method

1. Introduction

The level of congestion reached by some of the main land transport corridors within the European Union (EU) suggests the need to divert traffic from roads to alternative modes of transport with the aim of reducing the costs derived from the high traffic concentration borne by the former. This reduction would affect both social costs (related mainly to accident levels and environmental degradation) and private costs (longer travelling time).

To achieve this goal, the development of Short Sea Shipping (SSS) has been contemplated in European Transport Policy as a fundamental stretch of the intermodal chains. Although the definitions given for SSS are numerous, according to the communication

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from the European Commission of 29 June 1999, the term refers to 'the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports situated in non-European countries having a coastline on the enclosed seas bordering Europe'.

The main advantages associated with SSS compared to road transport are its lower number of accidents, its low infrastructure costs, its capacity to reach ultra-peripheral regions and its lower impact on the environment (authors such as Vanherle and Delhaye 2010 have made important clarifications regarding this subject). However, notwithstanding all these advantages, road transport continues to be predominant for channelling the flow of intra-communitarian freight. The main reasons why transport decision-makers are reluctant to adopt intermodal transport are related to the perception of SSS as an outdated, slower, rigid and complex alternative from an administrative point of view, in addition to being less reliable. Potential users thus, tend to consider SSS to be a less satisfactory option than road transport when offering a door-to-door service (Medda, Pels, and Trujillo 2010; Triunfante Martins et al. 2010).

In an attempt to invert this perception, the White Paper on Transport (2001) introduced the concept of the Sea Motorway as a tool to develop SSS. Motorways of the Sea are not only maritime corridors but also a network of ports and intermodal services, which are able to offer a door-to-door transport through their correct integration in the intermodal chains for a particular zone of the EU (Casaca and Ana 2008). In 2003, the European Commission revised the Trans-the European Network of Transport (TEN-T). It included, as an objective for 2010, the implementation of Motorways of the Sea in four corridors (TEN-T Project 21): (i) the Baltic Sea Motorway; (ii) the Western Europe Sea Motorway; (iii) the South-East Europe Sea Motorway; and (iv) the South-West Europe Sea Motorway, connecting Spain, Portugal, France, Italy and Malta, and linking up with the South-East Europe Sea Motorway, including links to the Black Sea. Despite this political support, the last decades have witnessed a distorted transport marketplace which has resulted in a favourable situation for the land transport (Baird 2007). Consequently, the responsibility for the establishment of the successful Motorways of the Sea and their correct integration within the intermodal chains was left by the most member states to the private initiative (Gesé and Baird 2013). One exception however, is the case of the Motorways of the Sea between Spain and France in the Atlantic. On this occasion both countries agreed to boost the most suitable and viable Motorways of the Sea projects (Government of Spain 2006), which met the requirements demanded, subsidizing up to 30% of the operative cost during the first three operation years.

Aside from the choice of ports of call, the setting-up of Motorways of the Sea requires the establishment of a frequency of service for these connections, which will make it possible to offer a door-to-door service in similar conditions of cost and quality to those offered by road transport alone (González Laxe and Novo Corti 2007). In other words, the success of the Motorways of the Sea depends on their capacity to integrate their services in an intermodal chain of transport without additional costs due to bureaucracy or inefficient port services (Casaca and Ana 2008; Paixão Casaca, Carvalho, and Oliveira 2010). The same principle is applicable to SSS services, since Motorways of the Sea are specific SSS services. All this makes the selection of the port critical for the success of the Sea Motorway (Casaca and Ana 2008). The selection of the ports, and therefore the maritime routes chosen in the intermodal transport was mainly tackled from two different approaches: from the point of view of the shipping companies and from the modal choice perspective. In the first group the works devoted to port selection within the SSS framework are very scarce and tend to be limited to the water borne context (the Motorways of the sea projects, which were presented by the shipping companies to take advantage of the public funds in the framework of the Bilateral Agreement between France and Spain for the development of the Motorways of the Sea, are very significant to this regard—GOVERNMENT OF SPAIN, Ministry on Foreign Relations 2006—), whereas in the second approach, the analyses are focused on establishing the minimum thresholds of distances between ports or between end routes to ensure the competitiveness of the intermodal transport versus other alternatives.

Nevertheless, these ranges of distances try to offer general recommendations from the study of particular cases approached as 'one origin to one destination' models. Hence, in accordance with the conclusions of previous researches, the Motorways of the Sea through Atlantic ports prove to be interesting for maritime inter-port distances ranging between 834 and 1400 km (see projects from the IV Framework programme of the European Commission, EMMA Study (1999), or those financed by the Spanish Ministry of Development, Olivella Puig, Martínez De Osés, and Castells Sanabra 2004). Likewise, the EU (European Parliament 1999) has also recommended respecting the minimum threshold of 1385 km of land distance to establish an intermodal chain of transport (these references were established for the European case) which is very close to the recommendation of Jiang, Johnson, and Calzada (1999) who proposed 1400 km. The WEST MOS project (2008) also concluded a minimum land distance of 1000 km for the use of intermodal transport in Spain. Other projects even proposed thresholds for the relative weight of the road haulage into the intermodal chain to keep the interest in this transport mode. Thereby in 2005, the INTEGRATION project (2005) suggested land stretches should be as much as 60% of the intermodal route distance, while Ametller (2007) affirmed that for the case of intermodal transport from Spain and a total distance of 1600 km the maximum road haulage should be 50%. For other contexts, see for example Brooks and Trifts (2008).

This paper propose to adopt the perspective of the transport service as a whole considering that the decision maker of the transport mode is the loader, in this case, the actual owner of the goods. Consequently, the transport need demanded by the decision maker will be a door-to-door service, this forces to evaluate the transport modes according to their capacity to offer this transport service. On the other hand, the intermodal transport through Motorways of the Sea must be analysed as a 'many-to-many' transport model. This is a transport network with many possible origins and destinations, *nodes*, which share a common trunk haul: the Sea Motorway (Daganzo 2005), which is identified by a pair of ports (*hubs*). According to previous considerations, the aim of this paper is to provide a method able to identify the ports that form the most suitable maritime route to support an intermodal chain that is competitive with respect to road transport. To support the comprehension of the proposed method, a case study: the implementation of a Sea Motorway that connects the Atlantic Coastline of Spain and France, has been used as an application example in this paper.

The method was split into two parts. The first one aims to rank quantitatively the maritime routes, for this a multi-criteria decision matrix has been initially defined. In a second step, a Monte Carlo simulation was applied to the matrix with the intention of meeting the risk assumed with the decisions made through the evaluation of the matrix, and to identify the most influent variables on the success of the intermodal transport.

2. The first step: the method for the quantification of the results

The multi-criteria decision method has been applied in combination with the analysis of scenarios by other authors for the selection of ports (Chou, Chu, and Liang 2003; Ugboma, Ugboma, and Ogwude 2006). However, most of these studies were focused on the tramp traffic and approached from the point of view of the shipping company, using data obtained from the stated preference methods. The present paper aims to evaluate different possibilities of maritime routes (Motorways of the Sea), but integrated into the intermodal chains. This involves that, the competitiveness evaluation of the whole intermodal route (door-to-door) must be carried out from the point of view of the actual owner of the goods. For this purpose a multi-criteria decision method has been applied where the competitiveness in terms of time and cost (evaluation criteria) of the intermodal chains versus the road is analysed. Thereby, the results obtained can be evaluated through a three-dimensional matrix formed by dimensionless relevance indexes.

A useful and realistic method for the transport decision maker (the actual owner of the goods), as said before, must necessarily contemplate door-to-door transport needs (Paixão Casaca, Carvalho, and Oliveira 2010; Romana, Pels, and Trujillo 2010). Nonetheless, from a conceptual point of view the articulation of the transport network must respond to a 'many-to-many' model, as such models are capable of reflecting the widest possibilities of transport routes. The 'many-to-many' transport models can be characterized by having a combination of *nodes,* or extreme points in the routes, and *hubs,* or cargo consolidation centres (Daganzo 2005). In the application of this transport model to the method proposed in this paper, the *nodes* correspond to final points of the intermodal routes and the *hubs* to the ports which define the Motorways of the Sea (see Figure 1). The number and location of *nodes* and of *hubs* is discrete and deterministic. This means the method considers that the number of end routes and possible ports must be finite and previously defined by the analyst.

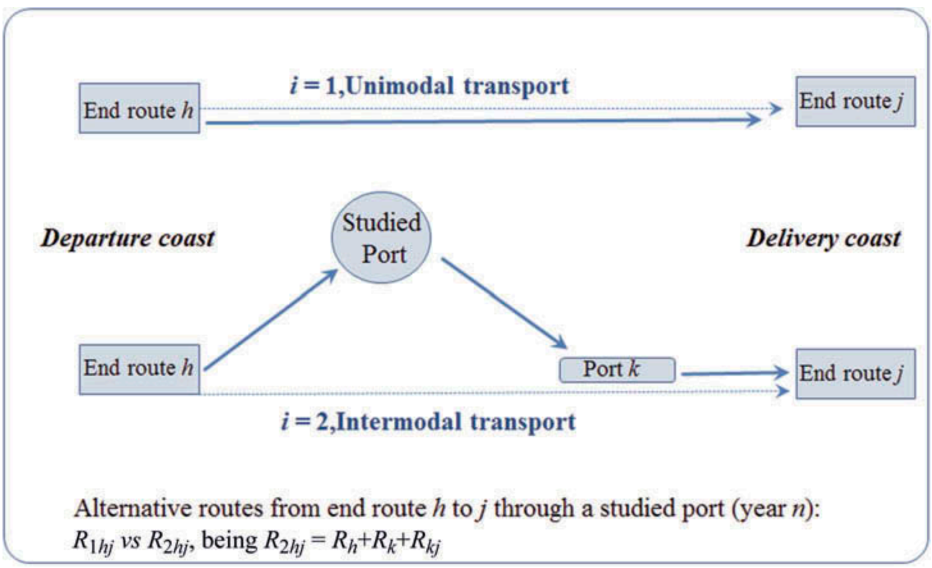

Figure 1. Model 'many-to-many' applied for the study of the transport alternatives.

For the analysis the following assumptions have been made:

- The study is undertaken by considering one direction. Thus, every port of the departure coast is independently studied by taking into account all the connections from that port to all the possible ports of the delivery coast $K = \{1,2,3,\ldots,k\}$.
- For this analysis an identical fleet of ro-ro vessels (the same cargo capacity and speed) has been considered for all cases studied.
- The transport alternatives in the analysis are the road and the intermodal transport ($i = 1, 2$).
- The end routes on both coasts (*nodes*) have an associated possibility that the load departs from this end route (γ_h), with respect to all other possible departure end routes ($H = \{1,2,\ldots,h\}$), or it delivers (α_j) to a concrete end route ($J = \{1,2,\ldots,j\}$).These weighting factors should be defined by considering the scenario conditions evaluated. As a first approach, these can be assumed as unitary population factors (Equations (1) and (2)) bearing in mind the location of the main production and consumer centres (Callejón 2003; Van Oort and Stam 2005):

$$\alpha_j = \frac{\text{Population}_j}{\sum_j \text{Population}_j} \sum_j \alpha_j = 1 \quad \forall j \in J, \tag{1}$$

$$\gamma_h = \frac{\text{Population}_h}{\sum_h \text{Population}_h} \sum_h \gamma_h = 1 \quad \forall h \in H. \tag{2}$$

- The analysis considers the competitiveness of the transport alternatives in terms of the cost during an elapsed time period in the past. For this, the study takes into account the evolution of the traffic pattern between each pair of ports in the range of years considered (Tasto 2010) $N = \{1,2,\ldots,n\}$ through their weighting with respect to the yearly cargo volume moved (in tonnes):

$$\beta_n = \frac{\text{Volume}_n}{\sum_n \text{Volume}_n} \sum_n \beta_n = 1 \quad \forall n \in N. \tag{3}$$

Owing to the fact that volume of trade and the evolution of transport costs are inversely related, the flows of freight could benefit from a reduction of the latter. Such a reduction could be in monetary terms or in terms of time (Limao and Venables 2001). Likewise, the time and cost variables have been remarked as decisive factors in the selection of the transport mode by numerous previous studies (Garcia-Menendez, Martinez-Zarzoso, and Pinero De Miguel 2004; Cullinane and Toy 2000). Consequently, the competitiveness of the transport modes was evaluated according to the time and the costs expended on each route. Assuming the previous points, indexes to assess each of these criteria, as in Equations (4) and (5) are proposed, where Equation (4) is the cost index and Equation (5) is the time index. Both indexes are normalized according to the two transport alternatives, which have been taken into consideration (i):

$$I^{\mathrm{C}}_{ihjkn} = 1 - \frac{\mathrm{Cost}_{ihjkn}}{\sum_{i=1}^{2} \mathrm{Cost}_{ihjkn}} \sum_{i=1}^{2} I^{\mathrm{C}}_{ihjkn} = 1, \tag{4}$$

$$I^{\mathrm{T}}_{ihjk} = 1 - \frac{\mathrm{Time}_{ihjk}}{\sum_{i=1}^{2} \mathrm{Time}_{ihjk}} \sum_{i=1}^{2} I^{\mathrm{T}}_{ihjk} = 1. \tag{5}$$

Thus, the closer the index value is to 1, the less time/cost will be needed with respect to its alternative. Therefore, the interest of the loader in that transport mode, versus the alternative one, will be higher when evaluating only each pair of nodes h and j (like a 'one-to-one' model, this is, all transportation load departures from the same point h and it deliveries to the same port j) through two ports (the studied port and the port k).

Once the indexes have been calculated, the assessment of each Sea Motorway alternative is aggregated. This aggregation is done using Relevance Indexes (RI), defined according to Equations (6) and (7). In this case, they are interpreted as the probability (or relevance) of the decision-maker choosing a particular transport option (mode and route), taking into account the transport attributes (in terms of time and cost) to the all extreme routes defined ('many-to-many' model approach):

$$\mathrm{RI}^{\mathrm{C}}_{ikn} = \sum_{h} \sum_{j} \left(\gamma_h \times \left(I^{\mathrm{C}}_{ihjkn} \times \alpha_j \right) \right) \quad \forall h \in H; \quad \forall j \in J, \tag{6}$$

$$\mathrm{RI}^{\mathrm{T}}_{ik} = \sum_{h} \sum_{j} \left(\gamma_h \times \left(I^{\mathrm{T}}_{ihjk} \times \alpha_j \right) \right) \quad \forall h \in H; \quad \forall j \in J. \tag{7}$$

It is worthwhile to know the advantages that the intermodal alternative offers compared to road transport. For this purpose, the Differential Indexes of Relevance (DIR) in terms of time and cost have been defined according to Equations (8) and (9).These indexes facilitate the comparison of the competitiveness associated with the intermodal chains articulated through different Motorways of the Sea:

$$\mathrm{DIR}^{\mathrm{T}}_{k} = \mathrm{RI}^{\mathrm{T}}_{2k} - \mathrm{RI}^{\mathrm{T}}_{1k}, \tag{8}$$

$$\mathrm{DIR}^{\mathrm{C}}_{kn} = \left(\mathrm{RI}^{\mathrm{C}}_{2kn} - \mathrm{RI}^{\mathrm{C}}_{1kn} \right) \times \beta_n. \tag{9}$$

Indeed, the Differential Indexes of Relevance can be assumed as the final Port Indexes (PI), because they are able to reflect the appeal of each Sea Motorway versus the road alternative for transport users. The higher the index value, the higher the appeal of the intermodal option is. Thereby, in terms of time, the Port Index matches the respective Differential Index of Relevance $\left(\mathrm{PI}^{\mathrm{T}}_{k} = \mathrm{DIR}^{\mathrm{T}}_{k}\right)$. However, this coincidence does not occur in terms of cost. In this case the Differential Index of Relevance $\left(\mathrm{DIR}^{\mathrm{C}}_{kn}\right)$ is related to a particular year (n), whereas the Port Index must take into account the total period of time considered, as shown in Equation (10):

$$\mathrm{PI}^{\mathrm{C}}_{k} = \sum_{n} \left(\mathrm{DIR}^{C}_{kn} \right) \quad \forall n \in N. \tag{10}$$

2.1. *The assessment model for the case of France–Spain*

For this particular case, it is important to bear in mind that the amendment of the TEN-T led to the signing of a bilateral agreement between Spain and France in 2006 to promote the development of Motorways of the Sea by linking up their respective Atlantic coastlines ('The declaration of intentions about the Motorways of the Sea', Government of Spain [2006]). As a result, an intergovernmental commission was created with the aim of drawing up a proposal for the selection of Sea Motorway projects. The requirements are: (i) a service frequency of at least four departures per week each way during the first 2 years of operation; (ii) a frequency of at least seven departures per week each way once these 2 years have elapsed; (iii) annual traffic of at least 350 000 semi-trailers should have been reached at the end of 5 years; and (iv) it should have risen to 850 000 after 10 years. The selected projects would receive additional resources. Taking into account, the date of this agreement and the convenience of the medium term study a time range of 4 years from 2006 to 2009 ($N = 1,2,\ldots,4$) has been assumed for the analysis. In this manner, the real advantage obtained by the use of intermodal transport during these years versus the road alternative can be demonstrated.

Afterwards it is necessary to identify the end points of the routes on both coasts. For this purpose the most consumption and production centres of load, which could be transported through SSS in the Atlantic were assumed as the most probable end routes. In the case of France, these are coinciding with the most populated cities; these should be considered as possible end points. In 2008, the most populated cities in France were (in thousands of habitants according to INSEE, 2009, French Government [1999]): Paris 11 694, Lyon 6121, Lille 4022 and Rennes 3139. Excepting Lyon, the rest of the cities could be reached from the Atlantic coast specifically through the ports of St. Nazaire, Le Havre and Calais. For the case of Spain the situation is different. The most important ports on the Atlantic coast are also the most important production centres of their hinterlands (García-Alonso and Sánchez-Soriano 2010), therefore the land distance on the Spanish coast can be rejected with respect to the whole intermodal chain. Consequently, the end routes in Spain can be assumed as the ports and the 'many-to-many' transport model previously presented (see Figure 1) must be adapted to this situation through a 'one-to-many' model (Daganzo 2005) (see Figure 2). Hence, in this particular case:

- The *studied ports* were those Spanish ports on the Atlantic coast, which are considered as Category A ports (they have international relevance and an annual volume of traffic of over 1.5 million tonnes of freight or 200 000 passengers). These are Vigo, Ferrol, A Coruña, Gijón, Santander and Bilbao. On the other coast the French ports (k) considered were: St. Nazaire, Le Havre and Calais; $K = \{1,2,3\}$.
- For the analysis of the time invested in the maritime stretch a fleet of ro-ro vessels with cargo capacity of 157 trucks each (1960 lane metres) and with a service speed of 30 knots (kn) has been assumed. Additionally, a constant loading speed at all ports of 34 trucks per hour (trucks/h) (information provided by Spanish Stowage Society) has been estimated for all ports studied.
- The transport alternatives in the analysis were the road and the intermodal transport ($i = 1, 2$).
- The end routes on the Spanish coast were coincident with the ports, therefore for each Spanish *studied port* it is always $h = 1$, while the French nodes were: Rennes, Paris and Lille; $J = \{1, 2, 3\}$.

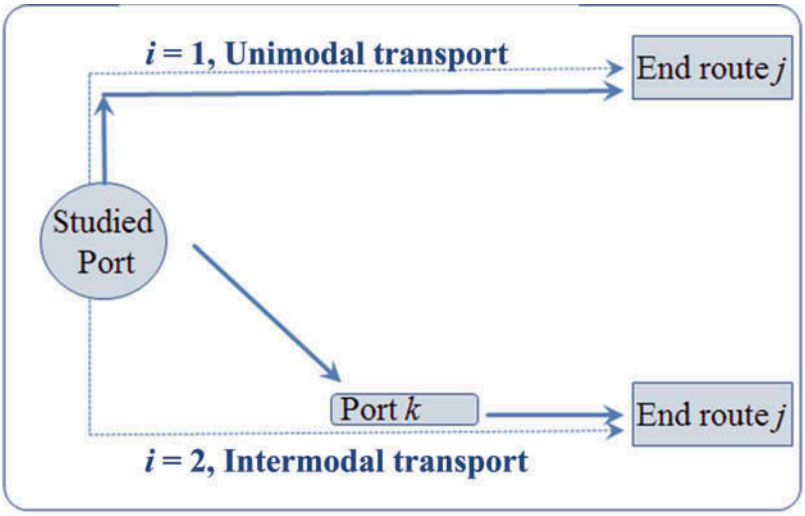

Figure 2. Model 'one-to-many' applied for the study of the transport alternatives in the case: Spain—France.

To calculate the duration of the road haulage, the European legislation determines the minimum rest periods for the drivers (European Parliament 2006) and the maximum truck speed allowed: 90 kilometres per hour (km/h) (92/24/EEC 1992; 92/6/EEC 1992) was taken into account. Likewise, to calculate the cost indexes corresponding to the maritime stretch (see Table 1), estimations used in the intermodality between Spain and Europe (INECEU) Project (Olivella Puig, Martínez De Osés, and Castells Sanabra 2004) were replicated by considering the influence of the time in the costs (Polo 2000). For road distances, the annual data given by the Observatory of Road Freight Transport Costs (Government of Spain 2010) were considered. Finally, the same port dues were assumed for all facilities (Vigo's dues were taken as a pattern).

Figure 3 shows the location of the ports and end routes selected for this particular application. Considering Table 1 and Figure 3, it can be concluded that, the French port (*k*) of Le Havre is the closest to all the possible end routes in France (*j*) by road (16% of the average land haulage), whereas the port of St. Nazaire articulates the intermodal chains with highest land stretches (average of 32% land haulage).

Integrating these results, finally, Port Indexes in terms of the time $\mathrm{PI}_k^{\mathrm{T}}$ and the cost $\mathrm{PI}_k^{\mathrm{C}}$ have been obtained which can each be appreciated in Figures 4 and 5, respectively. In terms of the time all the indexes are positive for the intermodal transport in all *studied ports* from Vigo to Gijón on the Atlantic Spanish coast. The situation changes, however, when the studied ports are closer to the Pyrenees (Santander and Bilbao), the same occurs for the indexes in terms of the cost (see Figure 5). This confirms the conclusions obtained by previous authors, such as Olivella Puig, Martínez De Osés, and Castells Sanabra (2004) who affirmed that the competitiveness of the intermodal routes from Spain to France decreases when the ports are located close to the Pyrenees.

Considering the indexes values obtained in terms of the time and the cost (see Figures 4 and 5), the range of values is larger for cost indexes, as was expected (Feo,

Table 1. Maritime distances (D_k) and road distances 'door to door' (d_j) for the routes studied in the case of France–Spain.

Spanish ports (*Studied port*)	French ports (k)	D_k (km)	French cities (j)	d_j (km)
Vigo	Calais	1390	Rennes	1453
	St. Nazaire	915	Paris	1577
	Le Havre	1232	Lille	1793
Ferrol	Calais	1206	Rennes	1412
	St. Nazaire	717	Paris	1553
	Le Havre	1049	Lille	1751
A Coruña	Calais	1225	Rennes	1392
	St. Nazaire	735	Paris	1514
	Le Havre	1067	Lille	1731
Gijón	Calais	1138	Rennes	1061
	St. Nazaire	563	Paris	1184
	Le Havre	980	Lille	1400
Santander	Calais	1164	Rennes	892
	St. Nazaire	508	Paris	1015
	Le Havre	1006	Lille	1231
Bilbao	Calais	1206	Rennes	795
	St. Nazaire	522	Paris	917
	Le Havre	1049	Lille	1134

Source: Spanish Merchant Navy Association.

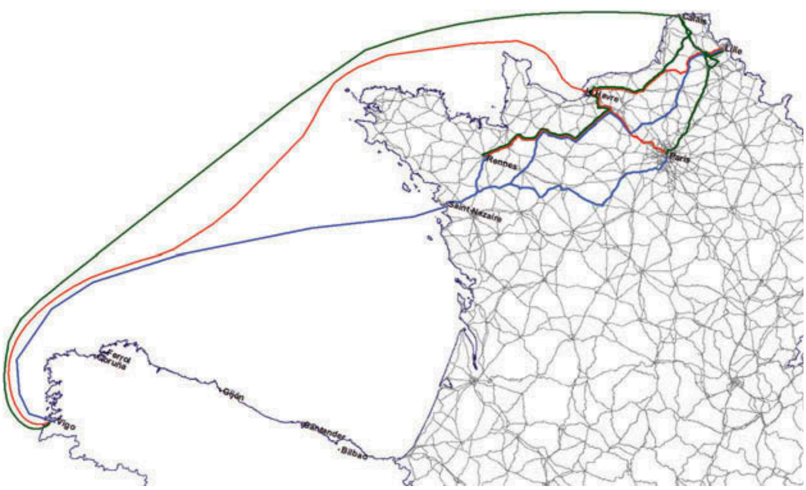

Figure 3. Model 'one-to-many' for the studied port of Vigo to France into the application case of Spain–France.

Espino, and García 2009; Castells I and Sanabra 2009), thereby, the most restrictive attribute of the competitiveness is the time. In fact, this becomes critical. Taking into account both transport attributes the best Motorways of the Sea to articulate intermodal

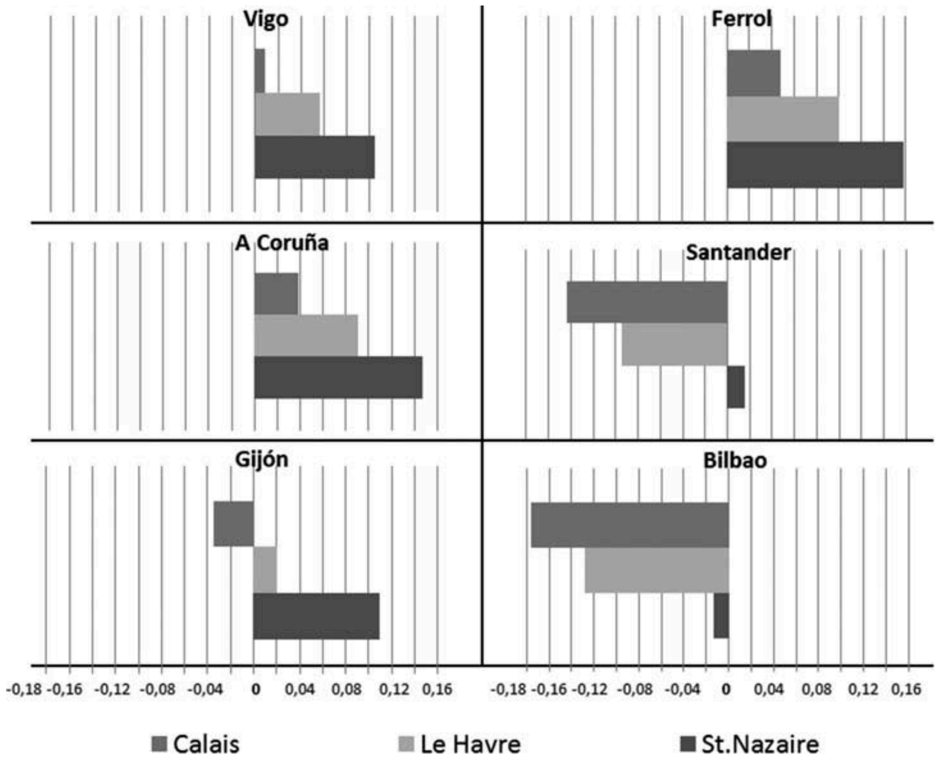

Figure 4. Port Indexes in terms of time PI_k^T for the case of France–Spain.

routes with the highest opportunities of success versus the road from a quantitative perspective are Ferrol–St. Nazaire, A Coruña–St. Nazaire and Vigo–St. Nazaire.

As regards costs, Le Havre and St. Nazaire are very close in terms of competitiveness of the intermodal routes, which are articulated through them (see Figure 5). Nevertheless, in terms of the time (see Figure 4), St. Nazaire followed by Le Havre articulates the most competitive intermodal routes versus the road for the Spanish Ports with positive indexes (Vigo, Ferrol, A Coruña and Gijón). This is true despite the fact that St. Nazaire is the furthest French port from the end routes in France (considering the average land distances). This point is important because the distance between end point and the port is one of the main attributes considered by the loaders when selecting delivery or departure ports (Paixão Casaca, Carvalho, and Oliveira 2010; D'Este and Meyrick 1992). Therefore, each possible door-to-door route must be analysed with more attention through the assessment of the time indexes (5) I_{ihjk}^T (see Table 2).

Table 2 shows the time indexes (Equation (5)) for every routes (for all cases $h = 1$), the non-competitive indexes ($I_{ihjk}^T < 0.5$) for the intermodal alternative have been highlighted. As said before, these indexes evaluate the interest of the loader in a transport mode versus the alternative one by assuming a 'one-to-one' transport model. Through the assessment of this table, numerous cases where the most competitive intermodal routes in terms of the time are not those with the least distance for land haulage can be found. For example, on the Vigo–Lille route the closest port to Lille is Calais, so through this port the land

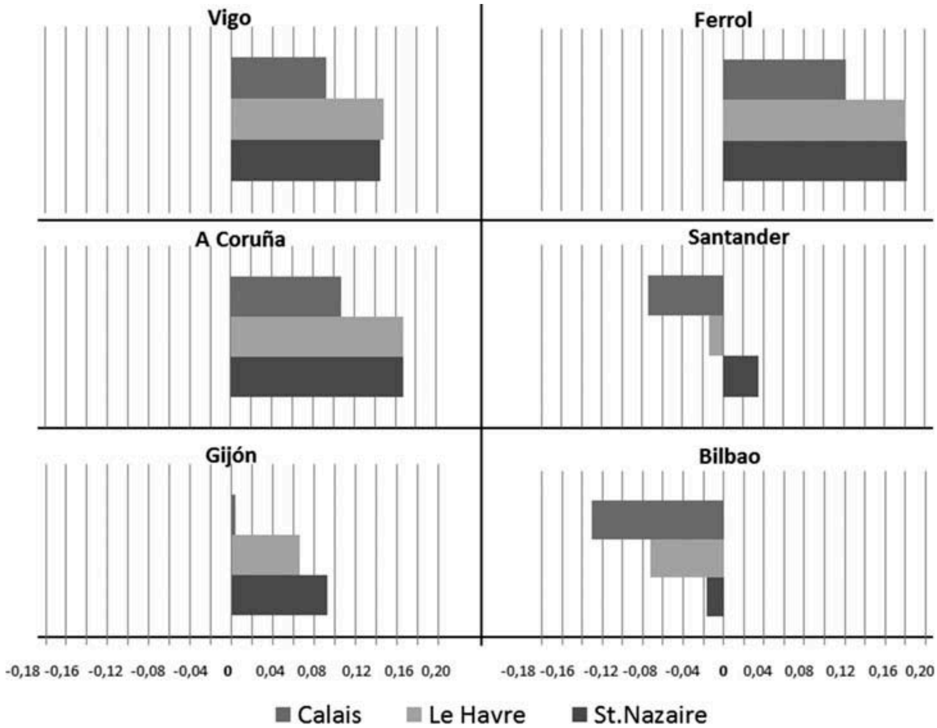

Figure 5. Port Indexes in terms of cost PI_k^C for the case of France–Spain.

haulage is 7.5% of the chain and the time index is I^T_{2133} = 0.60 whereas the intermodal chain of Vigo–St. Nazaire–Lille with a land haulage of 42% achieves I^T_{2131} = 0.61.

Moreover, numerous cases have been detected where the recommended range of maritime distances for the transport through SSS is not accomplished, but they are shown as competitive routes in terms of the time and vice versa. For instance, as Vigo–Le Havre-Rennes, this route has a land haulage distance of 18% (less than the 30% is recommended by Ametller 2007) and the land distance between Vigo–Rennes is 1453 km thus, reaching all the minimum distances recommended by previous authors: Jiang, Johnson, and Calzada (1999); EU recommendation (1999). Furthermore, the maritime distance of Vigo–Le Havre (Table 1) also meets the minimum distance recommended: 833 km by SPC-Spain (2008) and INECEU project (2004). Notwithstanding all these aspects the intermodal route is still not competitive with respect to the road in terms of time (I^T_{2122} = 0.49).

Thus, according to the analysis undertaken, the application of the recommended distances and minimum thresholds is not enough to ensure the competitiveness in terms of the time (a critical parameter) for intermodal chains versus the road. Moreover, the proximity of a port to the consumer or production centre has not been shown as the most suitable attribute for port selection regarding the intermodal transport. As a result, the selection of an intermodal route should be

Table 2. Time indexes (I_{ihjk}) for the routes studied in the case of France–Spain.

		St. Nazaire		Le Havre		Calais	
		Truck	SSS	Truck	SSS	Truck	SSS
Studied ports	*French cities (j)*	I^{T}_{11j1}	I^{T}_{21j1}	I^{T}_{11j2}	I^{T}_{21j2}	I^{T}_{11j3}	I^{T}_{21j3}
Vigo	Rennes	0.45	0.55	0.51	**0.49**	0.55	**0.45**
	Paris	0.47	0.53	0.49	0.51	0.52	**0.48**
	Lille	0.39	0.61	0.39	0.61	0.40	0.60
Ferrol	Rennes	0.42	0.58	0.49	0.51	0.53	**0.47**
	Paris	0.44	0.56	0.47	0.53	0.50	0.50
	Lille	0.36	0.64	0.37	0.63	0.38	0.62
A Coruña	Rennes	0.42	0.58	0.49	0.51	0.54	0.46
	Paris	0.45	0.55	0.47	0.53	0.50	0.50
	Lille	0.37	0.63	0.38	0.62	0.38	0.62
Gijón	Rennes	0.42	0.58	0.51	**0.49**	0.55	**0.45**
	Paris	0.45	0.55	0.49	0.51	0.52	**0.48**
	Lille	0.46	0.54	0.48	0.52	0.48	0.52
Santander	Rennes	0.67	**0.33**	0.76	**0.24**	0.79	**0.21**
	Paris	0.45	0.55	0.51	**0.49**	0.54	**0.46**
	Lille	0.46	0.54	0.50	0.50	0.50	0.50
Bilbao	Rennes	0.70	**0.30**	0.78	**0.22**	0.81	**0.19**
	Paris	0.47	0.53	0.52	**0.48**	0.55	**0.45**
	Lille	0.48	0.52	0.51	**0.49**	0.52	**0.48**

considered for every concrete scenario and for the door-to-door needs (Magala and Sammons 2008).

3. The second step: the sensitivity analysis and the risk assessment

Owing to the fact that the inputs used for the construction of the multi-criteria matrix in the first step of the method are related to a temporal range ($\forall n \in N$), their values are the result of forecasts or estimates. This necessarily implies to accept a risk level on the variables used (uncertainty variables or inputs) and therefore on results obtained. Consequently, the decisions made through the quantitative evaluation of the Port Indexes (see Equations (8) and (10) and their values in Figures 4 and 5) can involve some mistakes. Thus, to assess the goodness of a particular Sea Motorway selection, a risk analysis of the Port Index values was carried out by taking into account the variation in the variables contemplated. For that, once the multi-criteria decision matrix has been performed, the most uncertainty variables were firstly identified; the variation of these led to different scenarios which should be analysed. Notwithstanding this, there are different methods for the simulation of the scenarios. In this case, the Monte Carlo method (already used in this field by other authors, e.g., Lu and Meng 2010; Clark and Watling 2005; Sumalee and Kurauchi 2006) was chosen because it allows the evaluation of all selected variable variations at the same time to calculate the Port Indexes according to an initially determined probability distribution for all variables. This signifies a notable advantage with regard to most of the methods for simulating scenarios (Herz, Unidimensional, etc.) which uniquely contemplate static scenarios through an optimistic or pessimistic approach.

The probability distributions for the value of the Port Indexes and their sensitivity analysis were thereby obtained from Monte Carlo simulations. On the one hand, this allows ascertaining the risk associated with the selection of the ports. For that purpose, the Port Indexes were evaluated to check whether these indexes were good estimators for the corresponding distributions obtained and, consequently, whether the decisions made based on the values of these indexes would be reliable. On the other hand, the sensitivity analysis obtained from the simulation allows determining the influence of the different inputs (controllable and non-controllable variables) assumed for the construction of the decision matrixes.

In the particular case of Spain and France in the Atlantic coast, all the scenarios evaluated were generated in a past period of time (2006–2009) this involves that the variables values were already known (they are not the result of forecasts). However, these were provided by different information sources through diverse formats (formulations and data) therefore a reasonable level of risk was also recognized in this case. For this reason triangular probability distributions being assumed for all variables (Sapag 2001; Suddhendu 1991) with a variation range of 20% between the most and least probable values (see Figure 6). The amount of tests carried out in each simulation was 1 600 000, with a 100% certainty for all results obtained.

For each simulation, the statistical data related to the real probability distribution of the Indexes (and the theoretical distribution that best fits) and the influences of each variable on the Port Indexes were obtained. This last point will also allow the risk to be quantified in association with the lack of control over any variables, and to explain the results achieved in the risk analysis.

The measurement of the goodness of the Port Indexes as estimators was carried out by considering three features:

- Bias: measured as the difference between the mean and the base case (value of the index obtained through the expressions provided).

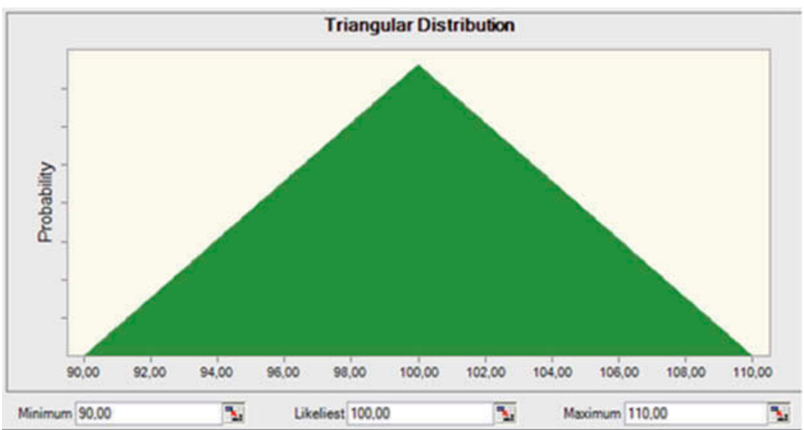

Figure 6. Triangular distribution selected for all variables of the scenarios obtained through the Monte Carlo simulations.

- Consistency level: considered as the proximity from the base case to the most probable value in the distribution.
- Efficiency level: the lowest standard deviation means the highest efficiency level for the indexes (Sapag 2001; Ayyub 2003). This was measured through the Coefficient of Variability.

3.1. *The analysis of the Port Indexes in terms of the time for the case of France–Spain*

For the calculation of the Port Indexes in terms of time, the following inputs were assumed as variables: population factors (α_j), the loading/unloading speed in port, the truck speed and the vessel speed. The values of these inputs were taken as uncertainty variables and so could change in other scenarios. This fact implies a risk for the value of the Port Indexes and, hence, for the selected route. Accordingly, these inputs were considered as variables in the simulations for this Index.

Figure 7 shows the probability distributions shapes obtained from the simulations undertaken for each port. As can be seen in this figure, all the probability distributions shapes of the Port Indexes are very similar for the intermodal routes articulated through

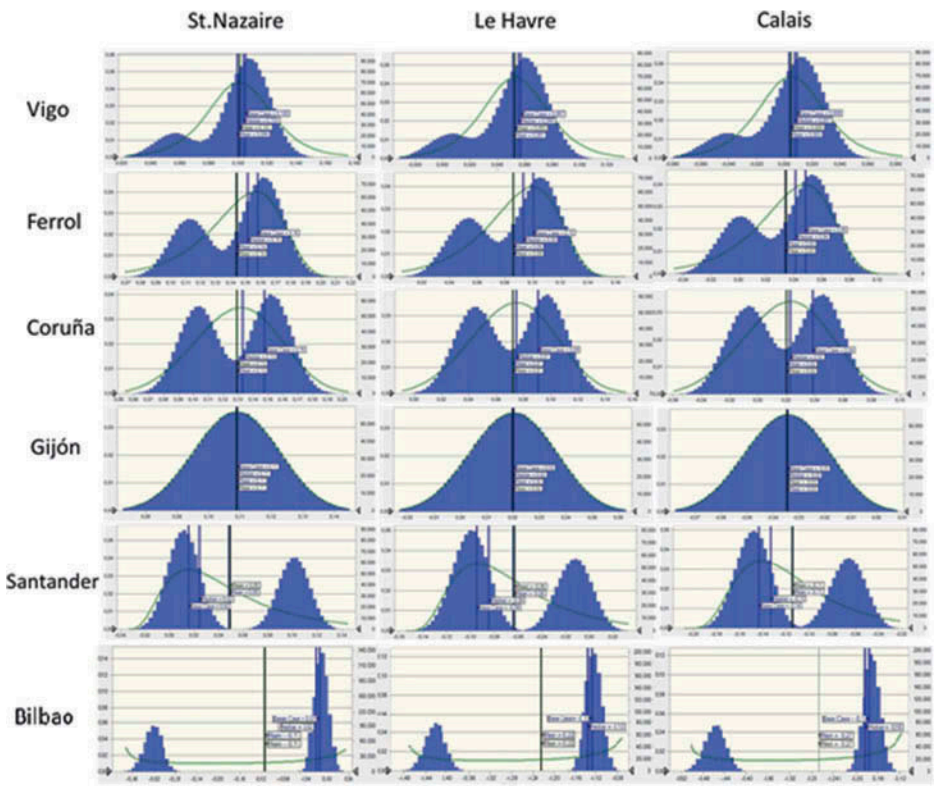

Figure 7. Probability distributions of the Port Indexes in terms of time PI_k^T obtained in the Monte Carlo simulations for the case of France–Spain.

Table 3. Contribution of inputs to the variance (%) of PI_k in the case of France–Spain.

	Vigo			Ferrol			A Coruña		
	SN	LH	C	SN	LH	C	SN	LH	C
Truck speed	−54.40	−55.40	−54.70	−71.00	−71.40	−71.10	−74.70	−74.80	−74.50
Vessel speed	31.00	35.90	37.80	15.70	21.10	23.00	14.30	19.00	20.50
Loading/unloading speed	12.80	7.90	6.60	10.70	6.50	5.30	9.30	5.70	4.70
Lille (α_3)	1.00	0.70	0.70	0.70	0.50	0.50	0.40	0.30	0.30
Paris (α_2)	0.80	0.10	−0.10	1.70	0.40	0.00	1.20	0.30	0.00
Rennes (α_1)	0.10	0.00	−0.10	0.20	0.00	0.00	0.20	0.00	0.00
	Gijón			Santander			Bilbao		
	SN	LH	C	SN	LH	C	SN	LH	C
Truck speed	−14.40	−20.70	−19.70	−73.10	−73.90	−73.50	−71.30	−71.20	−70.30
Vessel speed	37.70	58.50	63.30	10.60	19.00	19.90	11.60	19.30	19.60
Loading/unloading speed	42.80	20.70	16.40	15.00	6.30	4.90	15.50	5.90	4.50
Lille (α_3)	0.30	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Paris (α_2)	4.10	0.10	−0.40	1.00	0.00	−0.50	0.00	−1.10	−3.00
Rennes (α_1)	0.70	0.00	−0.20	−0.30	−0.80	−1.20	−1.60	−2.10	−2.60

Note: SN, Saint Nazaire; LH, Le Havre; and C, Calais.

the maritime routes from the same Spanish port to every French ports (in Figure 7 in horizontal sense, e.g. Vigo–St. Nazaire, Vigo–Le Havre, Vigo–Calais). Nevertheless, the opposite is not met. In other words, in terms of the time the choice of the Spanish port from a French one involves more risk for the intermodal transport than the choice of the French port from a Spanish one. This is mainly due to the coastal geography of the countries (Spain is a peninsula see Figure 3) and to the fact that 'one-to-many' transport model is assumed for the case of France–Spain (see Figure 2). The latter implies that the election of the Spanish port from the French side, not only determines the Sea Motorway, but also the extreme point of the whole route (for the intermodal chain and also for the unimodal transport). However, independently on the French port selected, from one Spanish port the end routes were always the same for the unimodal and intermodal transport.

The distributions shapes obtained (continuous for the routes articulated from Vigo to Gijón on the Spanish coast) can be explained by taking into account the results obtained from the sensitivity analysis (see Table 3). According to the two parameters that influence greatly on the variance of the PI_k^T: the truck speed (negative influence) and the vessel speed (positive influence). The relative importance between them determines the shape of the distributions obtained.

Indeed the influence of the truck speed on the PI_k^T is greatly governed in the EU by the Regulation 561/2006 which determines the driver's maximum continuous driving hours per day along with rest periods. This leads to stepped functions for the time invested in the road transport, which likewise influences on the probability functions shapes obtained for the Port Index. Consequently, depending on road route geography slight changes in truck speed could mean a difference of one day's travel.

Even though the influence of the truck speed is a very important factor in all cases, its effect is moderate for the case of Vigo and Gijón due to the higher influence of the vessel speed in these ports. Consequently, the positive and negative contributions balance themselves out for the case of Vigo, whereas in the case of Gijón the positive contributions are even higher than the negative ones (the real distribution is actually very close to a continuous beta distribution).

Here it is important to pay attention to the fact that the intermodal routes articulated through the Le Havre port have the shortest road haulages distances. For this reason, their competitiveness versus the road is highly influenced by the truck speed. The opposite occurs for the intermodal routes through St. Nazaire (those with the largest road haulage distance), their competitiveness is the least dependent on the truck speed as these routes also take advantage (positive influence) of an increase of the speed on the road haulage. Finally, as expected, while the relative importance of the vessel speed increases with maritime distance, the relative weight of the loading/unloading speed is inversely proportional to the maritime route (Siu and Van De Voorde 2010).

It is interesting to note that routes with Indexes, which are less dependent on the truck speed (non-controllable variable), are those with the highest improvement range. In this case, they are the routes articulated through Gijón and Vigo to any French port (see Table 3).

Table 4 shows the values obtained from the simulations carried out using the Monte Carlo method. Differences between the index values and the means reflect that the bias taken in the selection of the port is low for all cases. However, the level of dispersion of the data is high, with elevated standard deviations and coefficients of variability. Nonetheless, the preferential order of the considered optimal routes remains the same

Table 4. Statistical results from the Monte Carlo simulations (in terms of time) in the case of France–Spain.

	Vigo			Ferrol			A Coruña		
	SN	LH	C	SN	LH	C	SN	LH	C
Base case: value PI_k^T	0.105	0.057	0.009	0.160	0.100	0.050	0.150	0.090	0.040
Mean	0.099	0.051	0.003	0.140	0.090	0.030	0.130	0.070	0.020
Median	0.103	0.055	0.007	0.150	0.090	0.040	0.130	0.070	0.020
Standard deviation	0.028	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Coeff. of variability	0.278	0.580	9.55	0.188	0.339	0.862	0.215	0.416	1.500
/Mean-base case/	0.006	0.006	0.006	0.020	0.010	0.020	0.020	0.020	0.020
	Gijón			**Santander**			**Bilbao**		
	SN	LH	C	SN	LH	C	SN	LH	C
Base case: value PI_k^T	0.110	0.020	−0.030	0.020	−0.090	−0.140	−0.010	−0.130	−0.180
Mean	0.110	0.020	−0.030	0.050	−0.060	−0.110	−0.110	−0.220	−0.270
Median	0.110	0.020	−0.030	0.020	−0.080	−0.130	−0.020	−0.130	−0.180
Standard deviation	0.010	0.020	0.020	0.050	0.050	0.040	0.150	0.140	0.140
Coeff. of variability	0.118	0.777	−0.440	0.953	−0.708	−0.375	−1.300	−0.630	−0.509
/Mean-base case/	0	0	0	0.030	0.030	0.030	0.100	0.090	0.090

Note: SN, Saint Nazaire; LH, Le Havre; and C, Calais.

due to the consistency of the index in all the cases and the distance in absolute values of the Indexes among ports.

Looking at the coefficients of variability at Table 4, the lowest dispersion has been achieved in the intermodal routes through Gijón–St. Nazaire (0.118), Ferrol–St. Nazaire (0.188), A Coruña–St. Nazaire (0.215) and Vigo–St. Nazaire (0.278). Therefore, taking into account the risk analysis, the Indexes in these routes are good estimators (their port indexes are centred, efficient and consistent). As such, for these routes the decisions made through the quantitative analysis of values of Port Indexes in terms of the time does not involve risk.

From the risk assumed and the dependence on non-controllable variables obtained from sensitivity analysis of the Port Indexes in terms of time, the most suitable routes would be Gijón–St. Nazaire and Vigo–St. Nazaire. Moreover, these routes obtained very close absolute values for the Port Indexes in the decision matrix $\mathrm{PI}_k^{\mathrm{T}} = 0.11$ (see Figure 4).

3.2. *The analysis of the Port Indexes in terms of the cost for the case of France–Spain*

For the risk analysis of this index, the assumptions taken into account were population size at the French route endpoints (α_j), the weighting factor regarding the recorded annual volume of traffic between France and Spain (β_n), the land transport cost per kilometre and the freight per transport unit (considering the fuel cost and the capital cost for the shipping company independently).

The probability distributions shape is shown in Figure 8. According to this, it can be concluded that in all cases the theoretical probability distribution (beta) fits the real

Figure 8. Probability distributions of the Port Indexes in terms of cost $\mathrm{PI}_k^{\mathrm{C}}$ obtained in the Monte Carlo simulations for the case of France–Spain.

Table 5. Contribution of inputs to the variance (%) of PI_k^C for the case of France–Spain.

	Vigo			Ferrol			A Coruña		
	SN	LH	C	SN	LH	C	SN	LH	C
€/km	62.30	67.20	79.68	48.48	57.27	71.95	52.46	60.64	75.16
Paris (α_2)	15.60	15.90	5.45	23.51	22.36	9.94	21.03	20.21	7.86
Rennes (α_1)	3.50	0.30	−0.09	4.52	0.52	−0.02	4.54	0.46	−0.06
Lille (α_3)	1.40	2.20	4.32	1.90	2.71	5.42	1.83	2.63	5.27
β_n	12.60	9.40	4.43	17.86	12.81	7.21	16.15	11.45	5.98
The rest of the freight costs (€)	−4.40	−4.70	−5.49	−3.46	−4.03	−5.08	−3.66	−4.23	−5.22
Freight costs due to fuel (€)	−0.40	−0.30	−0.53	−0.27	−0.30	−0.38	−0.33	−0.39	−0.46
	Gijón			**Santander**			**Bilbao**		
	SN	LH	C	SN	LH	C	SN	LH	C
€/km	97.32	87.79	90.85	89.58	92.08	80.32	89.59	85.23	67.20
Paris (α_2)	−0.02	2.88	−0.02	0.34	−0.03	−6.26	−2.30	−3.59	−15.06
Rennes (α_1)	−0.95	−0.01	−0.92	2.13	−0.72	−3.33	0.74	−1.79	−4.50
Lille (α_3)	1.68	0.62	1.55	0.03	0.13	0.73	−0.18	−0.02	0.13
β_n	0.02	2.34	0.02	1.22	−0.20	−3.24	−0.34	−2.87	−7.92
The rest of the freight costs (€)	0.00	−5.98	−6.25	−6.21	−6.30	−5.65	−6.28	−5.95	−4.74
Freight costs due to fuel (€)	0.00	−0.38	−0.38	−0.49	−0.54	−0.48	−0.57	−0.55	−0.45

Note: SN, Saint Nazaire; LH, Le Havre; and C, Calais.

distribution. This already forwards a reduction of the risk associated to the decisions made through this index (PI_k^C) in comparison to the previous index (PI_k^T). In this case, all the distributions are continuous (there are no important steps).This is mainly owing to the fact that the total influence of all the variables for all the routes is positive (see Table 5).

Table 5 shows the results from the sensitivity analysis. Once again, the most influential variable on the index value is related to the truck: the cost per kilometre. For each Spanish port, the positive influence of the road cost increases when the influence of the road stretch in the intermodal transport decreases. Namely, the intermodal routes with large maritime stretches take advantage of the effects of economies of scale. Therefore, an increase of the cost per kilometre by road still favours more this advantage in costs. So the influence of this variable is higher for the maritime routes to Calais versus those to St. Nazaire when the Port Indexes are positive, this is true from Vigo, A Coruña and Ferrol. As the cost per kilometre by road is not controllable, the preferable maritime routes are those, which articulate intermodal routes that are less influenced by it. This is so for the maritime routes from Vigo, A Coruña and Ferrol (see Table 5). Furthermore, as expected, the influence of the loading/unloading costs increases with decreasing maritime distance, but total freight costs exert little influence on the index value for all the routes.

On the other hand, it is worth noting that the influence of the population factor on the Port Index is not only dependent on the average distance from the city to the port, or on the absolute value of the population factor for one city versus the others, but rather on a combination of all these factors. Hence, once again, the attribute of the distance between port and end route is under discussion now in terms of the cost.

Table 6. Statistical results from the Monte Carlo simulations (in terms of cost) for the case of France–Spain.

	Vigo			Ferrol			A Coruña		
	SN	LH	C	SN	LH	C	SN	LH	C
Base case: value PI_k^C	0.144	0.147	0.092	0.180	0.180	0.122	0.170	0.170	0.108
Mean	0.144	0.147	0.092	0.180	0.180	0.121	0.170	0.170	0.108
Median	0.144	0.147	0.092	0.180	0.180	0.121	0.170	0.170	0.107
Standard deviation	0.008	0.010	0.009	0.010	0.010	0.009	0.010	0.010	0.009
Coeff. of variability	0.058	0.067	0.098	0.049	0.057	0.076	0.050	0.060	0.083
/Mean-base case/	0	0	0	0	0	0	0	0	0
	Gijón			**Santander**			**Bilbao**		
	SN	LH	C	SN	LH	C	SN	LH	C
Base case: value PI_k^C	0.090	0.070	0.004	0.040	−0.010	−0.075	−0.020	−0.070	−0.131
Mean	0.090	0.070	0.004	0.030	−0.010	−0.075	−0.020	−0.070	−0.131
Median	0.090	0.070	0.004	0.030	−0.010	−0.075	−0.020	−0.070	−0.131
Standard deviation	0.010	0.010	0.011	0.010	0.010	0.009	0.010	0.010	0.009
Coeff. of variability	0.094	0.166	2.970	0.182	−0.597	−0.117	−0.358	−0.119	−0.072
/Mean-base case/	0	0	0	0.010	0	0	0	0	0

Note: SN, Saint Nazaire; LH, Le Havre; and C, Calais.

The statistical results obtained for all the routes (see Table 6) show, as expected (see Figure 8), a high coincidence between the respective value of the Port Indexes in terms of cost and the means of their simulated distributions. Furthermore, the indexes are efficient and consistent. These are, consequently, good estimators of the probability distributions obtained and, the risk associated with the selection of all the routes considering the absolute value of this index is, therefore, low. Thereby, the analysis of risk for the Port Index in terms of the cost in the study case is not selective.

4. Conclusions

The method presented involved two evaluations of the intermodal transport articulated through different Motorways of the Sea based on the 'many-to-many' transport model: a quantitative and qualitative analysis. The method may be used to make an initial assessment of the alternative potential routes in order to develop a Sea Motorway that articulates competitive intermodal chains versus unimodal transport. In the first step of the method, a multi-criteria decision matrix is built through different indexes. From this first step applied to the study case presented in the paper, the case of France–Spain, it can be concluded that the advantage of the intermodal services versus unimodal transport is especially noticeable when considering the cost of the service. As expected, the time criterion is the most restrictive point with respect to the competitive advantage of intermodal transport. Considering both perspectives, the intermodal alternative is preferable to its unimodal counterpart for all the maritime routes from the Spanish ports: Vigo, A Coruña and Ferrol to the French ports (see Table 7). The port of Gijón represents an inflexion point where the Indexes start to take negative values towards the Pyrenees until Bilbao. The maritime

Table 7. Summary table for the application of the method to the Sea Motorways.

		Vigo			Ferrol			A Coruña		
		SN	LH	C	SN	LH	C	SN	LH	C
1 Step: Quantification of results	PI_k^T	0.105	0.057	0.009	0.160	0.100	0.050	0.150	0.090	0.040
	PI_k^C	0.144	0.147	0.092	0.180	0.180	0.122	0.170	0.170	0.108
2 Step: Sensitivity analysis	Truck speed	−54.40	−55.40	−54.70	−71.00	−71.40	−71.10	−74.70	−74.80	−74.50
	€/km	62.30	67.20	79.68	48.48	57.27	71.95	52.46	60.64	75.16
2 Step: The risk assessment	Coeff. of variability on PI_k^T	0.278	0.580	9.55	0.188	0.339	0.862	0.215	0.416	1.500
	Coeff. of variability on PI_k^C	0.058	0.067	0.098	0.049	0.057	0.076	0.050	0.060	0.083
		Gijón			Santander			Bilbao		
		SN	LH	C	SN	LH	C	SN	LH	C
1 Step: Quantification of results	PI_k^T	0.110	0.020	−0.030	0.020	−0.090	−0.140	−0.010	−0.130	−0.180
	PI_k^C	0.090	0.070	0.004	0.040	−0.010	−0.075	−0.020	−0.070	−0.131
2 Step: Sensitivity analysis	Truck speed	−14.40	−20.70	−19.70	−73.10	−73.90	−73.50	−71.30	−71.20	−70.30
	€/km	97.32	87.79	90.85	89.58	92.08	80.32	89.59	85.23	67.20
2 Step: The risk assessment	Coeff. of variability on PI_k^T	0.118	0.777	−0.440	0.953	−0.708	−0.375	−1.300	−0.630	−0.509
	Coeff. of variability on PI_k^C	0.094	0.166	2.970	0.182	−0.597	−0.117	−0.358	−0.119	−0.072

Note: SN, Saint Nazaire; LH, Le Havre; and C, Calais.

routes with the highest potential for success from a quantitative point of view are A Coruña–St. Nazaire, Ferrol–St. Nazaire and Vigo–St. Nazaire (see Table 7).

In the first step, it is important to note that the competitiveness of the intermodal route in terms of the time does not increase when the road haulage is lower. Hence, this feature for the selection of the ports in the intermodal chain is under discussion. Additionally, in this step there are many occasions where the traditional distance ranges recommended for the intermodal chain are met but the chains are not competitive versus the road transport. Consequently, the generalization of distance ranges is not recommended to ensure the establishment of competitive intermodal chains versus the road.

As the value of the indexes depends on the assumptions considered to calculate them, in the second step it has been convenient to analyse the risk assumed when selecting a particular alternative through the evaluation of the indexes. The Monte Carlo simulation was the chosen tool for this purpose. The results obtained from the simulations allow for stating that, while the Port Indexes in terms of the cost are good estimators of the probability distributions obtained for all cases, the Port Indexes in terms of the time just proved to be good estimators for the routes: Gijón–St. Nazaire, Ferrol–St. Nazaire, A Coruña–St. Nazaire and Vigo–St. Nazaire. According to this method, the risk assumed by accepting the results of Port Indexes associated with intermodal versus unimodal transport on these routes is low (see Table 7).

The Monte Carlo simulation also led to the drawing of conclusions from the sensitivity analysis. For both indexes, the most influential variable is a non-controllable one: the truck speed (limited by regulations) and the road cost (limited by the cost of gasoil in the trade), respectively. Thereby, routes with the least sensitive indexes to these variables have a larger improvement range through their own capacities (they are more sensitive to controllable variables). The influence of the truck speed (negative) on the Port Indexes in terms of time is less for the intermodal routes with longest land stretches (see Table 7). The opposite occurs, however, regarding the influence of the road cost on the positive Port Indexes in terms of cost.

Considering the time advantage as being preferential and the independence of the route with respect to the non-controllable variables, the selected routes should be Vigo–St. Nazaire and Gijón–St. Nazaire (see Table 7). Finally, it should be noted that the influence of the truck speed on the competitiveness of the intermodal transport, in the EU, is not continuous but occurs in steps. Therefore, for many routes, slight modifications in truck speed lead to high differences in the competitiveness of intermodal transport. This point is highly dependent on the geographical location of the routes as well as on the European Regulation for road transport. Thereby, the results achieved in this paper confirm that the European Regulations about maximum permitted speed and the driver's maximum continuous driving hours on road can be used as efficient policy instruments to discourage the European road freight transport (Baindur and Viegas 2011).

On the other hand, it was concluded that the loading/unloading speed is highly relevant in the intermodal routes with the shortest maritime routes, as previous authors had noted. Finally, from the results achieved the total freight costs were not so relevant with regard to competitiveness in terms of cost as expected. This paper has accordingly also tried to order and quantify the main factors that determine the competitiveness of intermodal versus unimodal transport in order to act on them.

Disclosure statement

No potential conflict of interest was reported by the authors.

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