

Article

Assessing the Potential of Short Sea Shipping and the Benefits in Terms of External Costs: Application to the Mediterranean Basin

Antonio Comi *  and Antonio Polimeni 

Department of Enterprise Engineering, University of Rome Tor Vergata, 00118 Rome, Italy;
antonio.polimeni@uniroma2.it

* Correspondence: comi@ing.uniroma2.it; Tel.: +39-06-7259-7061

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Abstract: The paper aims to investigate short sea shipping services as a competitive, sustainable freight transport system which is able to respond to economic, social and environmental needs. An assessment methodology is proposed which considers an aggregate discrete choice model, simulating the split between the competitive transport alternatives in the Mediterranean basin. The proposed methodology was used to assess the potential of short sea shipping (SSS) and the net benefits deriving from lower external costs in the north-western Mediterranean basin. Two future scenarios are considered: introduction of new SSS services as envisaged by current EU projects and plans, and the introduction of new SSS routes and an increase in frequencies of existing services. Significant results were obtained in terms of shifting freight traffic from the road network as well as external benefits.

Keywords: short sea shipping; SSS; Ro-Ro; freight transport; freight demand; modal choice; discrete choice models; scenario assessment; Mediterranean area

1. Introduction

In recent years, the European Union (EU) has sought to tackle the negative externalities due to road haulage (congestion, environmental impact, etc.) and has set some goals for a competitive and resource-efficient transport system [1]. One such goal is a modal shift from road transport to other more sustainable transport modes, such as rail or waterborne transport. Short sea shipping (SSS), defined by the European Commission as maritime transport of goods between ports in the EU on the one hand, and ports situated in geographical Europe, on the Mediterranean and Black Sea on the other ([2]), could be a means to achieve such goals. Developing the Trans-European Network (TEN-T), the European Commission planned 30 priority axes and projects including land to sea transport networks and the implementation of SSS lines and services [3–6]. In terms of the freight quantity transported to/from the main European ports, in 2017, SSS attracted well over half (almost 58%). However, focusing on the Mediterranean basin, the proportion of freight transported by SSS in the same year was close to 33% [2], even allowing for the fact that some connections are only possible by sea (i.e., towards islands) Hence, the need to implement strategies and action to make SSS more competitive over road transport germinates.

Furthermore, as recognized by COP 21 ([7]), climate change represents an urgent and potentially irreversible threat to human societies and the planet. It is crucial to accelerate the reduction in global greenhouse gas emissions and also pollutant emissions. Haulage also has to contribute to achieve environmental goals, given that it contributes significantly to emissions of NO_x, NMVOCs, PM and CO. NO_x contributes to acidification, the formation of ground-level ozone and particulate formation.

In particular, contribution of the transport sector to total emissions is: 72% in terms of greenhouse, 66% of NO_x, 21% of CO, 14% of PM₁₀ and 20% of PM_{2.5} emissions [8]. Even if several studies have investigated the environmental issues arising from technology changes, they are mainly devoted to the improvement of the operational energy efficiency of vessels as well as environmental regulations [9,10], and refer to transport providers' perspective and on the role of a shipper [11], while few of them identify the visions of planners in order to favor the integration of SSS in European intermodal transport chains [10,12]. This shows that further work is needed in this field. Therefore, as stated above, pushed by the desirability to plan European freight transport to meet environmental/green goals, this paper presents the results of an ex-ante assessment of some actions promoted by national and international plans and programs, and identifies some further actions that can be implemented easily for limiting the freight transport impacts. In fact, SSS offers environmental and social benefits compared to road transport and it can facilitate the connection of remote and peripheral regions without requiring high infrastructure investments. Therefore, in a "what if" framework, the opportunity to have an assessment framework that allows us to calculate first scenario metrics to be compared with target ones can support planners in future scenario definitions (e.g., giving indications on which measures are most suitable for freight transport purposes).

After a literature review focused on short sea shipping (Section 2), the first macro-objective of the paper emerges, i.e., to propose a methodology to estimate impacts and system performance, and hence, compare future scenarios according to a set of given target values (Section 3). Besides, such a methodology should not suffer the lack of harmonization and limits comparability of national/international data [13] in developing performing models. The methodology aims to compare different scenarios, where changes in modal choice and services are foreseen with subsequent variations in external costs. The benefits of such a transport mode can thus be evaluated through an assessment methodology that helps identify the share of freight that can be captured by SSS, as shown in Section 4. Therefore, starting from these results, the second macro-objective of the paper is generated: i.e., to investigate the changes of freight transport thanks to SSS as a reasonable alternative to road. The analysis of socio-economic characteristics, as well as level of service attributes, allows to assess their impact on modal choices and then the shift between road and SSS. This modal shift could drive modifications in fleet characteristics (e.g., type of ship and equipment) and operation management [14–18], exploiting the benefits deriving from shifting to SSS.

The paper is structured as follows. In Section 2, a literature review is reported to highlight the main aspects of SSS. Section 3 presents an assessment methodology of the competition of SSS services. In Section 4, the case study is reported, considering two possible future scenarios. Finally, Section 5 reports some conclusions and the road ahead is drawn.

2. Literature Review

Several studies on short sea shipping (SSS) have highlighted the competition of SSS over land transport modes and the benefits produced by increasing its share. Such studies are reviewed below, especially with regard to simulating mode choice and assessing external impacts.

SSS is a transport mode known to be in competition with land transport [19,20]. The question of modal choice is widely covered in the literature [21,22], identifying the factors that influence such a choice (e.g., cost, frequency, reliability). In order to identify the attributes influencing modal choice, Bergantino et al. ([23]) propose a stated preferences approach to test the potential success of initiatives aimed at enhancing the use of SSS. Similarly, Brooks et al. ([24]) analyze the competitiveness of SSS in Australia in order to evaluate the willingness to pay (WTP) for services on specific transport corridors. The attributes considered in the choice models are frequency, transit time, distance, direction (headhaul/backhaul), delivery window, reliability and price offered by the operators. In [25], the transport companies' perception between SSS and road transport is investigated so as to identify the service attributes influencing the choice of SSS services. With reference to the Black Sea area, Yotsov et al. ([26]) analyze a set of possible alternatives (i.e., SSS, railway and road) to transporting freight,

considering as assessment criteria, time, costs and CO₂ emissions. In order to provide information on performance of road transport and intermodal transport using SSS, Lopez et al. ([27]) propose cost and time models, taking into account attributes related to the technical and operative conditions of the fleet, attributes related to routes, and those in relation to cargo units. Koliouisis et al. ([28]) explore how road transport deregulation influences SSS from two perspectives: the negative effects on SSS due to changes (improvements) in road transport and the possible environmental benefits of supporting SSS. López-Navarro ([29]) analyzes the possible strategies and issues for road transport actors when they have to choose the combined transport (road and SSS) rather than 'all road' transport. The latter study focuses on the change in the business model needed to use SSS, considering the strategies of accompanied or unaccompanied transport.

Another aspect treated in the literature concerns the external effects of SSS, considering both technological aspects and impact quantification in relation to other transport modes. Windover et al. ([30]) report an investigation to assess the technical, economic and environmental potential of an electric propulsion system in SSS operations in the state of New York. Similarly, Spoof-Tuomi and Niemi ([31]) analyze emission performance by using an engine powered by liquefied natural gas (LNG) and liquefied biogas in SSS, comparing the result with conventional diesel engine emissions. The approach proposed by [32] aims to determine the technical characteristics of a Ro-Ro (roll on-roll off) ship and the size of the fleet required for a route in order to satisfy the demand level. In order to find the optimal fleet composition that maximizes the opportunities for success of SSS with respect to road transport, an optimization model able to provide the technical and operative features of fleets is proposed by [33].

In terms of impact quantification, Hjelle ([34]) calculates the CO₂ emissions per ton-km transported by SSS services for each trip. The results are compared with emissions from road transport for the same freight tonnage and distance. Similarly, Vallejo-Pinto et al. ([35]) propose an approach to compare SSS and road transport in terms of emissions which, in the authors' opinion, can be viewed as a complementary approach with respect to cost and time studies. Konstantinus et al. ([36]) provide an assessment of SSS opportunities in the South Africa region, comparing energy consumption of SSS against that of road transport. Spoof-Tuomi and Niemi ([31]) evaluate the emissions performance of fuel choices for SSS, comparing emissions due to the use of different fuels and analyzing impacts in terms of acidification, eutrophication and human health. Bengtsson et al. ([37]) define four criteria (local and regional impacts, overall impact, infrastructures and relation with other transport modes) in order to evaluate the type of fuel to choose in SSS transportation. It has been shown (e.g., [38,39]) that the low energy consumption of SSS per transport unit may be useful to reduce air pollution and contribute to implementing a sustainable transport system. Johnson and Styhre ([40]) consider the reduction in waiting times in ports as a means of reducing energy requirements: the analysis evaluates the possibility of reducing ship speed at sea by reducing the waiting time (also intended as an improvement in port efficiency). The efficient use of energy in SSS is investigated in [41], who use a case study to highlight patterns and barriers to implementing energy efficiency. Schøyen and Bråthen ([42]) propose an activity-based approach in order to estimate energy efficiency for ships involved in SSS, both during navigation and during stops in port.

As shown above, promoting further studies on the potential offered by SSS as an alternative to road transport would appear beneficial. Therefore, Section 3 presents a methodology for assessing freight transport scenarios where a key role can be played by SSS, while not neglecting changes in infrastructures and services as well as in technology [24,36,43,44].

3. Approach

This section aims to highlight the opportunities offered by short sea shipping for reducing negative externalities of road haulage at the European level. An assessment methodology is thus introduced. It can support the analysis of competition of SSS services and is schematized as follows (Figure 1):

1. Transportation system identification (study area). The objective of this first phase is to identify the elements of the system under analysis and their relationships;

2. Origin-Destination (O-D) matrices. This stage aims to estimate the O-D matrices, and it is integrated and related to transportation system identification;
3. Mode choice. The relevant interactions among the various elements of the freight transportation system are simulated in order to assess how socio-economic characteristics as well as level of service attributes impact on modal choices; this phase provides the input for future scenario assessment;
4. Future scenario assessment. Different design scenarios have been implemented according to different hypotheses on the further development of SSS services coming from national and supra-national plans. Subsequently, some scenario metrics and/or performance indicators are calculated and the impacts for the proposed future scenarios, which could be compared with target ones, are estimated.

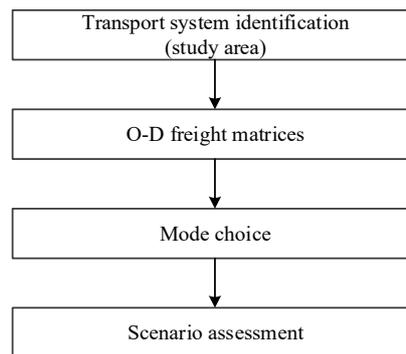


Figure 1. Assessment methodology.

3.1. Transportation System Identification

The aim of this phase is to determine the elements that make up the system of analysis and their relationships. The elements of interest pertain to three spheres:

- The demographic, economic and spatial characteristics of transport demand;
- The supply of transport and logistics infrastructures and services;
- The external environment, as it plays a role in estimating some impacts.

3.2. Origin-Destination Matrices

The definition of freight service supply and estimation of its impact requires accurate knowledge of freight demand which, for forecast scenarios, can be developed using a modelling system, while for current scenarios, it can be obtained from source. Although the literature contains several methods and models developed for simulating freight demand [45,46], many require extensive information, and the matrices from sources are quite aggregated in their reproduction of freight flows between countries. Therefore, disaggregation approaches are customarily used for splitting country-based freight O-D flows [47].

Given two zones o and d , belonging to two countries R and S , respectively, the quantity of freight exchanged between zones o and d , q_{od} , can be obtained as follows:

$$q_{od} = q_{RS} \cdot \frac{(X_o)^{\beta_o} \cdot (c_{od})^{\beta_c}}{\sum_{h \in R, k \in S} (X_h)^{\beta_o} \cdot (c_{hk})^{\beta_c}} \quad (1)$$

where

- X_o is the value of production in region o (equal to the regional GDP);
- c_{od} is the average transport costs between zones o and d ;
- R is the origin country that contains zone o ;

- S is the destination country that contains zone d ;
- q_{RS} is the freight flow (quantity) between countries R and S ;
- β_o and β_c are model parameters to calibrate.

3.3. Mode Choice

The freight mode-service choice model plays a key role in the assessment methodology. It simulates competition among alternative modes (e.g., combined road-railway, SSS and road transport). In order to predict long-term effects, the mode-service choice model can be specified through easy-to-capture variables, mainly represented by level-of-service attributes by using a consignment approach [48–50]. Therefore, assuming a fixed quantity q for a given load unit, the probability $p[m/od]$ of using transport mode-service m to shift freight in load units (e.g., containers or swap bodies) from origin zone o to destination zone d can be expressed as:

$$p[m/od] = \exp(V_m^{od}) / \sum_{m'} \exp(V_{m'}^{od}) \quad \forall m' \neq m, m' \in I_{od} \quad (2)$$

where I_{od} is the set of possible transport mode-services available on the od pair (e.g., road, combined road-rail, sea) and V_m^{od} is the systematic utility of transport mode-service m , which can be expressed as a linear combination of attributes $X_{m,k}^{od}$ (e.g., travel times and monetary costs) as follows:

$$V_m^{od}(X_{m,k}^{od}) = \sum_k \beta_{m,k} \cdot X_{m,k}^{od} \quad (3)$$

with $\beta_{m,k}$ model parameters to estimate.

3.4. Scenario Assessment

Design and evaluation of transportation systems, in addition to performance variables perceived by the users, require the modelling of impacts borne by the users, but not perceived in their mobility choices, and of impacts on non-users. Examples of the first type include indirect vehicle costs and accident risks with their consequences. The impacts on non-users include those for other subjects directly involved in the transportation system, such as costs and revenues for the transport service suppliers, and impacts “external” to the transportation system (or market). Examples of externalities are the impacts on the real estate market or on the environment, such as noise and air pollution. Often such functions are named after the specific impact they simulate (e.g., fuel consumption functions or pollutant emission functions). Some impacts may be associated with individual network links and depend on flows. The impacts include:

- Impacts on users (e.g., travel time and generalized travel cost);
- Impacts on non-user externalities (e.g., air pollution, energy consumption).

Therefore, the scenarios can be evaluated with respect to indicators of economic (e.g., related to efficiency), social (e.g., related to congestion and safety), and environmental sustainability. The values obtained for the indicators are compared with some reference values (targets). The indicators chosen for this stage of the ex-ante assessment could be monitored in the ex-post assessment to track their real evolution over time. These indicators could be developed considering the set of variables promoted by the European Environment Agency (TERM, Transport and Environment Reporting Mechanism; [51]). In fact, the TERM indicator list covers the most important aspects of the transport and environment system (driving forces, pressures, state of the environment, impacts and societal responses). It represents a long-term vision of the indicators that are ideally needed to monitor the progress and effectiveness of transport and environment integration strategies.

In general, some other types of impacts could be considered, such as financial impacts by reducing costs to carriers and shippers, and energy consumption by changing the amount of energy used.

4. The Case Study

The proposed assessment methodology was implemented to assess the future potential of short sea shipping (SSS) and its benefits in terms of lower external costs in the north-western Mediterranean basin. It focuses only on freight flows between Italy and other Mediterranean countries in which SSS could be a reasonable alternative without requiring substantial changes in transport operators' businesses.

4.1. Transportation System Identification

Once the study area had been identified, zoning was carried out, with the main Ro-Ro ports taken as reference. The choice of traffic areas fell on those accessible by sea and with at least one other modal transport alternative (e.g., combined road-rail transport as shown in Figure 2):

- Italy, with the ports of Ancona, Brindisi, Catania, Civitavecchia, Genova, Livorno, Marghera and Ravenna, Salerno, Savona, Trieste;
- France with the port of Marseille;
- Spain with the ports of Barcelona and Valencia;
- Slovenia with the port of Koper;
- Croatia with the ports of Dubrovnik and Split;
- Montenegro with the port of Bar;
- Albania with the port of Durres;
- Greece with the ports of Igoumenitsa and Patras.



Figure 2. Main Ro-Ro ports considered in the north-western Mediterranean basin.

For each listed Ro-Ro port, an area of influence with a radius of 300 km from the port was considered in order to determine the traffic areas taken as a reference for zoning. The zoning adopted, and the consequent reconstruction of the transport demand, was implemented assuming a level of regional zoning (NUTS2—Nomenclature of Territorial Units for Statistics), in which the traffic zones coincide with the regions, and O-D matrices are interregional. In all, 86 zones were identified.

The current transport scenario (2018) was defined starting from the current freight transport system, including inter-modality and logistics. Based on the characteristics of freight transport in the Mediterranean, transport services mainly comprise road, rail (traditional and combined) and sea transport (motorways of the sea—SSS) modes.

In the current scenario, a total of 958 weekly freight services (784 combined road-rail transport services and 174 SSS services) were considered for 70 terminals (14 ports and 56 intermodal terminals).

4.1.1. Short Sea Shipping Supply Model

In the Mediterranean basin, there are numerous SSS/Ro-Ro services, and to construct the current transport scenario, a total of 174 international Ro-Ro weekly services were considered, involving the ports of Barcelona, Valencia, Ancona, Brindisi, Catania, Civitavecchia, Genoa, Livorno, Ravenna, Salerno, Savona, Bar, Igoumenitsa and Patras, with a frequency of at least one ship/week. They cover 12 origin-destination pairs. In constructing the supply of services, those between Sardinia and Africa were excluded, given that, for this region and continent, Ro-Ro services represent an exclusive mode of transport and not one of the possible modal alternatives, whereas Sicily was considered, assuming the presence of a road link across the Strait of Messina connecting Messina with Villa San Giovanni [52].

The SSS supply model allows the following O-D level of service attributes to be obtained: travel distance; travel time (return time, include the access/egress time); travel cost and A/R frequency. Figure 3 reports the lines and the average level of service attributes at country level.

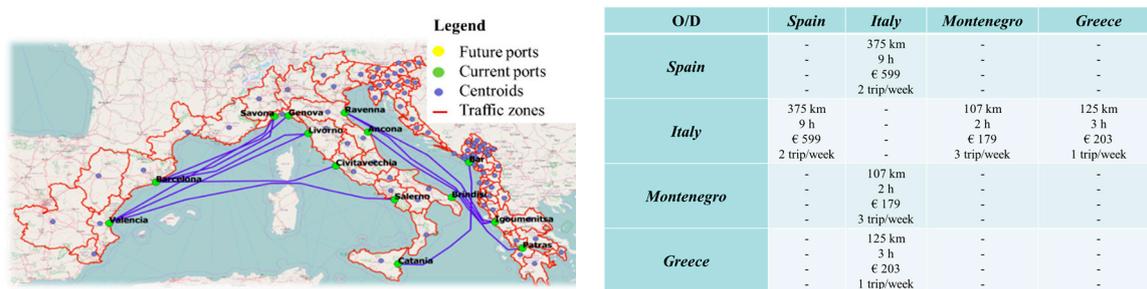


Figure 3. SSS (short sea shipping) services and average level of service attributes (174 weekly services).

4.1.2. Railway Supply Model

As well as for the supply model of the SSS supply, the combined road-rail transport supply model refers to the entire national and international network of interest for freight transport, while private railways and those for the exclusive use of passenger transport were not taken into consideration. Consistent with the level of zoning adopted, all the railway infrastructures relevant to connections between the zones of the study area were extracted. Overall, 1,998,098 kilometers of railway network were taken into consideration, represented through two-way links and representative nodes of stations and freight terminals. An overview of the topological model implemented and the average level of service attributes at country level are shown in Figure 4 below.

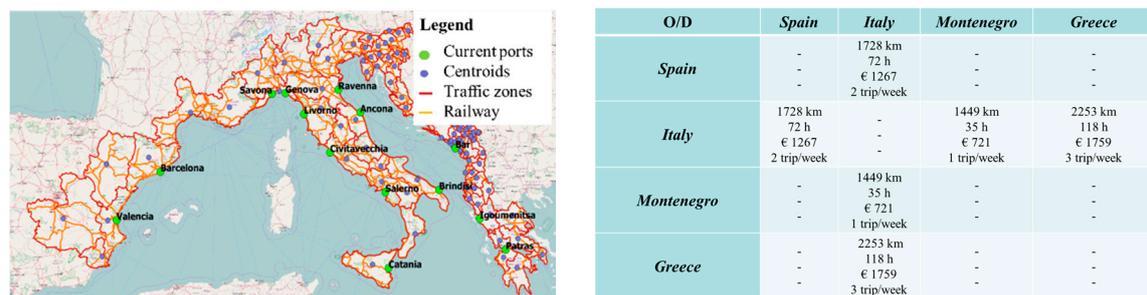


Figure 4. Combined road-rail services and average level of service attributes (784 weekly services).

4.1.3. Road Supply Model

The road transport supply was built in order to represent all the main national and international road infrastructures. For the road network, the main infrastructures considered were as follows: highways, motorway junctions and main roads, capable of adequately serving the transport demand implemented in the demand model used (described below). Provincial roads were added to the above road infrastructures, which were necessary for the connection of all national and international routes

and the main maritime routes. The level of service attributes (Figure 5) were then calculated as the sum of on-road travel time and stop time (detailed information can be found in [53]).

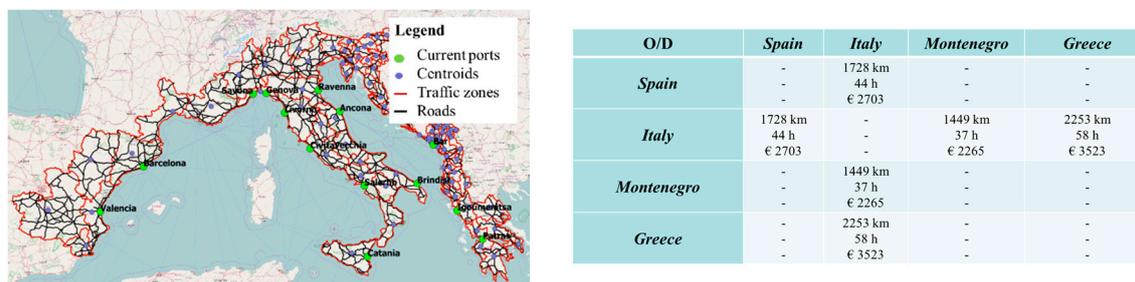


Figure 5. Road services and average level of service attributes.

4.2. Origin-Destination Matrices

The transport demand is expressed in terms of Origin-Destination matrices, whose elements represent the flow of freight, in a given historical time, between territorial areas. Demand is consequently correlated with the division of the study area into zones (zoning) previously described. The process used to define the overall freight transport demand for the transport mode of the study area started from the retrieval and homogenization of all the databases made available by Eurostat. Through the transport thematic section, Eurostat provides traffic data relating to the individual modes of transport (road, sea, rail, air) in aggregate (e.g., vehicle-kms and national and international km-tons divided by the type of traffic and goods transported) and disaggregated terms. In the latter case, particular attention is paid to port traffic. In this regard, O-D matrices of unitized loads that can be potentially transferred to SSS (e.g., container traffic between ports in the EU27 area and the world) are also available.

Table 1 below reports the freight volumes exchanged among the countries of the study area. Having considered a level of regional zoning, the need arises to build O-D matrices for each transport mode considered in the analysis. However, as regional data were not directly available, a regionalization model was developed, as described in Section 3 (Equation (1)), capable of disaggregating national flow data into regional ones.

Table 1. Origin-Destination matrix at country level.

O-D [tons/year]	Spain	Italy	Montenegro	Greece
Spain	-	SSS: 652,000 (26%) Railway: 272,000 (5%) Road: 3,664,000 (69%)	-	-
Italy	SSS: 603,000 (28%) Railway: 141,000 (3%) Road: 3,294,000 (69%)	-	SSS: 1000 (50%) Railway: 8000 (35%) Road: 9000 (15%)	SSS: 245,000 (73%) Railway: 9000 (0%) Road: 858,000 (27%)
Montenegro	-	SSS: 1000 (58%) Railway: 2000 (16%) Road: 10,000 (26%)	-	-
Greece	-	SSS: 256,000 (70%) Railway: 2000 (0%) Road: 947,000 (30%)	-	-

4.3. Mode Choice

Once the Origin-Destination matrices had been determined, the next step was to set up a modal choice model. The aim of the model was to summarize the user choice process. The model used belongs to the family of random utility models, which represents the richest paradigm for simulating the choice of transport and, generally speaking, the choices between discrete alternatives ([54–56]).

According to Equation (3), the systematic utility of transport mode-service m (i.e., road, combined road-rail transport, SSS) was expressed as a linear combination of the identified attributes as follows:

$$\begin{aligned} V_{road}^{od} &= \beta_1^{road} \cdot C_{road}^{od} + \beta_2^{road} \cdot TT_{road}^{od} + \beta_{10} \cdot ROAD \\ V_{rail}^{od} &= \beta_3^{rail} \cdot C_{rail}^{od} + \beta_4^{rail} \cdot TT_{rail}^{od} + \beta_5^{rail} \cdot Freq_{rail}^{od} + \beta_{11} \cdot RAIL \\ V_{sss}^{od} &= \beta_6^{sss} \cdot C_{sea}^{od} + \beta_7^{sss} \cdot TT_{sea}^{od} + \beta_8^{sss} \cdot Freq_{sea}^{od} \end{aligned} \quad (4)$$

where TT^{od} is the travel time on O-D pair od (h), C^{od} is the travel cost on O-D pair od (€), $Freq^{od}$ is the service frequency on O-D pair od (runs/weeks), and $ROAD$ and $RAIL$ are the dummy alternative specific attributes for road and combined road-rail transport, respectively. The handling times at origin and destination terminals both for combined road-rail transport and SSS alternatives as well as the access and egress travel times by road were included.

Different specifications were tested and the model with the best statistical performances, according to the above expression, is reported in Table 2. All parameters are correct in sign and the ability of models to reproduce the revealed values is shown by the high value of R^2 (0.98).

Table 2. Mode choice model: Parameter estimation.

Attribute/ Mode Alternative	SSS	Combined Road-Rail	Road
Time (h)	-0.0403	-0.0408	-0.0386
Cost (€)	-0.6572	-0.7646	-0.5241
Frequency (runs/week)	0.0300	0.0182	-
ASA	-	-0.7418	1.1046
R^2		0.98	
VoT (€/h)	61.34	53.41	73.71

Further tests were also performed in order to validate the reasonableness and the significance of estimated coefficients. In particular, the direct and cross arc elasticities were calculated as follows:

$$E_{km}^{p[m]} = \frac{\Delta p[m]}{p[m]} / \frac{\Delta X_{km}}{X_{km}} \quad (5)$$

$$E_{kh}^{p[m]} = \frac{\Delta p[m]}{p[m]} / \frac{\Delta X_{kh}}{X_{kh}} \quad (6)$$

where $\Delta p[m]/p[m]$ represents the percentage variation of the choice probability of mode-service m divided by the percentage variation ($\Delta X_{km}/X_{km}$ in Equation (5) or $\Delta X_{kh}/X_{kh}$ on Equation (6)) of the attribute k relative to the same mode-service m (direct elasticity) or to another mode-service h (cross elasticity). Both direct and cross-elasticities are useful measures of the model's sensitivity to variations in the attributes.

The coefficient reciprocal relationships (Table 2) and the above direct and cross elasticities (Table 3) were compared with similar results reported in the literature [53,57,58]. Besides, the ratio between time and monetary cost coefficients, which can be interpreted as value of time (VoT) corresponding to different components of travel time (i.e., check-in and boarding time) on the different mode-services, decreases in value for less appreciated mode-services (i.e., rail and sea).

Table 3. Validation results of mode choice model: Direct and cross arc elasticities.

Percentage Variation of the Cost	SSS	Combined Road-Rail	Road
SSS: $\Delta C_{sea}/C_{sea} = +10\%$	-0.61	0.29	0.31
Combined road-rail: $\Delta C_{rail}/C_{rail} = +10\%$	0.02	-0.68	0.03
Road: $\Delta C_{road}/C_{road} = +10\%$	0.65	0.70	-0.39

4.4. Future Scenario Assessment

This section reports the application examples of the methodology for the assessment of SSS transport strategies to be suggested for further development of SSS according to the European Commission and Italian National Transport Plans. In particular, application examples were performed to ascertain whether and to what extent the aims of the EU plans are realistic by quantifying the share of freight traffic that can be transferred to more sustainable modes by 2030.

The hypotheses for the development of SSS were defined with the aim of verifying the effects induced by policies in the freight transport capable of implementing the guidelines of the European Community, which promote an increase in the use of SSS transport with a view to transferring by 2030, on distances greater than 300 km, 30% of the demand by road to other modes, such as SSS and combined road-rail transport.

To this end, the future scenarios, starting from the demand for transport and the supply of infrastructures and services for the future time horizon (2030), implement the following actions devoted to increase the services and to promote incentives. As regards to the service supply, the effects of the following actions were simulated by nesting them in two scenarios (Figure 6):

- Introduction of new services in line with EU projects as detailed below (scenario 1);
- Introduction of new SSS services on long-distance connections characterized by the presence of potentially attractive demand from road transport (scenario 2);
- Boosting of services due to a 10% increase in frequencies of existing SSS services (scenario 2).

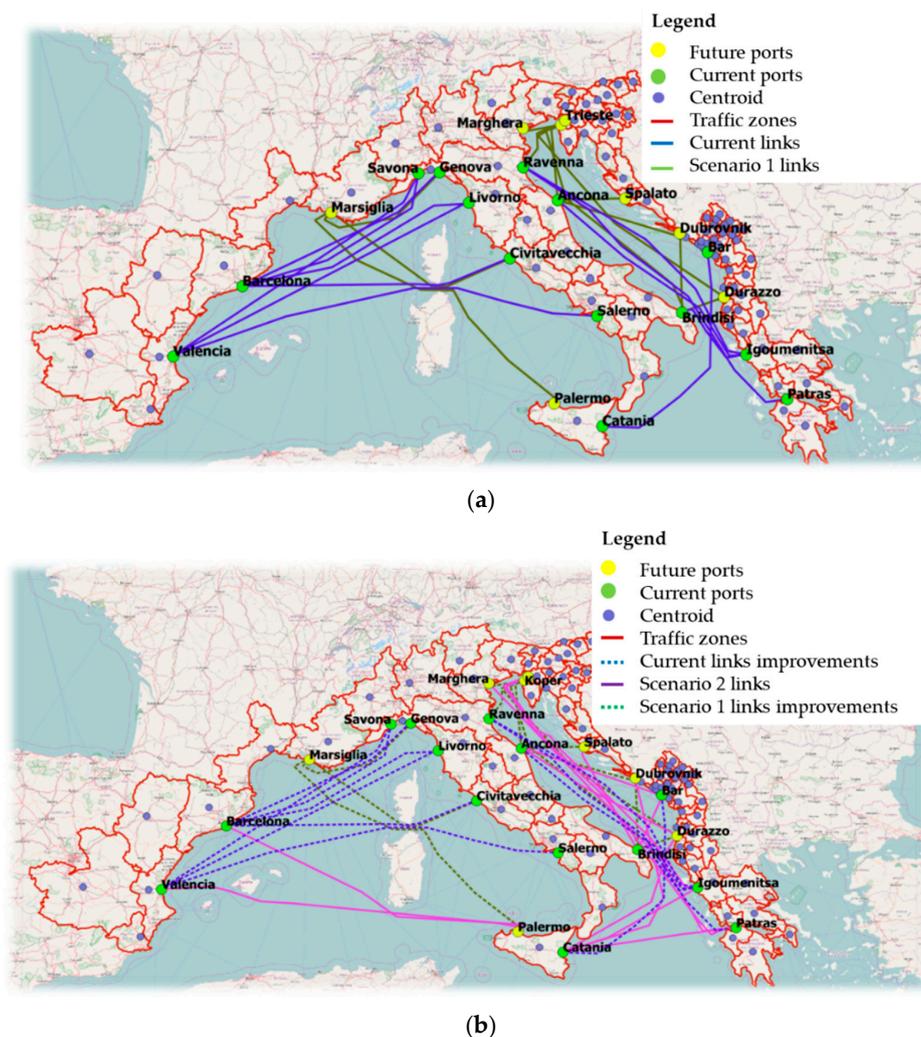


Figure 6. Scenario definition: Scenario 1 (a), scenario 2 (b).

4.4.1. Scenario 1

This scenario was implemented to simulate the effects of the introduction of the new SSS services as illustrated in Figure 6. In accordance with European Directives and especially with the objective of the White Paper (Roadmap towards a single European transport area—for a competitive and sustainable transport policy) regarding the need, by 2030, to shift about 30% of freight demand over 300 km from road to SSS, in the first instance, estimation of the potential demand for transport by SSS was pointed out. Therefore, the main potential sea routes were identified, and evaluation of minimal weekly frequency and load factor were identified. Such an analysis was performed in order to verify the possibility of working without exogenous incentives. At the end of this process, 12 new round-trip connections were introduced with 201 new services capable of attracting demand from road and combined road-rail transport.

The reference scenario (base scenario) was also thus defined. It is the scenario to which the system would trend if no further actions were implemented. From the analysis of the results obtained in terms of annual tons transported, it may be observed that the effect of the introduction of new services leads to an increase in the modal share of the Ro-Ro sea service of 12%, which is achieved at the expense of slightly higher road transport, leaving the combined railway transport practically unchanged (2%).

The benefits of introducing scenario 1 are evaluated in terms of modal shift (i.e., freight tons from combined road-rail or road transport to SSS; Table 4) and in terms of total annual distances travelled (i.e., tons-km/year; Table 5). Particularly, it can be seen that the gain of 12% in terms of annual tons (from 12% in base scenario to 24% in scenario 1; Table 4) corresponds to benefits +11% if calculated in terms of total annual distances (i.e., from 13% to 24%; Table 5). This gain is achieved at the expense of road journeys (−11%, i.e., from 84% in base scenario to 73% in scenario 1; Table 5), while for the combined road-rail, there are no significant differences.

Table 4. Assessment results: Modal share in scenario 1 in terms of tons.

Transport Mode	Base Scenario	Scenario 1	Scenario 1 vs. Base Scenario
SSS	12%	24%	106%
Combined road-rail	2%	2%	−21%
Road	86%	74%	−14%

Table 5. Scenario 1 assessment results: Modal share in terms of t-km/year.

Transport Mode	Base Scenario	Scenario 1	Scenario 1 vs. Base Scenario
SSS	13%	24%	68%
Combined road-rail	3%	3%	−23%
Road	84%	73%	−21%

4.4.2. Scenario 2

This scenario was constructed to simulate the effects of the increase in the frequency of existing SSS services and the inclusion of routes not provided for in Europe-wide program documents in order to reduce travel times.

From the analysis of the results obtained in terms of annual tons transported (Table 6), it may be observed that the effect of the increase in frequency of existing services leads to about a 20% increase in the modal share of SSS (from 12% to 31%), which is achieved at the expense of road (−19%, from 86% to 67%) and combined road-rail (−1%). As shown in Tables 6 and 7, this scenario entails a particularly large increase in demand for SSS (167% in terms of tons, 123% in terms of t-km/year). However, compared to the previous scenario, it has the disadvantage of triggering competition between combined road-rail and road transport since the demand is captured by both transport modes.

Table 6. Assessment results: Modal share in scenario 2 in terms of tons.

Transport Mode	Base Scenario	Scenario 2	Scenario 2 vs. Base Scenario
SSS	12%	31%	167%
Combined road-rail	2%	2%	−30%
Road	86%	67%	−22%

Table 7. Scenario 2 assessment results: Modal share in terms of t-km/year.

Transport Mode	Base Scenario	Scenario 2	Scenario 2 vs. Base Scenario
SSS	13%	32%	123%
Combined road-rail	3%	2%	−29%
Road	84%	66%	−24%

4.4.3. Externality Scenario Comparison

Although the transport sector is fundamental for socio-economic development, its “unsustainable” development imposes significant costs on society in terms of economic impacts (traffic congestion, barriers to mobility, accidents, service costs, etc.), social impacts on human health and environmental impacts (greenhouse gas emissions, air pollution, noise, habitat loss, etc.). Therefore, the two above scenarios were assessed in terms of such costs: pollutant and greenhouse gas emissions, safety, noise and congestion.

The methodology for estimating the economic value of the impacts is based on the application of unit monetary values (€/t-km) to the value of goods expressed in tons-km, through the unit costs provided by the Handbook on External Costs of Transport [59]. Therefore, the annual external cost of type s due to transport mode m for scenario h , $CE_{s,m}^h$, was expressed as follows:

$$CE_{s,m}^h = TKM_m^h \cdot tkm_{s,m} \quad (7)$$

where

- TKM_m^h is the annual tons-km covered by transport mode m in scenario h ;
- $tkm_{s,m}$ is the unit cost for externality s (e.g., air pollutant emissions, greenhouse gas emissions, accidents, congestion, noise) due to transport mode m as proposed by the Handbook on External Costs of Transport.

Table 8 reports the comparison with the base scenario. Significant improvements in terms of external impacts can be observed mainly for project scenario 1. Scenario 2 shows that the inclusion of new connections and a potential increase in the frequency of maritime services yields a further benefit (with respect to scenario 1). In detail, for both scenarios, the impact of SSS increases due to the increase of the share of freight captured by SSS, but, at the same time, for combined road-rail and road transport, the impact decreases. Comparing the total external costs of current scenario with those of scenario 1, there is a reduction of around 16%. Similar considerations emerge for scenario 2, where the reduction of the external costs is about 19%. It shows that Mediterranean freight system has further share of freight that can be captured by SSS if suitable services are planned and implemented.

The described project scenarios show that the development of the Motorways of the Sea could have, in the reorganization of the road haulage, one of the crucial elements for the success of the previously proposed policies. Indeed, an increase in maritime services capable of offering the country-system an integrated sea-road network requires, on the one hand, an investment in human resources for the efficient management of intermodal terminals and new services; on the other, it requires conversion of part of road transport towards access/egress function from/to the land terminals. In particular, pursuant to the predetermined objective (maximization of the modal share on the sea), the reduction of long all-road journeys can contribute to the increase in load factors and favor short-term termination gravitating on the main maritime and railway terminals.

Table 8. Assessment results: Comparison in terms of external costs.

Scenario 1 vs. Base Scenario			
	SSS	Combined Road-Rail	Road
air pollutant	91%	−23%	−21%
accidents	93%	−23%	−21%
congestion	93%		−21%
noise	93%	−23%	−21%
greenhouse	70%	−23%	−21%
Total	86%	−23%	−21%
Average		−16%	
Scenario 2 vs. Base Scenario			
	SSS	Combined Road-Rail	Road
air pollutant	147%	−29%	−24%
accidents	148%	−29%	−24%
congestion	148%		−24%
noise	148%	−29%	−24%
greenhouse	125%	−29%	−24%
Total	142%	−29%	−24%
Average		−19%	

Finally, the proposed analysis could support the decisions of maritime transport operators (e.g., shipping lines, carriers, etc.). It could be suitable to analyze maritime penetration of such services in other sea basins. At the end, it could contribute to provide quantitative support to transport planning activities in progress at EU-Mediterranean level, focusing on the role that shippers can play for the integration of multiple traffic modes into a seamless intermodal transport chain and identifying the main barriers that prevent SSS from being a viable alternative to road transport for certain transport routes. According to these findings, cooperation and shared planning among transport chain agents and a different management approach could be explored more in depth, in order to evaluate the opportunity that large shippers can have in ensuring high frequencies of services for smaller forwarders and shippers, in particular, on origin-destination relations currently not served.

5. Conclusions

The paper analysed the competitive advantage of using SSS services for maritime freight flows between Italy and a set of countries belonging to the north-western range of the Mediterranean basin. An assessment methodology was developed to include an aggregate discrete choice model simulating the split between road, combined road-rail transport and SSS. The study aimed to prepare a competitive and sustainable freight transport system capable of responding to the economic, social and environmental needs of society on a Euro-Mediterranean scale.

Research involved setting up the supply model and the demand model, as well as some ideas on the possibility of integrating transport and macroeconomic models. The supply model was implemented through a theoretical approach and topological and analytical database. First, a road, rail and maritime graph were implemented separately. Air mode was neglected as freight transported by air weights very little compared to freight via other modes. Each of the graphs comprises a topological and analytical element. As regards to the topological part of the road and rail graphs, we started from rather rough bases implemented on GIS support. For the analytical part, it was necessary to proceed with a substantial systematization of the supply model for each mode, with specific state-of-the-art advances, especially with regard to cost functions and fares. In particular, for sea and for combined road-rail transport, the fares currently applied on each section were taken into account.

As regards to demand, a first phase concerned the collection of data on freight flows for the construction of the O-D matrices. The source used, from which to retrieve data according to the geographical size of such flows, is Eurostat, specifically for flows to/from European countries. Once these data were collected, separately for the three modes of transport where available, harmonization in the division of the geographical areas (disaggregation of flows at NUTS 2 level) into the units of measurement (tons/year) was necessary. The O-D matrices obtained, in addition to representing an estimate of current flows, were used to construct the calibration databases of the modal choice model.

Use of the calibrated multinomial logit model showed the potential of improving the SSS supply and was the input for assessing external costs showing the potentiality offered by further sea routes not considered in the planning documents. The negative externalities of the transport system due to their growing monetary and social costs have become a topic of great interest on a global level. Therefore, resources will continue to be used in research applied to mitigate such externalities. In sea transport, where the problem of local pollutants is less commonly felt, the application of liquefied natural gas is a very interesting solution since, as seen above, it does not have particular negative implications. In the long term, the possibility of a combined application of solutions cannot be ruled out, namely electrification of port docks and liquefied natural gas (LNG).

Solutions exist for mitigating emissions and, in some cases, they do not have particularly high costs. As a result, at least in the transport sector, the main constraints to applying short-term solutions are not so much technological or economic, but rather, consequent to behavioural aspects and to the inertia of the system itself.

From the transport perspective, however, the results obtained made it possible to achieve the objective of the European Community regarding the transfer of 30% of road and combined road-rail freight to SSS. Indeed, with the implementation of project scenario 2 (introduction of new services on long-distance connections not envisaged by European documents and boosting of existing services), it is observed that thanks to the addition of new maritime services, a freight flow of 32% takes place on SSS, also bestowing environmental benefits. In conclusion, ships could become the greenest, most effective and cheapest mode of transport.

Attention to the complex mechanisms that underlie current modal choice behaviour of users is a fundamental aspect for the development of user information systems. Therefore, it could push the improvement in the potential of the model with reference to its capacity to predict the effects that the dissemination of information to users has on road traffic, within a specific socio-cultural context.

It can be said, however, that what was developed in this work may be useful for the analysis of possible interventions of new shipping lines in order to be able to boost markets on the shores of the Mediterranean. Consequently, the key to development should consist in a synergistic growth of the various infrastructures and related services, while also allowing the effectiveness of the individual components to be maximized. In this perspective, there should be no doubt about the need to consider interventions to boost the interchange capacity between ports and freight villages or internal logistics platforms as a priority, taking into account the specific nature of the traffic and current market demand.

Finally, the proposed analysis could support the decisions of SSS transport operators (e.g., shipping lines, carriers, etc.), who operate with unitized cargos. It could also be suitable to support the analysis of market penetration of the analysed maritime services in other sea basins, such as the Baltic in Europe. In the end, it could contribute to provide quantitative support to transport planning activities in progress at EU-Mediterranean level.

Further developments of this research mainly regard the specification and calibration of more sophisticated regionalization and mode-service choice models (e.g., based on more disaggregate data, when available) as well as to introduce an heuristics to design the SSS service network.

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