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The Sensitization of optimization models of fleets for sea motorways.

Lessons from the analysis of the fleet for the sea motorway: St.Nazaire-Vigo.

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Abstract

This work attempts firstly to identify the influence of uncontrollable variables (road cost, truck speed, speed of cargo handling systems, and the relative weight of possible origins/destinations for transport networks) on the selection of optimized fleets for sea motorways, integrated in multimodal chains. To achieve this aim, the impact of modifications of these variables on the selection of the most suitable fleet, considering the maximization of success opportunities for the multimodal transport against the road, was analysed. Thus, the multi-objective algorithm NSGA-II was applied to a mathematical model, able to integrate the fleet and the route, evaluating, in terms of time and cost simultaneously, the influence of uncontrollable inputs on the competitiveness of multimodal chains, covered by optimized fleets. Once the decisions about the fleet and the route have been adopted for an initial scenario, the second aim of the paper consists on assessing the risk assumed with their operation in different scenarios. This analysis allows to obtaining the range of values for uncontrollable variables, which ensure the competitiveness of multimodal transport. Additionally, it is possible to test different sensitivities of multimodal chains articulated through optimized fleets, in comparison to those covered by commercial fleets. This study was applied to a particular case: the sensitization of the most suitable fleets for the sea motorway St Nazaire-Vigo. The results show that the most influential variable is the truck speed. Even operating with optimized fleets, the competitiveness of multimodal chains remains very conditioned by the attributes of road transport, which are highly influenced by the transport normative.

Keywords: Sea Motorways; Multi-Objective Algorithm; Sensitivity Analysis, Optimization of Fleets

1. Introduction

In April 2011, the European Commission approved the new White Paper on Transport, which will lead the European policy on transport for the next few years. Among the ideas collected on it, four objectives are remarkable: liberation of the congestion of European roads; reduction of the fuel dependence of the transport; emissions' reduction; and the idea that the user of the infrastructures must pay for them. From the first White Paper on Transport (1992), one of the more supported solutions by the European Union (EU) — to lighten the traffic load on European roads — was the development of Short Sea Shipping (SSS).

In 2001, this idea was enlarged within a new transport concept: the sea motorways, which meant a group of multimodal services and ports where the SSS was able to offer a 'door-to-door' transport service (Magala and Sammons, 2008). The development of sea motorways was considered as a priority project by the EU in 2003 (N21 project according to Van Miert Report) and, therefore it should be finished before 2020. Since then different European studies were aimed at identifying the weakest points of the multimodal transport articulated through sea motorways, in order to solve them and to identify the routes with the highest opportunities for success. While the European Administrations attempted to simplify and standardize the bureaucratic processes, by applying the recommendations obtained from the competitiveness studies (projects: INTEGRITY, FREIGHTWISE, MOSES, among others), they also lightened the protectionist attitude towards European maritime traffic. Consequently, the responsibility for the success and development of the sea motorways and, therefore of multimodal transport, was transferred to private initiatives, especially to the shipping companies (Gesé and Baird, 2013).Considering the analysis of business strategies for shipping companies (Ambrosini et al, 1998), two decisions are essential in this framework: selection of the fleet (feasibility analysis regarding necessary resources); and maritime route (analysis of opportunity and acceptability). For the most suitable fleet chosen, shipping companies are forced to face the eternal dichotomy of specialization versus versatility (Woxenius, 2010). This decision is even more complicated as the majority of studies about the competitiveness of the multimodal transport versus the road, do not pay sufficient attention to the influence of the different features of the vessels, or of the whole fleet (the number of vessels) in the analysis. Vessels are usually taken as rigid elements (regarding the type and technical features), and the influence of fleet is normally disregarded. This fact can be appreciated in the case of the sea motorway: St Nazaire-Vigo (maritime distance, 915 km), which remains inoperative despite the great effort made by the European transport policy to boost sea motorways. In this case, not only did the Coordination Platform for maritime transport in the EU (Atlantic Transnational Network, 2006, through the study on the potentials of the sea motorways Programme in the Sixth Research Framework) consider the high potential between the central French coast (ie. St Nazaire port) and the northern Spain ports (ie. Vigo port), but also other research projects (INECEU, 2004, WEST MOS, 2008) pointed out it. Even the bilateral commission created by Spain and France (CIG, July 2006), to support with additional resources the development of the Atlantic sea motorways between both countries, selected St.Nazaire-Vigo as the first project in 2009. Reasons for this failure are several, but port authorities indicated that the necessary number of vessels, to cope with the operation requirements (a minimum amount of 350,000 cargo units moved in 5 years, with 4 weekly departures in each direction) demanded by Spanish and French Authorities for a sea motorway service (BOE No. 265, 2006) was, in this maritime route much higher than in others.

Although previous studies have dealt with the technical improvements of the vessels (EU-CARGOXPRESS, 2009), or with the port facilities in the SSS service (Mbiydzenyuy et al, 2010, INTEGRATION, 2005), very few were aimed at searching for the optimal fleet for a particular sea motorway when considering the competitiveness of the whole multimodal chain versus the road (Martínez et al, 2012a). Nevertheless, these latter examples did not consider, from a quantitative point of view, the risk assumed by the shipping companies with the selection of an optimized fleet when the initial scenario changes. Thus, and with the intention of providing information for supporting the shipping companies decisions, this work attempts to identify the influence of uncontrollable variables (those which cannot be selected by the decision-maker, but which characterize the operation scenarios) on the optimization of the fleets, and consequently on the competitiveness of the multimodal routes operated by these vessels. Owing to the significance of the case of St Nazaire-Vigo, this sea motorway has been taken as the study case. This analysis has not only allowed us to determine the most relevant uncontrollable variable by considering at the same time, its influence on the transport attributes of time and cost, but has also enabled us to define its range of values which ensure the competitiveness of multimodal transport. Additionally, advantages of using an optimized fleet against a commercial one have been analysed by comparing their sensitivity to the uncontrollable variables and by evaluating the multimodal transport performance covered by a fixed optimized fleet and route, when the initial scenario changes.

2. Previous work: Background of St.Nazaire-Vigo

This work has assumed, as starting points, the method and results obtained mainly in two previous analyses:

- Sensitivity analysis and risk assessment using a multi-criteria decision method (Martinez-Lopez et al, 2012b) carried out for different sea motorways, among them the maritime route St Nazaire-Vigo.

- Optimization of a fleet for a sea motorway (Martinez et al, 2012a) and the adaptation of the model for the case of St Nazaire-Vigo.

In the first work, a multi-criteria decision method is developed for selecting the best maritime route, able to articulate the most competitive multimodal routes versus the road. Due to the significant predominance of the time and cost in the modal choice studies and in the transport competitiveness assessments (Button, 1993; Mangan et al, 2001; Lalwani, et al 1991, García-Menendez and Feo-Valero.,2009), these two attributes were independently evaluated in the possible routes to know the relative performance of the multimodal transport against the road. In order to do this, two indexes were defined: Port Index in terms of the cost (IP^c) and in terms of the time (IP^T).These indexes are Differential Indexes of Relevance which reflect the users appeal of the multimodal chains through each Sea Motorway versus the road alternative. The higher the value of the index, the higher preference level for the intermodal option is for the ‘door to door’ transport decision maker (Martinez-Lopez et al, 2012b). The indexes are:

$$IP^C = \frac{CU - CMU}{CMU + CU} \qquad (1)$$

$$IP^T = \frac{TU - TMU}{TMU + TU} \qquad (2)$$

Where cost of unimodal transport (CU) and multimodal transport (CMU) are measured per Tonne and per trip and times of unimodal transport (TU) and multimodal transport (TMU) have been estimated in hours per travel and per cargo unit. For the costs calculation of road haulage and road stretches in the multimodal chains, a unitary cost per km has been assumed (Observatory of Road Freight Transport Costs, 2010). This cost includes temporary costs (truck depreciation and finance, staff, insurance, etc.), kilometer costs (fuel, tyres, maintenance, repairs, etc.) and indirect costs (structural and commercialization costs and others).Indeed, the time invested in the road transport considered the European Normative (Council Directives 92/24 EEC and 92/6 EEC). Regarding the seaborne in the multimodal chains, the capital costs, variable costs (fuel and port dues) and fixed costs (maintenance, insurance and personnel costs) were considered as well as port operations and navigation times. As the most important ports in Spain along the Atlantic coast are also the most important production centres of their hinterlands (García-Alonso and Sánchez-Soriano, 2010), for the application of the case of Spain-France the initial transport model ‘many to many’, operating with fixed fleets of commercial Ro-Ros vessels (with capacity of 157 trailers operating at 30 kn), was adapted to ‘one to many’ nets (from the Spanish coast) where the extremes of routes were: the Spanish ports, on the one coast, and Lille, Paris and Rennes on the another side.This generates, through St.Nazaire-Vigo, multimodal chains with a maritime stretch of 915 km and with an average distance for road hauls (´port to door´) of unimodal nets of 433.47 km. Additionally the average distance for the road alternative (´door to door´) is 1602.43 km.(see figure 1). The results of relative competitiveness obtained for multimodal chains (one-to-many model) through the sea motorway between St Nazaire-Vigo, covered by a commercial fleet, were IP^C=0.14 and IP^T=0.10. In other words, under these conditions the relative advantage for the multimodal transport against the road was 14% in terms of the cost, and 10% in terms of time.

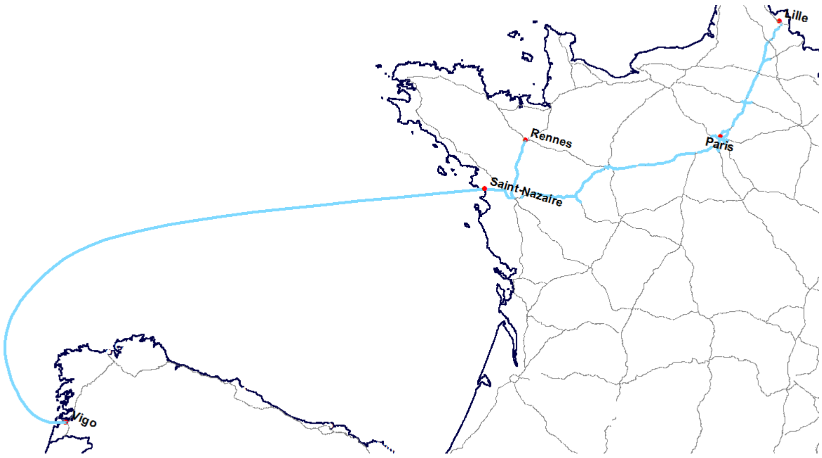

Figure 1 – Multimodal chains articulated through the sea motorway St Nazaire-Vigo

In the second part of this study, the sensitivity analysis of the model was carried out through Monte Carlo simulations, considering the uncontrollable variables. Afterwards, the risk assessment on the competitiveness calculated for the multimodal chains (indexes values) was analysed from the Monte Carlo simulations (by assuming triangular probability distributions with a variation range of 20% between the most and least probable values).

Table 1 – Contribution of main variables to the variance of port indexes of the multimodal transport through the route St Nazaire-Vigo operating with a commercial fleet.

Main variables	Contribution to variance of Port Indexes	
	IP^T	IP^C
Truck speed	-54.40%	
Speed of vessel	31.00%	
Loading speed	12.80%	
Road costs		62.30%
Probability of load destination is Paris	4.10%	15.60%
Probability of load destination is Rennes	0.70%	3.50%
Probability of load destination is Lille	0.30%	1.40%
Vessels costs		-4.80%
Weighting factor of Annual Volume of traffic between Spain and France		12.40%

As a conclusion of this work: St.Nazaire-Vigo was one of the sea motorways able to articulate the most reliable multimodal routes. As Table1 shows the sensitivities obtained for multimodal transport articulated through the sea motorway St Nazaire-Vigo operating with a commercial fleet(Martinez-Lopez et.al, 2012b).It is remarkable that the most influential variables on multimodal chain competitiveness (IP^T, IP^C) are related to the road transport: truck speed and costs of road. Thus, an increase of the first one involves that multimodal chains competitiveness in terms of time is significantly reduced whereas, the influence of the road cost on the competitiveness of multimodal chains in terms of cost has the same sign.

The second work (Martinez et al., 2012a) was focused on obtaining the fleet and cargo units which maximize the opportunities of success for the multimodal transport articulated through a particular sea motorway against the road. To this end, it was necessary to develop an optimization model able to integrate all features (technical and operatives) of the vessels (Ro-Ro and container vessels), fleets and the characteristics of the routes (models ‘one to many’ through a particular sea motorway).This model was define with the aim of identifying the parameters that maximized the difference in terms of cost (F_1) and time (F_2) between unimodal and multimodal transport.

$$F_1 = \max\left(CU - CMU\right) \qquad (3)$$

$$F_2 = \max\left(TVU - TVM\right) \qquad (4)$$

Table 2 – The optimized fleet for the sea motorway, St Nazaire-Vigo.

Features	The best solution
Type of cargo unit	TEUs
Amount of cargo	210
Speed of vessel (Kn)	19.19
Bow thruster	No
Cargo handling system	Port cranes
Number of vessels	3
Yearly voyages	740
L (m)	82.04
B (m)	15.00
D to upper deck (m)	7.59
GT (Ton)	2743
Kind of propeller	Conventional screw
Shaft lines	1
Kind of main engines	Diesel Engine
Main engines	1
F_1 (€/Ton per travel)	68.10
F_2 (h per travel)	8.39
IP^C	0.37
IP^T	0.10

However, in order to test the goodness level of the results obtained in the resolution of the model for the sea motorway St.Nazaire-Vigo, an evolutionary algorithm (Differential Evolution) and a local search optimization algorithm (Trust Region Reflective Optimization) were applied. As these algorithms are mono-objective, only the objective function in terms of the cost (F_1) was considered in the optimization processes. On the other hand, the considered routes were the same as those described in the previous work ('one-to-many' model to Lille, Paris, Rennes). Additionally, in this case, the values of the port indexes (IP^C=0.14 and IP^T=0.10) were introduced as minimum operating constraints. These should be met, in order to ensure that the obtained fleets during the optimization articulate more competitive multimodal chains than those covered by commercial fleets (ie. the vessels assumed in the first work). In this case, the model considered more than 150 variables and the work finally concluded, that the container fleet was the best solution (see table 2).

3. Methodology

In order to widen the knowledge level about the problem, achieved in the previous studies, a sensitivity analysis of the optimization model of the fleets will be carried out. This analysis will consider the influence of the most important variables (already identified for routes covered by commercial fleets) in the competitiveness of the multimodal routes. This will be performed by considering the two steps shown in sections 3.1 and 3.2 with different objectives.

3.1 Resolution of the optimization model of fleets for different scenarios.

Through the evaluation of the fleets obtained in each considered scenario, it would be possible to determine the most influent variable considering its impact on the competitiveness of multimodal chains in terms of time and cost, simultaneously.

In this step, the optimization model presented by Martínez et al, (2012a) will be resolved with different values of the variables, which were identified in Martínez-Lopez et al (2012b) as the most relevant ones. The first five variables are shown in Table 1.Hence, in order to generate different study scenarios, a variation range of 20% of the base value (between the maximum and minimum values) was assumed for each variable, taking reference values at intervals of 5%. In the case of the sea motorway: St Nazaire-Vigo, all of the relevant variables (see table 1) are uncontrollable by the optimization process (they are input data imposed by the framework), excepting the speed of vessel. Nevertheless, the influence of this technical feature in the optimization process will be also taken into account, not only because of its impact on the time invested on the multimodal transport (see table 1), but also because of its influence on the costs associated with it: operative cost, building and maintenance costs (Stopford, 2009, Klanac et al, 2010). The base values assumed for the main uncontrollable variables (see table 3) will be those taken into account for the generation of the initial scenario (Martínez et al, 2012), which were considered to obtain the initial optimized fleet (see table 2). In order to select these values, the information about the loading speed provided by the Spanish Stowage Society and the consignee companies, which are operating in Vigo Port, has been regarded.

Table 3- Base values for the main variables in the optimization of the fleet for the sea motorway - St.Nazaire-Vigo.

Main Variables	Base Values
Truck speed (Km/h)	90
Loading speed (units/h)	27
Road cost (€/km)	0.99
Pobability load destination is Paris (%)	62

Additionally, the following sources have been also considered: The European legislation, which determines the maximum truck speed allowed (90 km/h, Council Directives 92/24 EEC and 92/6 EEC); and the Observatory of Road Freight Transport Costs (General Department for Road Transport of the Secretariat of Spanish State for Transport of the Ministry of Public Works and Infrastructure), which publishes an annual report collecting the road costs associated with the trucks. Finally, the French Government Institute of Statistics and Economic Studies (INSEE, or *Institut National de la Statistique et des Études Économiques)* was also consulted. According to their records, in 2009 the most populated cities in France were (in thousands of habitants): Paris: 11,694; Lyon: 6,121; Lille: 4,022; and Rennes: 3,139. Hence, accepting that load destination is directly related to population (Costa et al, 2004), the initial probabilities of the load addressed to these cities are: Paris 62%; Lille 21%; and Rennes 17%.

3.2 Evaluation of the performance in terms of multimodal transport competitiveness with a fixed optimized fleet when the initial scenario changes.

Firstly, this analysis will allow identifying the loss of competitiveness of multimodal transport regarding the base scenario. As a consequence, the assumed risk level when a decision concerning to the fleet is taken could be defined. Secondly, it could be possible to identify the range of values of the analysed variables which ensures the competitiveness of multimodal transport competitiveness. Finally, the sensitivity to the uncontrollable variables of multimodal routes articulated through an optimized fleet (fixed) and a commercial fleet (fixed) will be compared in order to identify additional advantages, in terms of the reliability, of the operation with an optimized fleet.In this step the values of the objective functions and of the operative constraints (IP^C and IP^T obtained with the optimized fleet in the initial scenario) will be compared with the values obtained by the multimodal transport operating with the same fleet, but in different scenarios.

Table 4-Configuration parameters for the NSGA-II algorithm

Operator	Parameter	Value
Tournament Selection	Pool Size	2
SBX-Crossover	Probability	5%
Polynomial Mutation	Probability	60%
	N	1

As a difference from previous works, in this work the optimization model has been defined as a multi-objective problem (objective functions in terms of cost and time F_1, F_2), thus, for its resolution, the NSGA-II algorithm (Deb et al., 2002) was selected. The configuration parameters of the algorithm are shown in Table 4. Additionally, populations of 100 individuals were considered per run. According to the best fleet obtained for the sea motorway: St.Nazaire-Vigo (see table 2), only the container fleet was considered for the further sensitivity analysis.

4. Application and results for the sea motorway: St.Nazaire-Vigo

4.1 Resolution of the fleet optimization model in different scenarios

In this section, the optimization process for different proposed scenario is shown and the results of the obtained fleet are presented. Afterwards, an analysis of the influence of the variables on the reached results is undertaken, in order to allow, in the next step, to determine the risk assumed with the selection of the optimal fleet.

4.1.1 Influence of the truck speed (V_t)

The truck speed was identified as the most influential variable (negative influence) on the attribute of time for the multimodal transport, covered by a commercial fleet (see table 1). In figure 2, the possible solutions obtained from the optimization processes are shown in Pareto fronts. These optimization processes were carried out in scenarios generated by modifying the initial truck speed, base value (90km/h, see table3), from 81km/h to 94.5 km/h. Furthermore, in figure 3 possible results from optimizations for scenarios with a speed of 99 km/h are shown. Paying attention to figure 2, it can be concluded that for scenarios with truck speeds under 90 km/h (the most likely event considering the current European Normative), it is possible to find optimized fleets which articulate multimodal chains and meet all the operative constraints imposed (IP^C=0.14 and IP^T=0.10). Furthermore, the fleets optimized for these scenarios are very close to the selected fleet for the base scenario (see table 2). Nevertheless, this does not occur with the scenarios where the truck speed is over 90 km/h. For speeds of 94.5 km/h (see figure 2), only it would be possible to articulate multimodal chains meeting all the operative constraints imposed, with fleets of two vessels (for a cargo capacity of 128 FEUs operating at 27 kn, the technical feasibility of this kind of fleet would be very complicated). Additionally, the dispersion of the obtained results is very low (as seen in figure 2). In other words, the features of the possible optimized fleets, for this scenario, are very close to each other.

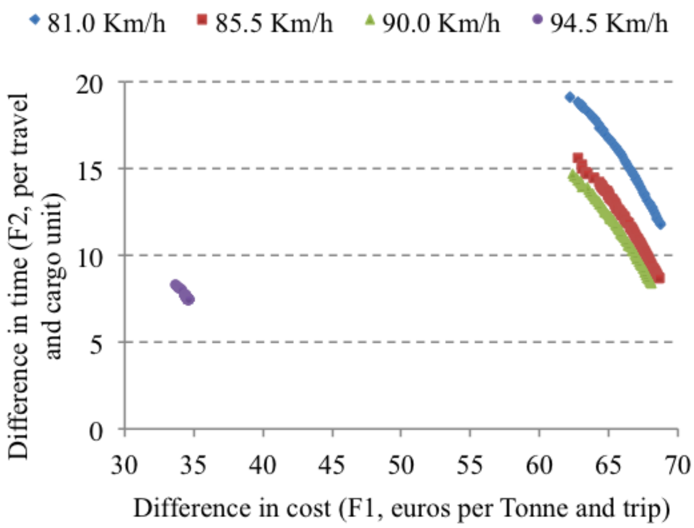

Figure 2 – Results obtained after optimization processes for the fleets for the sea motorway St.Nazaire-Vigo in the scenarios with truck speeds of the truck between 81 and 94.5 km/h

Otherwise, for truck speeds of 99 km/h, no fleet exists with the possibility of developing multimodal routes through the sea motorway: St.Nazaire-Vigo, and meet all the operative constraints. In spite of the fact that there are some fleets able to articulate more competitive multimodal routes than road transport, in terms of cost and time (F_1 and F_2 positive; see figure 3), this advantage is not enough to reach the minimum relative competitiveness imposed by the operative constraints (IP^C=0.14 and IP^T=0.10).

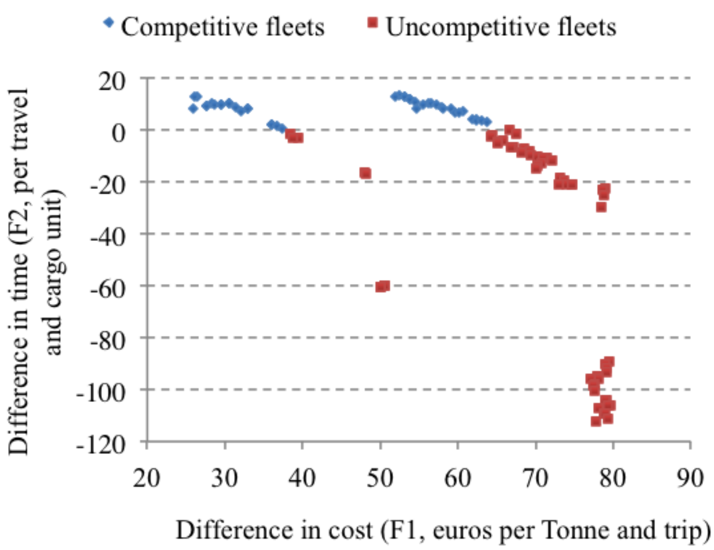

Figure 3_Results obtained after optimization process of fleets for the Sea Motorway St.Nazaire-Vigo in scenarios with truck speeds of 99 km/h

4.1.2 Influence of loading speed (V_l)

In this analysis, it is interesting to bear in mind that Portainer cranes were considered within the optimization model; this is, one crane for each 37 m of container vessel length, assuming a base loading speed of 27 cycles/h per crane. Under these base conditions, the loading speed has been modified; in figure 4 the optimized process is shown. Paying attention to figure 4, it could be appreciated that the obtained fleets offer proximate cargo capacities and technical and operative features. In other words, notwithstanding the loading speed has been recognized by numerous authors as a very critical parameter for the competitiveness of multimodal transport (Siu and Van de Voorde, 2010, Mbiydzenyuy et al, 2010, among others) and, thus, it has also been identified when the sea motorway was covered with a commercial fixed fleet (see table 1), its influence is not so high in the optimization processes of fleets. This is because the time invested in port operations depends more on the cargo capacity of vessels than on the loading speed of the cargo handling facilities. Therefore, the impact on the time invested in the port operation, by variations of loading speeds (up to 20%) of port cranes, can be minimized easily with slight changes in the cargo capacity of optimized vessels.

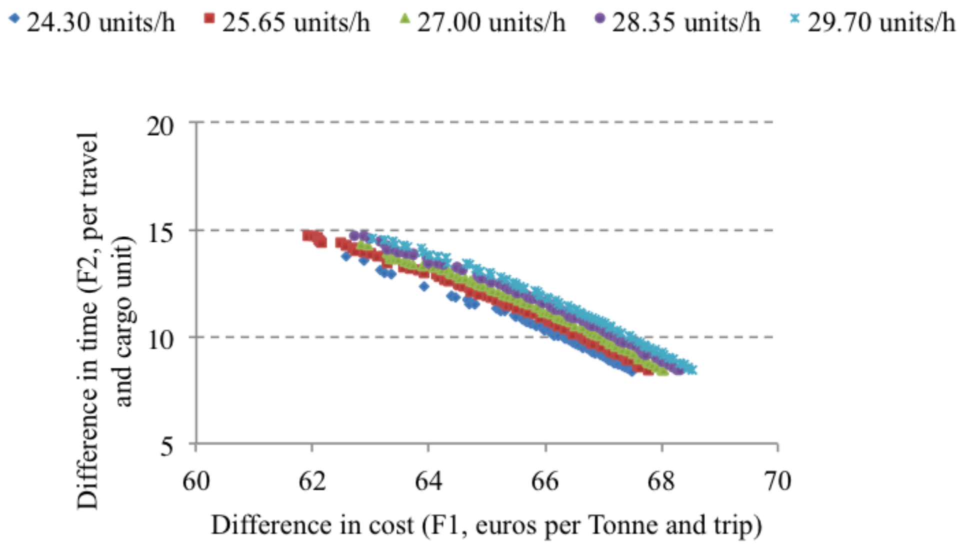

Figure 4 – Results obtained after optimization process for the fleets for the sea motorway St Nazaire-Vigo in scenarios with loading speed per crane between 24.3 and 29.7 units/h

4.1.3 Influence of road cost (Cr)

In the sensitivity analysis undertaken with a fixed commercial fleet, this variable has been shown as the most influential in terms of cost (Martinez-Lopez et al, 2012b; see table 1). This significant influence can be also appreciated in the optimization processes shown in figure 5, where road cost was modified between 0.89€/km and 1.089€/km. As can be seen in figure 5, the road cost modifications lead to parallel Pareto fronts (affecting uniquely the objective function F_1). Independently of the optimized fleet, each variation of 5% in road cost for the multimodal transport through the Sea motorway St Nazaire-Vigo implies a constant difference of the value of F_1 of approximately 4.5€. Thereby, in spite of the fact that the optimization of the vessels, for a particular sea motorway, provides greater advantages for the multimodal chains in terms of relative competitiveness against the road, this remains very dependent on the attributes of the road transport (uncontrollable parameters, especially the maximum truck speed, and the limitations for driving time per day) and these are conditioned by the European Regulation (European Directives 92/24/CE and 92/6/CE, and Regulation CE 561/2006).

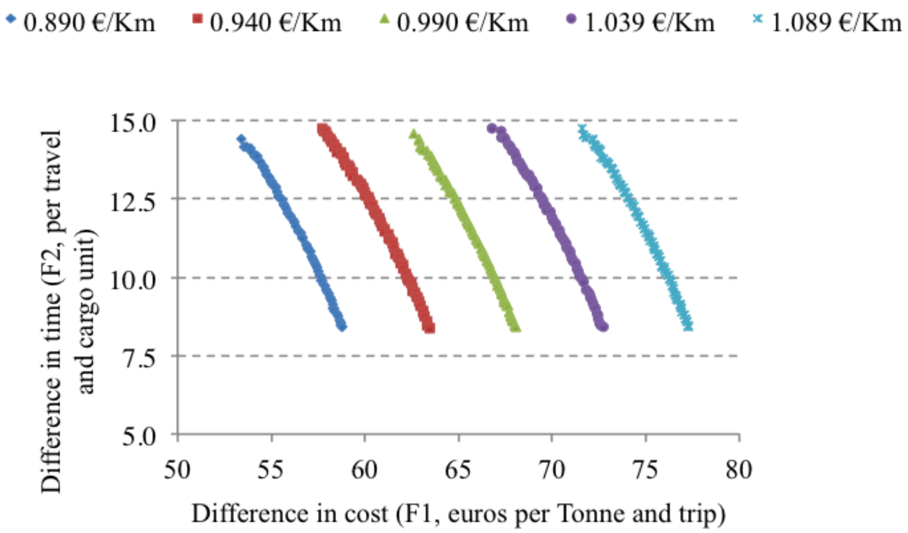

Figure 5 –Results obtained after the optimization process for fleets for the Sea Motorway St.Nazaire-Vigo in scenarios with road cost between 0.89 and 1.089 €/km

This conclusion also enhances the affirmations of other authors (Romana et al, 2010, Gesé and Baird, 2013), who indicated that to really support multimodal transport it is necessary, among other measures, to force the internalization of external costs for the road transport from the Administrations.

4.1.4 Influence of probability that load destination is Paris(X_1)

In the sensitivity analysis of the multimodal chains through St Nazaire-Vigo covered by commercial fleets (Martínez-Lopez et al, 2012b), the influence of changes in the distribution of the load to their possible destinations (Paris, Rennes and Lille) was evaluated, considering independently their impact on costs and time (see table 1). The results of this analysis showed that the probability that the load destination was Paris was one of the most influent variables in terms of costs. In the present section, this variable is analysed in different scenarios, but considering its influence on both objective functions (F_1 and F_2) simultaneously. The variation of the probability of load addressed to Paris implies a variation of the probabilities for the other destinations. Thus, the difference between initial and final probabilities to Paris will be divided equally between the other destinations. Hence, considering a whole modification range of 20% for this variable and study points every 5%, the obtained scenarios are shown in table 5.

Table 5 – Probabilities of load destination for generation of study scenarios (%)

Variations of probability of destination Paris with regard to base probability	-10%	-5%	0%	5%	10%
Paris (X_1)	55.80	58.90	62.00	65.10	68.20
Lille (X_2)	24.10	22.50	21.00	19.45	17.20
Rennes (X_3)	20.10	18.55	17.00	15.45	13.90

In figure 6, it can be appreciated that provided Pareto fronts resulting from the optimization process present practically identical results for both objective functions (F_1 and F_2). This means that the impact of this variable on the search for the optimized fleet, for the evaluated scenarios, is very slight. Thereby, contrary to what happened with the commercial fleet (see table 1), by only evaluating its impact on cost, the variation in the distribution of load between possible destinations (when the average land distance remains the same) will not imply significant changes in the competitiveness (in time or cost) of the multimodal chains covered by optimized fleets,. Hence, fleets obtained for all scenarios are practically identical.

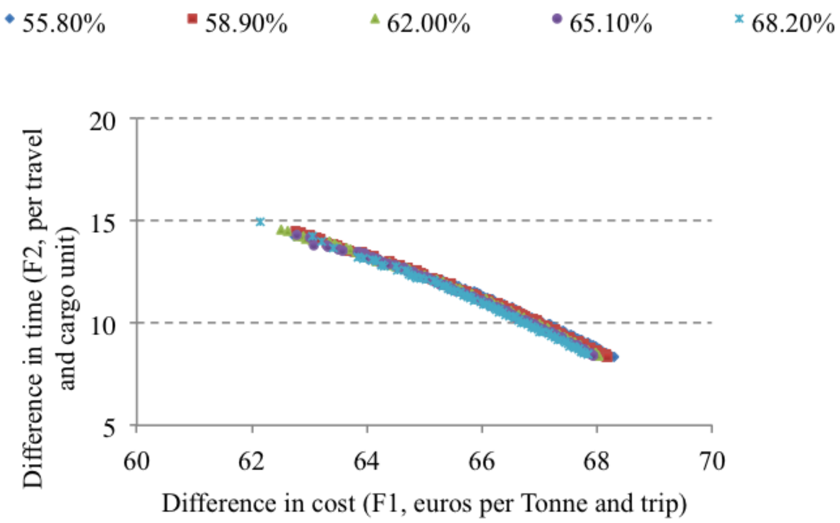

Figure 6 – Results obtained after optimization process of fleets for the sea motorway St Nazaire-Vigo in scenarios with probabilities that destination of load is Paris between 55.8% and 68.20%

4.1.5 Influence of the speed of vessel (VB)

The previous sensitivity analyses were performed over uncontrollable variables. This is, their values cannot be selected but are imposed by the framework (particular scenario). Therefore, they were taken as data during the optimization processes. However, the speed of the vessel is an optimization variable (ie. provided by optimization processes) and, therefore its value is very dependent on the technical parameters of vessels and fleets. Owing to the possible impact of the speed of the vessels on the weakest attribute of multimodal transport, the time, this variable has been studied widely in many works of SSS (SPIN-HSV, 2004; EMMA project, 1999; UK Marine motorways study, 2003). However, these studies routed out the operation with high speed crafts, due to the severe grave economic consequences for the SSS service and their emission levels (Martin and Fridell, 2010, Vanherle and Delhaye, 2010).

Hence, in spite of the fact that this variable had only been analysed in terms of time in multimodal transport (Martínez et al, 2012a) for commercial fleets (see table 1), in this section its relationship with both objective functions (F_1, F_2) has been taken into account, for the analysis of the solutions of the Pareto front. These solutions were obtained afterthe optimization process in the initial scenario (see figure 7).

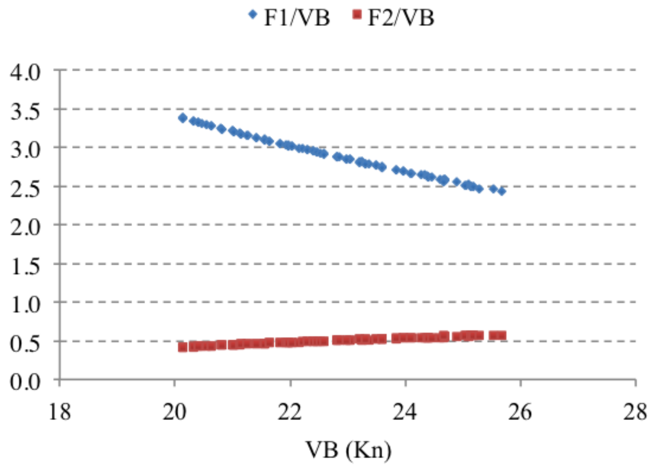

Figure 7 – Relationships of the speed of vessels and objective functions in the results obtained after optimization process of fleets for the sea motorway St Nazaire-Vigo in the initial scenario

In figure 7, the relationships of one competitiveness unit in cost and time per speed unit of the vessel for the best proposed solutions (from one extreme point of Pareto front to the another one) can be observed. Despite the fact that the speed of vessel more quickly influences on the competitiveness of the multimodal chains in terms of the costs (F_1), due to the wide initial advantage in this attribute (IP^C=0.14) against the road, modifications in the speed of vessels have been more determinant on the relative competitiveness of the whole multimodal chains in terms of time (the most critical attribute for the competitiveness of this transport system). In other words, as can be seen in the definition of the optimized speed for the vessel (figure 7), the penalization of a higher range of advantage in costs for the multimodal chains, as a consequence of an increase in speed of vessels, can be worthwhile if this addresses a slight improvement in competitiveness, in terms of the time for the whole multimodal system against the road.

4.2 Performance of multimodal transport operating with an optimized fleet in the different scenarios

In this section, multimodal transport, operated with an optimized fleet for a particular sea motorway, has been analysed by an evaluation of its performance in scenarios generated in the previous section. Thereby, taking as fixed the optimized fleet obtained in the initial scenario: base case (see table 2), the analysis of the changes in the competitiveness of the multimodal chains, obtained as consequence of their operation in different frameworks, has allowed us to determine the risk assumed with that decision of the fleet. On the other hand, this has also permitted to identify the range of values for the uncontrollable variables, which will not impede the competitiveness of multimodal transport, thus generated, against the road. Furthermore, this enabled the testing of the consequences of optimization, regarding the dependence of multimodal routes on uncontrollable variables. In the first columns of tables 6–9, the results of multimodal chains operating in the initial scenario with the optimized fleet (base case) are shown, and compared to the results obtained for these multimodal chains operating in other scenarios (shown in the other columns of tables 6–9). In table 6, it can be appreciated that, in all cases, relative competitiveness in terms of cost (IP^C) is higher than the obtained value with no optimized fleets (IP^C=0.14).Nevertheless, as was seen in the previous section, for truck speeds over 90 km/h, multimodal transport operating with optimal fleet (see table 2) does not reach the minimum relative competitiveness imposed in terms of time (IP^T=0.10). There is, therefore, a high risk that this transport service becomes uncompetitive against the road (negative values for F_2) for truck speeds over 94 km/h (see table 6).

Table 6 – Competitiveness of multimodal transport operating with an optimized fleet for different truck speeds

	Vt=90km/h	Vt=81km/h	Vt=85.5km/h	Vt=94.5km/h	Vt=99km/h
Values for Objetive functions					
F_1	68.10	68.74	68.62	66.00	66.65
F_2	8.39	11.78	8.67	1.28	0.00
Values reached for the operative constraints					
IP^C	0.37	0.37	0.37	0.35	0.36
IP^T	0.10	0.13	0.10	0.02	0.00

The important reductions of the competitiveness in terms of time for speeds between 90 and 94.5 km/h, is mainly a result of time invested in road transport, which corresponds to a step function. This is so because this function must integrate minimum rest periods for drivers and maximum driving time per day, as regulated by the EU (Regulation 561/2006). Hence, geographic locations at the extremes of the routes will be very decisive in defining values of truck speed which do not threaten the competitiveness of multimodal chains. Finally, it is important to note that the contribution of this variable to variance of the IP^T for multimodal transport with commercial fleet was 54.4%, while by operating with an optimized fleet this influence is much higher (see tables 6–9; the maximum value of IP^T=0.13 and the minimum value IPT^T=0.00 are a result of the modification of the speed of vessel, with a contribution to its variance of almost 100%). Looking at table 7, it could be stated that the influence of loading speed of cranes on the competitiveness of the multimodal chains is much more limited when their fleets have been optimized, than when these fleets are commercial (see table 1). This reinforces the affirmation that the correct sizing and characterization of vessels is even more influential on time invested in port operations, than the speed of the cargo handling facilities.

Table 7 – Competitiveness of multimodal transport operating with an optimized fleet and different loading speeds for cranes

	Vl=27uni/h	Vl=24.3uni/h	Vl=25.6uni/h	Vl=28.3uni/h	Vl=29.7uni/h
Values for Objetive functions					
F_1	68.10	67.50	67.76	68.32	68.52
F_2	8.39	8.39	8.40	8.41	8.44
Values reached for the operative constraints					
IP^C	0.37	0.36	0.36	0.37	0.37
IP^T	0.10	0.10	0.10	0.10	0.10

The impact of road costs on competitiveness in terms of cost (see table 8) is quite severe, as expected, but not so much as in the case of operating with a commercial fleet. Regarding this last point, the contribution of road cost to the variance of IP^C=0.14 reached 62.30% (see table 1). On the other hand, for all cases evaluated, operating with the optimized fleet, the minimum relative competitiveness, in terms of the required cost, is widely met (IP^C=0.14).

Table 8 – Competitiveness of multimodal transport operating with an optimized fleet and different road costs.

	Cr=0.99€/km	Cr=0.89€/km	Cr=0.94€/km	Cr=1.039€/km	Cr=1.089€/km
Values for Objetive functions					
F_1	68.10	58.80	63.45	72.70	77.31
F_2	8.39	8.41	8.39	8.41	8.42
Values reached for the operative constraints					
IP^C	0.37	0.35	0.36	0.37	0.38
IP^T	0.10	0.10	0.10	0.10	0.10

The impact of variations of probabilities for load addressed to Paris is very low, both in terms of cost as well as time (see table 9). Therefore, the multimodal transport covered with an optimized fleet (see table 2) is more independent of this variable in terms of cost than those covered by a commercial fleet (see table 1).

Table 9 – Competitiveness of multimodal transport operating with an optimized fleet and probabilities that load destination is Paris.

	X_1=62%	X_1=55.8%	X_1=58.9%	X_1=65.10%	X_1=68.20%
Values for Objetive functions					
F_1	68.10	68.28	68.17	67.90	67.83
F_2	8.39	8.35	8.37	8.44	8.47
Values reached for the operative constraints					
IP^C	0.37	0.36	0.36	0.36	0.36
IP^T	0.10	0.10	0.10	0.10	0.10

Considering the results obtained in the evaluation of the main uncontrollable variables, we can affirm that multimodal transport, articulated with an optimized fleet (obtained from the initial scenario), has shown a good performance in the different evaluated scenarios. Hence, excepting the scenarios with truck speed over 90 km/h, for all cases its competitiveness in terms of time and cost has been confirmed (positive values for F_1 and F_2), as well as its relative competitiveness (IP^C and IP^T), which is superior to the imposed values as operative constraints. Additionally, a minor dependence of the success of this transport service on the uncontrollable variables (excepting the truck speed) with optimized fleet has been detected, in comparison to its operation with a commercial fleet, especially with respect to road cost. Nevertheless, there exists a notable exception: the performance of multimodal chains with optimized fleet, in scenarios where truck speeds are over 90 km/h. For these cases, not only does its relative competitiveness not reach the minimum value required, but also there is a high risk of a lack of competitiveness in comparison to the road transport. In addition to this, the sensitivity of the success of chains to this variable is much higher than in the case of operating with no optimal fleets. This is because during optimization the characteristics of vessels (controllable variables, technical and operative parameters, which can be modified, such as length, beam, depth, speed of vessel, number of vessels, etc.) with a higher influence on the weakest point of the vessels operation (time) were specially adjusted. Consequently, operating with this optimized fleet, the improving range on the time invested in the transport will be very dependent on uncontrollable variables and, as seen, this is mainly the truck speed.

5. Discussion

In spite of the fact that the European Union has largely translated the responsibility for the success of multimodal chains to the private shipping companies, there are not many studies which were focused on the selection of the most suitable fleets for sea motorways, when considering the success of the whole multimodal service. The risk assumed by private companies with the decisions assumed for fleets and routes can be very high if the framework conditions vary from the expected ones. Thus, this work has aimed to provide knowledge about the risk assumed with the selection of an optimized fleet for a particular sea motorway when the initial considered scenario changes.

In order to do this, a two stage method was established. In the first step, different scenarios have been generated, varying the most important uncontrollable variables and reaching the optimal fleets for each of them, considering at the same time, the objective functions in terms of the cost and time. From the analysis of the optimization processes the most influential variables have been identified.

In the second step, the performance of the multimodal chain, operated through a sea motorway with an optimized fleet, has been evaluated by analysing the competitiveness of the chains in different scenarios and comparing it with those obtained in the initial conditions. This has allowed us to determining the assumed risk in terms of transport competitiveness with a borne decision of fleet; and meeting thresholds values for uncontrollable variables which turn the multimodal transport into an uncompetitive service. Finally, the application of this method has allowed the comparison of the sensitivity of multimodal chains covered by optimized and commercial fleets, and therefore meeting the additional advantages for the use of optimized fleets in terms of reliability.

For the application of this method the sea motorway St Nazaire-Vigo (between Spain and France) has been selected, articulating multimodal chains (‘one-to-many´ transport networks) from Vigo to Lille, Paris and Rennes. Considering these transport networks, from the results obtained in the first part of this method it can be concluded that the features of road transport have been the most influential variables in the search for the optimized fleet. Thereby, not only multimodal chains, operating with commercial fleets in the maritime stretch, do not depend on its own capacities to offer a competitive transport system against the road, but also the multimodal chains operated with optimal fleets. The influence of truck speed is especially relevant, which can lead to the impossibility of providing competitive multimodal chains with any fleet. For the particular case considered in this study, this occurred for truck speeds over 94.5 km/h. Contrary to what we expected, the influence of the speed of the cargo handling systems on the optimization process of fleets was very low, and enhanced the affirmation that the correct cargo capacity of vessels is more influent on the time invested in the port operations than the unitary speed of cargo handling systems. On the other hand, the sensitivity analysis performed over the variable speed of the vessel indicated that, notwithstanding the fact that the cost of maritime transport is the most sensitive attribute to modifications of this speed, its influence is much more significant in the relative competitiveness in terms of the time for the whole chain. This is so, owing to the wide initial advantage of the multimodal chains in terms of the cost against road transport.

In the second part of this study for the case of the St Nazaire-Vigo sea motorway, operating with the optimized fleet obtained in the initial scenario, there only exists a significant risk of loss of competitiveness of multimodal transport, when the truck speed is over 90 km/h, becoming an uncompetitive service with speeds over 94 km/h. Therefore, for this case, a maximum truck speed of 90 km/h would ensure the competitiveness of the multimodal chains in terms of time. In addition, it was seen that, multimodal transport with optimized fleet resulted in less sensitivity to the uncontrollable variables (excepting the truck speed), considering at the same time their consequences in time and cost, rather than the transport operated by commercial fleets. Consequently, the competitiveness of the multimodal transport remains not dependent on their-own capacities. Thus, despite operating with optimal fleets (adaptation of all possible controllable variables), the relative competitiveness results highly dependent on the features of the road transport, especially, in terms of time. Indeed, the road attributes are determined by the Administrations through the obligatory application of rules. Thus, for the transport networks considered in this paper, a possible increase in the maximum permitted truck speed, or greater flexibility in the application of the regulation about the maximum driving times per day in the European Union, would lead to multimodal chains becoming uncompetitive in terms of time, independently of the adaptation of the used resources (fleets) by private companies.

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