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# Performance assessment of alternative SSS networks by combining KPIs and factor-cluster analysis

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## Abstract

Performance assessment is a fundamental tool to successfully monitor and manage logistics and transport systems. In the field of Short Sea Shipping (SSS), the performance of the various maritime initiatives should be analyzed to assess the best way to achieve efficiency and guide related policies. This study proposes a quantitative methodology which can serve as a decision-support tool in the preliminary assessment and comparison of alternative SSS networks. The research is executed via a Mediterranean case study that compares a hypothetical Mediterranean ro-ro SSS network developed in the framework of a past Euro-Mediterranean cooperation project with the network of existing ro-ro liner services operating in the area. Performance benchmarking of the two networks is performed using a set of quantitative Key Performance Indicators (KPIs) and applying a factor-cluster analysis to produce homogeneous clusters of services based on the relevant variables while accounting for sample heterogeneity. Quantitative results mostly confirm the overall better performance of the prospective network and demonstrate that using KPIs and factor-cluster analysis to investigate the performance of maritime networks can provide policymakers with a preliminary wealth of knowledge that can help in setting targeted policy for SSS-oriented initiatives.

**Keywords:** KPIs, Maritime networks, Factor-cluster analysis, Performance assessment, Mediterranean, Short Sea shipping

## 1 Introduction

Interest in performance assessment of logistics systems has significantly grown in recent years. Particularly, performance measurement takes on relevant importance when involving the key sectors of the economy, such as maritime transport due to its crucial role in local and global economies.

This study focuses on evaluating the performance of roll-on roll-off (ro-ro) maritime transport services between the north-western and south-eastern shores of the Mediterranean Sea. The latter has always been a desirable market for shipping operators, mainly because of its geographical location at the centre of the major east-west international trade routes. In the last decades, following the development of MENA (Middle-East and North-Africa) countries and the increasing economic, political and social relationships between the southern and northern shores, the Mediterranean has also gained growing importance as a trade area for intra-regional traffic [14]. According to Eurostat statistics, from 2001 to 2014 maritime freight flows from the northern Mediterranean regions to MENA countries showed a 160% increase, 92% in the opposite direction. The development of a reliable, cost-efficient and sustainable maritime transport system connecting the two shores it is widely recognized as crucial to support this growth [37, 38]. In recent years an increasing number of studies and initiatives have been promoted by several Euro-Mediterranean programs in this direction. Particularly, Short Sea Shipping (SSS) and

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Motorways of the Sea (MoS) are the main options that European policy is focusing upon for developing sustainable and cohesive transport among countries [51]. However, despite the policy efforts made, the results of the maritime policies implemented so far have been somewhat disappointing [4, 15]. It is shared opinion that poor results may be partly attributed to the fact that policies mostly target transport buyers who shift goods from road to the sea and not how to make SSS more attractive by increasing its efficiency [62, 64]. A thorough analysis of transport alternatives to assess how efficiency is best attained is believed expedient to guide effectively SSS-oriented policymaking [53]. In this regard, the present study intends to provide a contribution to the literature by proposing a quantitative methodology which can serve as a decision-support tool in the preliminary assessment and comparison of the performance of alternative SSS networks. The research is executed via a Mediterranean case study that compares a hypothetical Mediterranean ro-ro SSS network developed in the framework of a past Euro-Mediterranean cooperation project with the network of existing ro-ro liner services operating in the area. The point of view taken in the analysis is that of a hypothetical superordinate decision-making body who, based on the efficiency parameters that characterize alternative transport options, can choose in which direction to orient its transport policies. The analysis takes into account the multiplicity of aspects that characterize the performance of SSS, including service quality and economic and environmental sustainability.

Although it is universally recognized that more efficient transport chains can enhance seamless logistics and promote efficiency, sustainability and interconnectivity of trade networks, quantifying the effectiveness of such initiatives can be hard, unless they can be checked against a set of performance indicators closely related to what has been implemented [43]. The present study compares the performance of two alternative SSS networks, one existing the other prospective, first on a global level and then considering sub-groups of homogeneous services. A comparative analysis of the maritime connections that make up the two networks is first performed using a set of operational and sustainability Key Performance Indicators (KPIs) and then applying a factor-cluster analysis to produce homogeneous clusters of observations based on the relevant KPIs.

The paper is organized as follows. Following this introduction, Section 2 addresses the previous literature in performance assessment for supply and transport chains with a focus on KPIs. Section 3 illustrates the case study by describing the two alternative networks considered. Section 4 describes the application data and introduces the proposed KPIs. Section 5 depicts the methodological framework, while Section 6 discusses the application and its main results. Finally, Section 7 concludes the paper.

## 2 Background literature

Performance assessment is a fundamental tool to successfully monitor and manage logistics systems and the lack of a suitable assessment can represent an important obstacle to an efficient Supply Chain Management - SCM [33]. Performance measurement is deemed essential for efficient planning and monitoring of activities within the decision-making process [45] and can help companies to improve the level of service offered. The crucial role of performance measures for enhancing the efficiency of logistics and business systems has been deeply investigated during the last decades [5, 61] and several methodologies have been suggested for their evaluation and management [2, 30].

Depending on the approach they use, existing performance measurement studies can be classified into three main categories [29]:

- perspective-based;
- process-based;
- hierarchical-based.

The first category is the most widespread as it allows investigating the performance of a supply chain from a specific product-oriented perspective. Perspective-based studies involve, among the others: food supply chains [3], high-tech supply chains [36], textile supply chains [11], automotive supply chains [13], intermodal transport chains [23, 24]. The second category focuses on the various processes that take place in a supply chain [10, 36, 50] while the third category differentiates performance measures based on planning levels: strategic, tactical and operational.

As for the methods used to analyze logistics and transport performance, they can include, among the others: KPIs [29, 34], fuzzy techniques [17, 66], DEA – Data Envelopment Analysis [21, 65, 70], multicriteria methods [10, 26], balanced scorecard methods [6, 68], and Supply Chain Operations Reference models [35, 52].

In particular, KPIs are among the most used models for the measurement of logistics performance [48] to understand the extent to which an area or process is working against the objectives that the company is responsible to achieve. The success of KPIs in SCM is due to the large number of advantages they offer. KPIs allow reducing the complexity of logistics systems to a small number of values, to control, monitor and improve the quality of the services provided. Based on the value an indicator assumes, decision-makers can identify which area needs intervention and which actions need to be taken for their enhancement. KPIs are also used to carry out comparative analyses between different logistics systems and allow to understand and monitor the quality of the performances concerning fixed strategic objectives, such as the quality of the services provided. They can be used to measure the performance of a specific process or segment of the supply chain, to monitor its performance over time and, through the implementation of benchmarking techniques, compare its performance with those of the others. Furthermore, KPIs are not predetermined but may change depending on the considered point of view and on the consequent criteria and priorities associated with each area.

Although supply chains are generally considered in their entire product life cycle, starting from material procurements until to final customers [28], they can be investigated according to different approaches. In this regard, an interesting classification of chains can be found in Woxenius [71] who proposes a distinction among:

- supply chains that focus upon a product and extends back over the different actors, activities and resources required for making it available at the place of consumption;
- logistics chains that focus upon an item or article and extends from when the item is created until it is dissolved;
- transport chains that focus upon a consignment and extends over activities directly related to transport.

As known, logistics and transportation activities traditionally represent the fundamental components of SCM as they strongly influence supply chain costs and the level of service offered. It means that whatever the approach is used to analyze the efficiency of supply chains, transport variables need always to be considered as key performance measures of logistics processes [23]. Although the use of performance indicators in the maritime industry is widespread, it seems to be limited almost exclusively to the port area (see, among others, [7, 16, 39, 40, 47, 54, 69]) while, as far as the authors are aware, only a few studies deal with performance assessment of maritime transport chains [23, 56].

Particularly, with reference to SSS, most studies have been developed to assess in turn the cost-competitiveness (for example, [25, 42, 46, 57, 63]), the importance of service quality attributes [8, 41, 49] and the environmental performance [32, 44, 55] of SSS services for accompanied cargo (truckers travel with their cargo on the ship) versus road haulage. The present study provides a case study focused on the performance evaluation and comparison of alternative Mediterranean SSS networks for unaccompanied ro-ro cargo. Specifically, following the chosen transport-based approach, this study uses KPIs to assess and compare the transport performance of two Mediterranean ro-ro networks, of which one hypothetical and one existing.

If on the one hand, good use of KPIs requires to compare them in order to determine who is doing best by simply comparing the numbers, on the other hand, their direct use may lead to misjudgements when analyzing miscellaneous samples in which differences can be misinterpreted as inefficiencies. The problem of distinguishing between heterogeneity and inefficiency when performing comparative analyses is widely acknowledged in the literature [43] and several studies have tried to address this drawback. Among others, the paper by Tovar and Rodriguez-Déniz [67] provides an interesting overview of the benchmarking techniques for efficiency assessment in ports while highlighting the necessity to use clustering techniques to avoid confusion between inefficiency and heterogeneity. The basic idea is that efficiency benchmarking can benefit from the combination of assessment measures with cluster analysis, especially when the sample is heterogeneous. In this application, transferring the same principle to the evaluation of maritime transport chains, a comparative analysis of the origin/destination (O/D) connections that make up the two networks is first performed using a set of KPIs and then applying a factor-cluster analysis to produce clusters of observations based on the relevant KPIs. Clustering is one of the most popular statistical tools with a plethora of applications in many fields, including the maritime transport sector where it is mainly used to investigate the performance of ports and container terminals [9, 22, 60, 72]. The goal of clustering is traditionally to find meaningful groups of observations so that the similarity among the elements in a cluster is greater than the similarity among different clusters. When used together with performance assessment measures it allows classifying observations into well-defined groups to facilitate a better comparative analysis.

## 3 Problem setting

This study builds on previous work as it examines the performance of the ro-ro network proposal that was developed in the framework of a project funded under the last 2007/2013 ENPI CBC MED - European multilateral Cross-Border Cooperation Programme, the so-called Optimed project. In 2017, the Union for the Mediterranean (UfM)[1] labelled the Optimed project as a strategic transport project to foster socio-economic development and regional integration in the Med area. The primary aim of the project was to optimize the trade network between the north-western and south-eastern shores of the

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[1] The UfM is an intergovernmental institution that brings together the 28 EU Member States and 15 countries from the Southern and Eastern shores of the Mediterranean with the main aim to promote growth and cooperation in the Mediterranean area.

Mediterranean by overcoming the limitations and weaknesses of the existing maritime transport supply [20]. These limitations were mainly identified in the irregularity of service provision (due to many shipping companies which only trade on the spot market constantly changing times and routes), lengthy journey times, long routes and low frequencies.

The study area concerns the Mediterranean basin and coincides with the geographic area involved by the project. It includes eight countries: France, Italy, and Spain in the north-western side, Cyprus, Egypt, Lebanon, Syria, and Turkey in the south-eastern one.

For the purpose of the research, a simplified maritime network graph was built using a centroid approach based on the ro-ro demand generation and attraction of the various areas. Each centroid represents a node of generation and attraction of demand which can comprise more than one port in the area. Since the project focused on the ro-ro sector, only the ports serving a consistent share of ro-ro traffic and with stable east-west trade relationships with the countries involved were considered. The resulting graph consisted of seven port centroids for the European coastal side, and seven for the MENA part, for a total of 98 potential O/D connections: 49 from west to east and 49 from east to west. Table 1 details the network centroids. In this configuration, each centroid can be understood as connected through a fictitious arch (times and costs are equal to zero) to each of the ports it comprises. For example, the Naples centroid includes also the port of Salerno which is only a few kilometres away, both ports are part of the same port system authority. Similarly, the Valencia centroid includes also the nearby ports of Sagunto and Castellon. The approach for port centroids is consistent with the logic of a network system designed not for the individual ports but the broader geographical areas. For the purposes of system operation, the ports belonging to the same centroid are considered equivalent in terms of the possibility of satisfying the connection function.

**Table 1** Network centroids

| | Country | Centroid | Ports comprised in the centroid |
|---|---|---|---|
| EU area | Spain | Valencia | Valencia, Sagunto, Castellon |
| | | Barcelona | Barcelona, Tarragona |
| | France | Marseille | Marseille |
| | | Sète | Sète, Toulon |
| | Italy | Genoa | Genoa, Savona |
| | | La Spezia | La Spezia, Livorno |
| | | Naples | Naples, Salerno |
| MENA area | Turkey | Mersin | Mersin |
| | Syria | Latakia | Latakia, Tartous |
| | Lebanon | Beirut | Beirut, Tripoli |
| | Egypt | Alexandria | Alexandria |
| | | Port Said | Port Said |
| | | Damietta | Damietta |
| | Cyprus | Limassol | Limassol |

The weekly demand matrices from EU to MENA and from MENA to EU ports are reported in Tables 2 and 3. The demand is highly asymmetric, traffic flows from EU to MENA almost double those in the opposite direction. Demand data refers to the peak season in 2012, thus before the political crisis that has long characterized the Eastern Mediterranean region. Data are provided in terms of linear meters (lm) of rolling cargo. A linear meter conventionally corresponds to a unit of space represented by an area of deck 1.0 m in length × 2.0 m in width. In ro-ro shipping, the linear meter is traditionally used both to measure the space capacity of ro-ro ships and to charge freight rates. O/D traffic volumes are therefore often recorded using the same unit of measurement.

The following two paragraphs describe respectively the structure of the maritime ro-ro services in operation between the port nodes considered and the hypothetical network examined.

### 3.1 The existing network

An investigation campaign was carried out to identify the existing Mediterranean ro-ro liner services connecting at least two of the considered ports on opposite shores. The data collection campaign was performed with the preliminary support of the port authorities of interest, which provided us with the list of ro-ro shipping companies regularly calling at their ports. The information in the official websites of the selected companies was used to identify the services of interest and characterize them in terms of routes, the sequence of ports of call, frequency of the service, features of the ships operating the service, and timetables, if available. This process made it possible to count 16 Mediterranean ro-ro liner services offering at least one service per month and connecting a minimum of two ports on opposite shores. Figure 1 shows the resulting map of the existing liner ro-ro services (intermediate connections with ports not included in the project network are shown in light grey). It is worth pointing out that for those services incorporated into much longer routes having origins and destinations beyond the Mediterranean corridor, only the portion of the service included between the first and the last port called among those of interest for the study is reported.

Afterwards, starting from the 16 identified services, each of the 98 O/D pairs was characterized in terms of distance, travel times, the sequence of ports of call, number of intermediate stops and frequency. The following criteria were applied:

**Table 2** Weekly O/D demand (lm) – from EU to MENA (year of reference: 2012)

| O/D | Mersin | Latakia | Beirut | Damietta | Alexandria | Port Said | Limassol | *Total* |
|---|---|---|---|---|---|---|---|---|
| Valencia | 1125 | 246 | 213 | 162 | 94 | 67 | 63 | *1970* |
| Barcelona | 1351 | 154 | 366 | 146 | 72 | 42 | 57 | *2188* |
| Marseille | 6705 | 90 | 644 | 375 | 244 | 161 | 31 | *8250* |
| Sète | 785 | 15 | 242 | 15 | 15 | 15 | 15 | *1102* |
| Genoa | 217 | 15 | 1102 | 415 | 252 | 168 | 28 | *2197* |
| La Spezia | 550 | 15 | 93 | 127 | 66 | 43 | 15 | *909* |
| Naples | 280 | 15 | 181 | 64 | 31 | 29 | 15 | *615* |
| *Total* | *11,013* | *550* | *2841* | *1304* | *774* | *525* | *224* | *17,231* |

Source: Optimed Project

- each O/D pair is characterized through the shortest connection selected among those available, based on the length of the itinerary;
- the possibility of interchange between lines is considered only when no single line offered a direct connection between two ports, thus necessitating the combination of at least two lines. In the case of interline shipment, the service frequency is taken as the lowest;
- when more than one line operates along the same O/D route, the frequency is calculated as the sum of the frequencies characterizing the various services provided by each company;

When the necessary information could not be drawn from the available data, the following assumptions were made:

- when not available from the information sheet of the service analyzed, navigation times are calculated based on distance travelled assuming an average speed of 18 knots;
- an average port time of 10 h for loading and unloading operations is assumed in all ports. When the O/D route requires interline shipment a port operation time of 20 h is considered for each port of call where freight is transferred from one carrier to another.

Table 19 in Appendix 1 provides a summary of the main features of the 98 O/D connections for the existing network. They seem to be characterized mainly by:

- lengthy journey times, some as long as 25 days due to a large number of intermediate port calls;
- long routes, in many cases shore-to-shore services are incorporated into much longer routes having origin and destination beyond the Mediterranean corridor;
- low frequencies, once a month or less (in some cases no medium-long term schedules are available).

### 3.2 The project network

To overcome the limitations identified, the project designed a new topological structure of the shipping network connecting the two Mediterranean shores and proposed an integrated organization of its transport services. The objectives to be achieved focused both on improving the efficiency of the Mediterranean shipping supply system in terms of reducing journey times, of regularity and frequency of connection services as well as rendering it more sustainable from an environmental perspective, and more effective concerning its ability to improve commercial relations and trade between the two shores.

From the topological point of view, the analyzed network has a "two-hub-based" configuration (Fig. 2).

**Table 3** Weekly O/D demand (lm) – From MENA to EU (year of reference: 2012)

| O/D | Valencia | Barcelona | Marseille | Sète | Genoa | La Spezia | Naples | *Total* |
|---|---|---|---|---|---|---|---|---|
| Mersin | 3087 | 516 | 1742 | 15 | 390 | 450 | 400 | *6600* |
| Limassol | 37 | 31 | 15 | 15 | 15 | 15 | 15 | *143* |
| Latakia | 31 | 42 | 15 | 15 | 15 | 15 | 15 | *148* |
| Damietta | 137 | 97 | 36 | 15 | 238 | 82 | 309 | *914* |
| Alexandria | 82 | 45 | 28 | 15 | 145 | 53 | 185 | *553* |
| Port Said | 55 | 31 | 31 | 15 | 96 | 39 | 126 | *393* |
| Beirut | 31 | 57 | 92 | 15 | 166 | 15 | 43 | *419* |
| *Total* | *3460* | *819* | *1959* | *105* | *1065* | *669* | *1093* | *9170* |

Source: Optimed Project

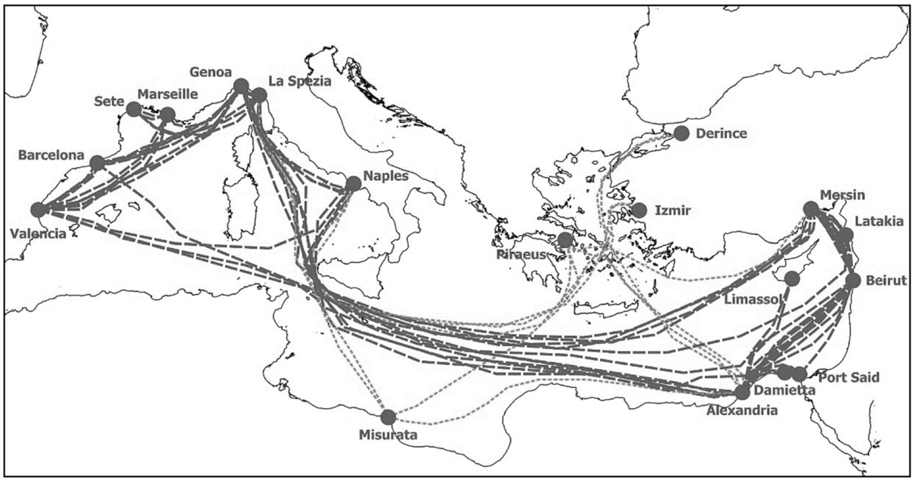

**Fig. 1** Map of existing liner ro-ro services

It has two hubs, one serving the western side and one for the eastern part. Each hub serves its origin/destination ports according to the hub and spoke distribution paradigm in which traffic volumes move along spokes through scheduled shipping services. The proposed network structure is completed with the connection between the two hubs. The designed configuration is supposed to concentrate on the two hubs and their connection the largest trading demand possible between the two Mediterranean shores. Once freight has reached the hub, it is forwarded to the destination port using short-haul ro-ro shipping services, systemically reorganized.

The various services composing the network result characterized concerning service frequencies, capacities and schedules. Their characterization within the Optimed project was performed using a tailored two-step optimization approach based on two Mixed Integer Linear Programming Models – MILPM [19]. In a first step, a MILPM for Service Frequency Selection was used to determine the optimal frequencies and capacities for each mother and feeder service in the network. The objective function was formulated to reconcile two conflicting goals: maximisation of service frequency for shippers and minimisation of unused capacity for companies operating the services. Appendix 2 illustrates the liner services that make up the three legs of the project network (Table 20. Western feeder services; Table 21. Inter-hub services; Table 22. Eastern feeder services) in terms of:

– optimal capacity (lm) of the selected ship operating the service;
– optimal weekly frequency of the service;

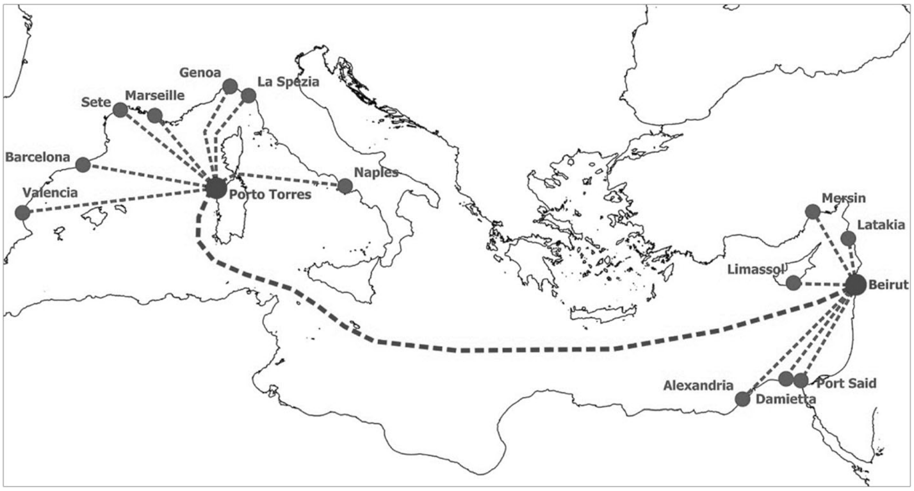

**Fig. 2** Topological structure of the project network analyzed

- weekly demand (lm) of the service and percentage of used capacity considering the two directions (west to east and east to west).

In a second step, a MILPM for Service Timetabling was used to define a weekly schedule for the services determined by the first model that maximised the service coverage of each port while minimising waiting time at the hubs.

Table 23 illustrates the main operational features of the 98 O/D connections in the optimized network. At first glance, these connections are mostly characterized by higher frequencies and shorter routes and journey times than the existing network. As an example, the optimized Spezia – Mersin connection has a weekly frequency, requires two intermediate stops, a navigation distance of 1808 NM and a total travel time of less than 10 days. In the existing configuration, the same O/D pair has a monthly frequency, requires five intermediate stops, has a sailing distance of 2040 NM and a total travel time exceeding 22 days.

## 4 KPIs definition

To evaluate the performance of the two networks including the general criteria that are normally considered by public decision-makers, KPIs were selected to reproduce the three primary dimensions of performance [53]:

- service quality, to account for the importance of time-related attributes that are normally considered by the shippers [12];
- economic effectiveness, to account for cost aspects that may be indicative of the economic sustainability of maritime services;
- environmental sustainability, to account for environmental considerations that are today crucial in the assessment of maritime transport systems [59].

Below is a description of the KPIs used in this application.
Service quality KPIs:

- WF – Weekly Frequency (number of travels moving in the same direction on a given O/D route within a week). For the project network, the service frequency for a complete O/D route “port of origin – hub 1 – hub 2 – port of destination” is taken as the least of the three legs of the route. For example, the frequency of the Limassol – Naples connection will be the shortest between the two legs Limassol - Beirut and Porto Torres – Naples, if it is less than the frequency between the two hubs. For the existing network, the sum of the frequencies indicated by shipping lines for a given route is considered. In the case of interline shipment, it is taken as the lowest.
  Starting from the weekly frequency, it is possible to account for the inconvenience of there not being a regular and frequent service by deriving the waiting time for the service (hours per week). Waiting Time (WT) is calculated in this study as a function of frequency, as the time between successive sailings divided by two as shown by Eq. (1):

$$\text{Waiting Time} = 168/(\text{frequency}/2) \tag{1}$$

where: 168 are the hours in a week. For example, if the service operates weekly then the waiting time is calculated as 3.5 days (84 h).

- NS – Number of Intermediate Stops (number of stops per travel): number of intermediate port calls from the port of origin to the port of destination.
- SD – Sailing Distance (nautical miles per travel): nautical distances from origin to destination port expressed in nautical miles (NM). For the project network, the distance between each O/D pair is calculated as the sum of the distances of the three travel legs that connect the port of origin with the destination port. When the hub is the port of origin or destination, only two legs are considered. For the existing network, the distance between each O/D pair is that for the shortest route operated by an existing shipping line (or interlines, should no connection exist operated by a single company).
- ST - Sailing time (hours per travel): navigation times from origin to destination ports expressed in hours (h). For the existing network, when not available from the service sheet, sailing times are calculated based on the distance travelled assuming an average sailing speed of 18 knots. The project network envisages mother ships with a speed of 21 knots for connections between the two hubs and feeder ships with a speed of 18 knots for journeys between each hub and the ports on the European or MENA shores.
- PT - Port Time (hours per travel): time assigned to each port of call along the route before reaching the final destination. It takes into account both the time for manoeuvring into and out of the port and turnaround time for port operations. For the existing network, when not available from the service information sheet, an average time of 1 h for manoeuvres and 10 h for port operations (cargo loading plus unloading) is assumed. When the shortest O/D connection cannot be provided by the same shipping

line but involves interline shipment, then 20 h are considered for each port of call where freight is transferred from one carrier to another. For the project network, port times were derived from the project timetables.

- TT - Total Travel Time (hours per travel). It is calculated as the sum of Sailing, Port, and Waiting times.
- RWT: Ratio between Waiting and Total Time. It is a dimensionless indicator; the lower the value, the more efficient the service.

Economic KPIs:

- OC – Operating Cost (€ per linear meter of goods transported): unitary operating cost of the route per linear meter of goods transported. This measure should not be understood as representative of the actual transport cost, whose assessment would require indeed much more extensive analysis, but as an indicator of the economic performance of the route based on its utilization. It is calculated by dividing the weekly operating cost of the route by its weekly demand (lm). The former is in turn calculated multiplying the operating cost of 173 €/NM [18] by the nautical miles travelled weekly divided by the number of O/D pairs that share the same connection service. The considered operating cost accounts for the expenses connected with the day to day running of the ship (cost of crew, costs of fuel and lubricants, port charges, insurance, stores, repair and maintenance). Weighing nautical miles was essential to avoid recounting the same miles several times.
- TC – Time Cost (€ per linear meter of goods): it provides a measure of the cost of time per lm of shipment. It is calculated multiplying the total travel time (sum of sailing, port, and waiting times) on a given route by a value of time equal to 1.9 €/lm/h derived from the paper by Feo et al. [25]. This indicator allows the inclusion of the time factor in the analysis. Time is not only one of the most important parameters in project assessment in the transportation sector but also the most significant benefit in any project aimed at improving transport systems.

Environmental KPIs

As for environmental sustainability, shipping is being forced to reduce its emissions by increasingly stricter regulations which are derived from environmental and climate concerns. The International Maritime Organization (IMO), as the body responsible for regulating maritime emissions, has recently developed a challenging roadmap for the decarbonization and desulphurization of the sector. Two cornerstones of this roadmap are the adoption of the Initial IMO Strategy to halve total GHG emissions of shipping by 2050, and the introduction of the IMO Global Sulphur Cap which, from 1 January 2020, has reduced to 0.50% (mass by mass) the limit for sulphur in fuel oil used on ships outside Emission Control Areas. The emission reduction targets set by the IMO are very ambitious and will require the shipping industry to implement substantial changes in fuels, technologies and operations [59]. To account for the importance of environmental aspects in the definition of transport policies and related initiatives, the following indicator for $CO_2$ emissions is included in the analysis:

- UE: Unitary emission of $CO_2$ per linear meter of transported goods (kg $CO_2$ per lm). It is calculated based on the paper by Serra et al. [58] and provides a measure of the environmental efficiency of the O/D route; the lower the value, the more efficient the route.

Table 4 summarizes mean values and standard deviations assumed by each indicator for the existing network and the prospective one. The desired trend column uses the major (>) or minor (<) symbols to indicate whether a higher or lower value is more desirable for the

**Table 4** Performance Indicators

| KPI | Unit of measure | Existing network | | Optimized network | | Desired trend | Best performing scheme | Variation (%) |
|---|---|---|---|---|---|---|---|---|
| | | Mean | StDev | Mean | StDev | | | |
| WF | times/week | 1.0 | 1.0 | 1.2 | 0.8 | > | Optimized | + 20.00 |
| NS | stops/travel | 3.8 | 0.8 | 1.8 | 0.3 | < | Optimized | −52.6 |
| SD | NM/travel | 2102.6 | 587.8 | 1865.1 | 123.3 | < | Optimized | −11.3 |
| TT | h/travel | 392.1 | 148.2 | 225.9 | 23.4 | < | Optimized | −42.4 |
| RWT | – | 0.5 | 0.2 | 0.3 | 0.1 | < | Optimized | −40.0 |
| OC | €/lm | 1976.0 | 1916.0 | 1089 | 1027 | < | Optimized | −44.9 |
| TC | €/lm | 745.0 | 281.6 | 429.2 | 44.5 | < | Optimized | −42.4 |
| UE | kgCO$_2$/lm | 5733.0 | 5451.0 | 465.5 | 212.6 | < | Optimized | −91.9 |

**Table 5** Unrotated factor loadings and communalities – Existing network

| Variable | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 | Factor 8 | Communality |
|---|---|---|---|---|---|---|---|---|---|
| WD - Weekly Demand | −0.396 | 0.036 | −0.816 | 0.072 | 0.414 | −0.005 | 0.007 | 0.001 | 1.000 |
| WF - Weekly Frequency | −0.802 | 0.530 | 0.065 | 0.116 | −0.051 | 0.234 | −0.032 | −0.015 | 1.000 |
| NS - N. of intermediate Stops | 0.557 | 0.133 | −0.261 | 0.751 | −0.199 | −0.023 | 0.003 | −0.005 | 1.000 |
| SD - Sailing Distance | 0.356 | 0.527 | −0.567 | −0.402 | − 0.332 | −0.039 | − 0.021 | −0.014 | 1.000 |
| RWT – Ratio WT/TT | 0.791 | −0.585 | 0.029 | −0.062 | 0.146 | 0.064 | −0.013 | −0.040 | 1.000 |
| OC - Operating Cost | 0.656 | 0.697 | 0.167 | −0.045 | 0.166 | 0.033 | 0.162 | −0.001 | 1.000 |
| TC - Time Cost | 0.913 | −0.261 | −0.224 | − 0.098 | −0.029 | 0.188 | −0.027 | 0.029 | 1.000 |
| UE – Unitary Emission of $CO_2$ | 0.608 | 0.694 | 0.246 | 0.025 | 0.254 | −0.052 | −0.145 | 0.002 | 1.000 |
| Eigenvalue | 3.4970 | 1.9539 | 1.1989 | 0.7602 | 0.4374 | 0.1001 | 0.0496 | 0.0029 | 8.000 |
| % Var | 0.437 | 0.244 | 0.150 | 0.095 | 0.055 | 0.013 | 0.006 | 0.000 | 1.000 |

corresponding indicator. The best performing scheme according to each indicator is listed in the last but one column while the potential percentage variation resulting from the transition from the existing to the optimized network is in the last column.

Looking at the data shown in Table 4, the optimized network appears to perform generally better than the existing network. However, looking at the standard deviation values it emerges that, especially for the existing network, data are very spread out from the mean indicating significant heterogeneity of the sample. In these cases, efficiency benchmarking can benefit from the combination of assessment measures with cluster analysis in order not to neglect heterogeneity and to better interpret the performances by redefining them for sub-groups of homogeneous observations. Following this principle, this application performs a comparative analysis of the 98 O/D connections that make up the two networks by applying a factor-cluster analysis to produce homogeneous clusters of observations based on the relevant KPIs.

## 5 Methodology

A preliminary Factor Analysis is performed to assess the structure of the data by evaluating the correlation between variables. Factor Analysis is a linear algebra method used for dimensionality reduction that allows condensing a large number of interrelated variables $Y_1$, $Y_2$, … $Y_n$ into a smaller number of latent unrelated factors $F_1$, $F_2$, … $F_k$. Each generic factor $F_i (i = 1, \ldots k)$ is a linear function of the original variables and can be written as shown in Eq. (2):

$$F_i = \delta_{i0} + \delta_{i1} Y_1 + \delta_{i2} Y_2 + \ldots + \delta_{ik} Y_n + \mathcal{E}_i \tag{2}$$

where $\delta_{i0}$ is the intercept, $\delta_{ik}$ are the factor loadings, $F_i$ is the factor value, and $\mathcal{E}_i$ are the residuals.

In the proposed application, the number of factors to extract has been preliminarily defined by performing the analysis using the principal components method of extraction, without rotation, and then repeated using the Varimax rotation to extract only the factors of interest.

In a second step, a cluster analysis is performed to join observations that share common characteristics into homogeneous groups. The existing wide variety of clustering techniques can be roughly classified into two main methods: hierarchical and divisive [1]. Hierarchical methods start with n classes, representing the n statistical units, and then use iterative processes of merging,

**Table 6** Rotated factor loadings and communalities using Varimax rotation – Existing network

| Variable | Factor 1 | Factor 2 | Factor 3 | Communality |
|---|---|---|---|---|
| WD - Weekly Demand | −0.200 | −0.335 | −0.819 | 0.824 |
| WF - Weekly Frequency | −0.958 | −0.029 | − 0.101 | 0.928 |
| NS - N. of intermediate Stops | 0.426 | 0.385 | −0.258 | 0.396 |
| SD - Sailing Distance | 0.099 | 0.532 | −0.658 | 0.726 |
| RWT – Ratio WT/TT | 0.963 | −0.007 | 0.205 | 0.969 |
| OC - Operating Cost | 0.070 | 0.946 | 0.104 | 0.911 |
| TC - Time Cost | 0.121 | 0.963 | 0.029 | 0.943 |
| UE – Unitary Emission of $CO_2$ | 0.928 | 0.281 | −0.111 | 0.953 |
| Eigenvalue | 2.9560 | 2.4473 | 1.2466 | 6.6498 |
| % Var | 0.369 | 0.306 | 0.156 | 0.831 |

**Fig. 3** Dendrogram of the existing network – Complete linkage - Euclidean Distance

until all units are assigned to a single cluster. Thus, the final result is not a single partition of *n* units but a series of partitions that can be graphically represented through a tree-like diagram, the so-called dendrogram. Divisive methods are used when a specific number of clusters is required as they provide a flat partition of the input data set into a fixed number of groups. In this application, a hierarchical method for partitioning a set of observations into groups so as maximize both within-cluster homogeneity and heterogeneity among clusters is used. The similarity between two clusters i and j is calculated as shown in Eq. (3):

$$S_{ij} = \frac{100\left(1 - d_{ij}\right)}{d_{max}} \tag{3}$$

where: $S_{ij}$ is the similarity between clusters I and j; $d_{ij}$ is the distance between clusters i and j; $d_{max}$ is the maximum value in the original distance matrix D. One of the attractive features of hierarchical techniques is that they do not assume any particular number of clusters fixed a priori. The decision about final grouping is also called "cutting the dendrogram" and allows obtaining any desired number of clusters by "cutting" the dendrogram at the appropriate level. The level of dissimilarity between clusters is given by the height of the point where their branches merge. This application uses as a linkage method the Ward's Method, which differs from other aggregation methods insofar as the merging criterion is based on the analysis of the within clusters variance.

## 6 Application

The described methodology was applied to the two networks in order to identify well-defined groups of O/D connections that can be benchmarked against one another to put into light inefficiencies and/or proper functioning. The following paragraphs describe the application performed using Minitab statistical software and discuss the main results.

### 6.1 Factor-cluster analysis of the existing network

The Factor-Cluster analysis was applied to the dataset of the existing network, counting 98 observations corresponding to the 98 O/D connections identified.

Table 5 shows unrotated factor loadings and communalities using the principal components method of extraction, without rotation, for the eight following variables: weekly demand, weekly frequency, number of intermediate stops, sailing distance, ratio waiting time / total travel time, operating cost, time cost, and unitary emission of $CO_2$. The first three factors have eigenvalues higher than 1 and account for most of the total variability in data (83.1%). Unrotated results are often difficult to interpret because the variables tend to load on both axes making it not easy to see the patterns. To better fit

**Table 7** Final partition – Existing network

| | Number of observations | Within cluster Sum of squares | Average distance from centroid | Maximum distance from centroid |
|---|---|---|---|---|
| Cluster 1 | 31 | 23.5631 | 0.78456 | 2.29198 |
| Cluster 2 | 5 | 24.3373 | 1.74836 | 4.22362 |
| Cluster 3 | 19 | 7.8942 | 0.60159 | 0.92245 |
| Cluster 4 | 25 | 17.1369 | 0.76535 | 1.32728 |
| Cluster 5 | 10 | 1.5942 | 0.35565 | 0.70828 |
| Cluster 6 | 8 | 5.0979 | 0.69001 | 1.38296 |

**Table 8** Distances between clusters centroids – Existing network

| | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 |
|---|---|---|---|---|---|---|
| Cluster 1 | 0.00000 | | | | | |
| Cluster 2 | 3.45919 | 0.00000 | | | | |
| Cluster 3 | 1.88519 | 3.01327 | 0.00000 | | | |
| Cluster 4 | 1.37287 | 3.65781 | 1.88847 | 0.00000 | | |
| Cluster 5 | 2.83023 | 4.05472 | 3.11212 | 1.58921 | 0.00000 | |
| Cluster 6 | 3.19406 | 3.86172 | 1.77217 | 2.33453 | 2.75311 | 0.00000 |

the actual data points and make the factors more easily interpretable, the axes of the factors can be rotated within the multidimensional variable space. The factor analysis is repeated using the Varimax rotation to extract only the factors of interest. Rotated factor loadings and communalities for the first three factors are in Table 6. Loadings can range from − 1 to 1, values close to − 1 or 1 indicate that the factor strongly influences the variable. Considering the size of the database and the suggestions given by Hair et al. [31], a 0.7 threshold is used for factor loading cut-offs.

The three factors can be interpreted as follows:

- RWT (0.963) and UE (0.928) have positive loadings on Factor 1 while WF (−0.958) has a large negative association. Factor 1 can be considered representative of both the quality and environmental sustainability of a service;
- OC (0.946) and TC (0.963) have large positive loadings on Factor 2, so this factor can be representative of cost aspects;
- WD (− 0.819) has a large negative loading on Factor 3, so this factor describes the extent to which a connection is used.

In a second step, a cluster analysis is performed, using as input variables the three factors, to join observations that share common characteristics into homogeneous groups. The results of the cluster analysis are graphically illustrated in the dendrogram in Fig. 3 featuring six main clusters.

The general characteristics of each cluster in the final partition and the distances between cluster centroids are in Tables 7 and 8, respectively. Distances measure how far apart the centroids of the clusters in the final partition are from one another. A larger distance generally indicates a greater difference between the clusters. At first sight, the dendrogram in Fig. 3 features three high-level groups which in the final clustering are further divided into sub-groups. The first group coincides with Cluster 1, the second group includes Clusters 4 and 5 while the third group includes Clusters 2, 3 and 6. The list of the O/D connections belonging to each cluster can be found in Table 9 while the average features of the six clusters are in Table 10.

Cluster 1 includes 31 O/D connections and can be considered representative of the average characteristics of the existing network under investigation. Its services are neither the best performing nor the worst

**Table 9** Clustering Results - Existing Network

| Cluster ID | N. of observations | Observations |
|---|---|---|
| 1 | 31 | Valencia–Limassol, Valencia–Damietta, Barcelona-Limassol, Marseille–Latakia, Marseille-Beirut, Marseille–Alexandria, Marseille–Damietta, Marseille-Port Said, Sète–Mersin, Sète–Beirut, Genoa–Limassol, Genoa–Damietta, Genoa-Port Said, Spezia–Mersin, Spezia-Beirut, Spezia-Alexandria, Spezia-Damietta, Spezia-Port Said, Naples–Mersin, Naples–Damietta, Naples-Port Said, Mersin-Spezia, Mersin–Naples, Beirut–Marseille, Alexandria-Spezia, Damietta–Genoa, Damietta-La Spezia, Damietta–Naples, Port Said–Genoa, Port Said-Spezia, Port Said-Naples |
| 2 | 5 | Valencia–Mersin, Barcelona–Mersin, Marseille–Mersin, Mersin–Valencia, Mersin-Marseille |
| 3 | 19 | Valencia-Latakia, Valencia-Beirut, Valencia-Alexandria, Barcelona-Latakia, Barcelona-Beirut, Barcelona-Alexandria, Barcelona-Damietta, Genoa-Mersin, Genoa-Beirut, Genoa-Alexandria, Naples-Beirut, Mersin-Barcelona, Mersin-Genoa, Beirut-Genoa, Beirut-Naples, Alexandria-Genoa, Alexandria-Naples, Damietta-Valencia, Damietta-Barcelona |
| 4 | 25 | Valencia-Port Said, Barcelona-Port Said, Marseille-Limassol, Sète-Alexandria, Sète-Damietta, Sète-Port Said, Genoa-Latakia, Spezia-Limassol, Spezia-Latakia, Naples-Limassol, Naples-Latakia, Limassol-Valencia, Limassol-Barcelona, Limassol-Genoa, Limassol-Spezia, Limassol-Naples, Latakia -Marseille, Latakia-Genoa, Latakia-Spezia, Latakia-Naples, Beirut-Spezia, Alexandria-Marseille, Damietta-Marseille, Port Said-Barcelona, Port Said-Marseille |
| 5 | 10 | Sète-Limassol, Sète-Latakia, Limassol-Marseille, Limassol-Sète, Mersin-Sète, Latakia-Sète, Beirut-Sète, Alexandria-Sète, Damietta-Sète, Port SaidSète |
| 6 | 8 | Naples-Alexandria, Latakia-Valencia, Latakia-Barcelona, Beirut-Valencia, Beirut-Barcelona, Alexandria-Valencia, Alexandria-Barcelona, Port Said-Valencia |

**Table 10** Descriptive features of the final partition – Existing network

| KPI | Unit of measure | Whole network | | Cluster 1 | | Cluster 2 | | Cluster 3 | | Cluster 4 | | Cluster 5 | | Cluster 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev |
| WD | lm/week | 269.5 | 775.0 | 212.0 | 195.1 | 2802.0 | 2310.6 | 249.3 | 237.2 | 23.0 | 12.9 | 15.0 | 0.0 | 46.8 | 17.7 |
| WF | times/week | 1.0 | 1.0 | 0.3 | 0.1 | 2.6 | 0.5 | 2.1 | 0.7 | 0.4 | 0.3 | 0.3 | 0.0 | 2.7 | 0.4 |
| NS | stops/travel | 3.8 | 0.8 | 3.6 | 0.8 | 3.8 | 0.4 | 3.6 | 0.7 | 4.1 | 0.8 | 4.8 | 0.4 | 3.3 | 0.5 |
| SD | NM/travel | 2102.6 | 587.8 | 1898.8 | 588.6 | 2451.0 | 462.9 | 1797.6 | 330.1 | 2152.7 | 554.6 | 2940.3 | 209.5 | 2195.6 | 493.7 |
| TT | h/travel | 392.1 | 148.2 | 458.1 | 83.8 | 237.4 | 31.7 | 208.2 | 20.4 | 463.2 | 107.1 | 579.0 | 15.5 | 214.4 | 29.9 |
| RWT | – | 0.5 | 0.2 | 0.6 | 0.1 | 0.1 | 0.0 | 0.2 | 0.1 | 0.6 | 0.1 | 0.6 | 0.0 | 0.1 | 0.0 |
| OC | €/lm | 1976.0 | 1916.0 | 502.6 | 391.0 | 93.2 | 54.4 | 706.9 | 493.0 | 3119.5 | 1126.9 | 5536.6 | 394.5 | 3847.4 | 1326.1 |
| TC | €/lm | 745.0 | 281.6 | 870.3 | 159.2 | 451.0 | 60.2 | 395.6 | 38.8 | 880.1 | 203.5 | 1100.0 | 29.5 | 407.4 | 56.9 |
| UE | kgCO2/lm | 5733.0 | 5451.0 | 1563.6 | 1332.2 | 261.3 | 157.2 | 2076.4 | 1415.0 | 8861.3 | 2577.0 | 15,494.0 | 2752.3 | 12,019.5 | 3943.9 |
| N. of observations | | 98 | | 31 | | 5 | | 19 | | 25 | | 10 | | 8 | |

performing. Clusters 4 and 5 together include 35 O/D connections. The features of these two clusters are very similar to each other. They group connections characterized by very low frequencies (WF), high sailing distances (SD) and the highest travel times (TT, RWT) and number of stops (NS). These connections are characterized by very low weekly demand and appear to be among the most inefficient also in economic (OC, TC) and environmental terms (UE). Particularly, Cluster 5 is by far the worst performing of the whole network from all points of view. The O/D connections belonging to Cluster 2, 3 and 6 are among the most efficient from a user's perspective as they are characterized by the highest frequencies (WF) and the lowest journey times (TT, RWT). The three clusters differ significantly both in the demand served and in the economic and environmental indicators. Cluster 2 is characterized by the highest demand served and performs best both in economic (OC) and environmental terms (UE). Conversely, the low demand that characterizes Cluster 6 makes it the worst performing in both environmental and economic terms. Cluster 3 is halfway between Cluster 2 and 6.

### 6.2 Factor-cluster analysis of the optimized network

To perform a comparative analysis between the two networks, the same factor-cluster analysis was applied to the optimized network. Even in this case, the dataset consists of 98 observations corresponding to the 98 O/D connections considered.

Table 11 shows unrotated factor loadings and communalities using the principal components method of extraction, without rotation, for the same set of KPIs used in the analysis of the existing network. The factor analysis was repeated using the Varimax rotation to extract only the first three factors, which alone explain more than 83% of the total variance. Rotated factor loadings and communalities for the three factors are in Table 12. Using the rotated factor loadings higher than 0.7, the three factors can be interpreted as follows:

- Factor 1 has large negative associations with WD (– 0.770) and WF (– 0.917), and a positive association with RWT (0.950). It can be representative of the time component of a service and its use;
- Factor 2 has large negative associations with NS (– 0.867), SD (– 0.886) and UE (– 0.714), so this factor

**Table 11** Unrotated factor loadings and communalities – Optimized network

| Variable | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 | Factor 8 | Communality |
|---|---|---|---|---|---|---|---|---|---|
| WD - Weekly Demand | –0.620 | – 0.483 | – 0.176 | 0.424 | – 0.389 | – 0.140 | 0.011 | – 0.000 | 1.000 |
| WF - Weekly Frequency | – 0.906 | – 0.137 | – 0.305 | – 0.067 | 0.143 | 0.041 | –0.203 | 0.003 | 1.000 |
| NS - N. of intermediate Stops | 0.550 | –0.635 | –0.301 | 0.284 | 0.207 | 0.282 | 0.033 | 0.005 | 1.000 |
| SD - Sailing Distance | 0.450 | –0.770 | –0.042 | – 0.352 | 0.034 | – 0.279 | 0.004 | 0.006 | 1.000 |
| RWT – Ratio WT/TT | 0.833 | 0.343 | 0.325 | 0.165 | –0.211 | – 0.006 | –0.104 | 0.012 | 1.000 |
| OC - Operating Cost | 0.427 | 0.459 | –0.637 | 0.269 | 0.238 | –0.270 | 0.002 | –0.000 | 1.000 |
| TC - Time Cost | 0.940 | –0.294 | 0.091 | 0.067 | –0.046 | –0.009 | – 0.121 | –0.014 | 1.000 |
| UE – Unitary Emission of $CO_2$ | 0.365 | 0.182 | –0.781 | –0.303 | – 0.337 | 0.139 | 0.005 | –0.000 | 1.000 |
| Eigenvalue | 3.6042 | 1.6961 | 1.3441 | 0.5838 | 0.4324 | 0.2711 | 0.0679 | 0.0004 | 8.000 |
| % Var | 0.451 | 0.212 | 0.168 | 0.073 | 0.054 | 0.034 | 0.008 | 0.000 | 1.000 |

**Table 12** Rotated factor loadings and communalities using Varimax rotation – Optimized network

| Variable | Factor 1 | Factor 2 | Factor 3 | Communality |
|---|---|---|---|---|
| WD - Weekly Demand | −0.770 | −0.119 | 0.205 | 0.649 |
| WF - Weekly Frequency | −0.917 | 0.298 | 0.054 | 0.932 |
| NS - N. of intermediate Stops | 0.055 | −0.867 | −0.205 | 0.796 |
| SD - Sailing Distance | 0.033 | −0.886 | 0.102 | 0.797 |
| RWT – Ratio WT/TT | 0.950 | −0.084 | −0.088 | 0.917 |
| OC - Operating Cost | 0.024 | −0.163 | −0.865 | 0.776 |
| TC - Time Cost | 0.248 | 0.063 | −0.856 | 0.798 |
| UE – Unitary Emission of CO2 | 0.677 | −0.714 | −0.099 | 0.979 |
| Eigenvalue | 2.8603 | 2.1875 | 1.5966 | 6.644 |
| % Var | 0.358 | 0.273 | 0.200 | 0.831 |

can be representative of the operating structure of the service and its environmental impact;

- OC (– 0.865) and TC (– 0.856) have large negative loadings on Factor 3, so this factor measures cost aspects.

In a second step, the three factors were used as input variables for the cluster analysis. The dendrogram in Fig. 4 illustrates the final partition in five clusters. Table 13 shows the characteristics of each cluster while Table 14 shows distances between clusters centroids. At a glance, the dendrogram in Fig. 4 features three high-level groups corresponding respectively to services with a low-to-medium, medium-to-high and low demand. The first group coincides with Cluster 1 and includes 43 observations, the second group includes Clusters 2 and 3 for a total of 19 observations, while the third group includes Clusters 4 and 5 for a total of 36 observations. The list of the O/D connections included in each cluster is in Table 15 while the general features of the five groups are in Table 16.

Cluster 1 includes almost half of the total O/D connections and can be considered representative of the general features of the optimized network under investigation. Services belonging to Clusters 2 and 3 appear to be among the most efficient both from a user's and sustainability point of view. They are characterized by the lowest journey times (TT) and number of intermediate stops (NS). As for the latter aspect, it can be easily explained through the presence in both clusters of several services for which the origin (or destination) port coincides with the hub of reference. The main distinguishing element between the two clusters is represented by the WF indicator, with Cluster 2 tripling Cluster 3.

As for the services belonging to Clusters 4 and 5, they are the least performing from all points of view. They are very similar in terms of weekly frequency (WF), number of stops (NS) and travel times (TT). The main distinctive elements between the two clusters are represented by the cost and environmental KPIs, with cluster 4 that performs slightly better than cluster 5 in terms of both cost (OC, TC) and environmental efficiency (UE).

## 7 Results and discussion

Table 17 summarizes the general features of the two networks, both in terms of single clusters and overall

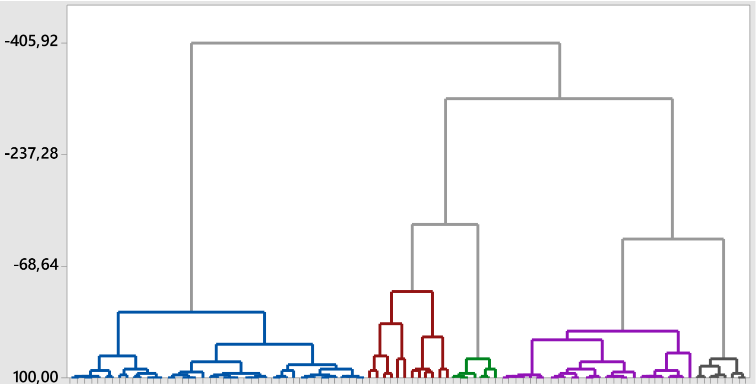

**Fig. 4** Dendrogram of the optimized network – Complete linkage - Euclidean Distance

**Table 13** Final partition – Optimized network

| | Number of observations | Within cluster sum of squares | Average distance from centroid | Maximum distance from centroid |
|---|---|---|---|---|
| Cluster 1 | 43 | 12.9316 | 0.49768 | 1.10522 |
| Cluster 2 | 12 | 55.5534 | 2.02022 | 4.15169 |
| Cluster 3 | 7 | 2.3129 | 0.51510 | 1.09527 |
| Cluster 4 | 28 | 13.4079 | 0.58521 | 2.18239 |
| Cluster 5 | 8 | 2.4428 | 0.49996 | 0.85302 |

network. Although the hypothetical hub-based network seems to perform better overall than the network of existing multi-port-calling services, some considerations are necessary to better understand the results.

The O/D connections that make up the optimized network are characterized by performance levels that remain fairly constant from cluster to cluster. This is not surprising, as it directly depends on the layout of the optimized network itself. The double hub and spoke structure causes that the main part of each O/D connection, the so-called inter-hub leg, is shared among all the O/D connections that make up the network. Table 18 provides further quantitative confirmation of this greater homogeneity. It shows, for both networks, the percentage deviation in the means of the indicators, calculated once for the global network and once for the clusters. Deviations are in absolute value; the smaller the value the greater the homogeneity.

Clustering of the existing network highlights a small cluster of O/D connections (Cluster 2) that perform on average better than the others. These O/D connections (Valencia–Mersin, Barcelona–Mersin, Marseille–Mersin, Mersin–Valencia, Mersin-Marseille) would not see significant improvements in transport performance in an eventual transition from the existing to the optimized network scheme.

Clustering of the existing network also highlights a group of O/D connections (Cluster 6) characterized by good indicators of the quality of the service for users but poor economic and environmental performance. The reason can be found in the over sizing (not always justified by the actual transport demand) of the transport offer in the O/D pairs concerned. Conversely, the dual hub structure of the proposed network allows O/D pairs characterized by low demand to be incorporated into the network with lower environmental and cost impacts (Clusters 4 and 5).

**Table 14** Distances between clusters centroids – Optimized network

| | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|---|---|---|---|---|---|
| Cluster 1 | 0.00000 | | | | |
| Cluster 2 | 2.82683 | 0.00000 | | | |
| Cluster 3 | 2.75412 | 3.36254 | 0.00000 | | |
| Cluster 4 | 1.40772 | 2.80434 | 2.55142 | 0.00000 | |
| Cluster 5 | 3.10678 | 3.69529 | 4.10518 | 1.87917 | 0.00000 |

From an environmental perspective, if excluding the small Cluster 2 of the existing network, the integrated nature of the optimized network ensures lower UE values for all clusters. This data indicates the greater environmental effectiveness of the optimized network and confirms the potential contribution shifting freight flows to integrated network schemes can yield for mitigating shipping emissions [58].

The performed factor-cluster analysis confirmed the better overall performance of the optimized network compared to existing one but also identified small groups of O/D pairs for which the transition from the existing to the optimized network could produce a slight decrease in performance. In identifying homogeneous groups of services based on economic, environmental and quality of service indicators, the analysis also highlighted the presence in the existing network of O/D routes well-performing from the user's point of view but unsatisfactory from an economic and environmental perspective. Based on the results of the performed application, it is the authors' opinion that combining KPIs and factor-cluster analysis can help to improve the knowledge of the studied phenomenon through better description of its features and specificities. In the decision-making context of SSS initiatives, such a tool may provide decision-makers with additional knowledge that can help in setting targeted policy initiatives as a function of the specificities detected. In the development of SSS policies, factor-cluster analysis can support a preliminary comparison of the network alternatives at hand by segregating SSS routes into homogeneous groups based on attributes chosen according to the decision-makers' objectives (e.g., reduction of the environmental impact, improvement of the level of service, cost reduction, etc.). Based on the clustering outcomes, and in line with the political priorities to be promoted, decision-makers can thus decide to focus on either run separate targeted policy initiatives for each group of services or focus on just one to achieve greater benefits.

This application also made it clear that each cluster must be carefully analyzed since its classification not only cannot be explained by a single variable but may also vary depending on the perspective considered. In this regard, the application showed the extent to which some services that may

**Table 15** Clustering Results - Optimized Network

| Cluster ID | N. of observations | Observations |
|---|---|---|
| 1 | 43 | Valencia-Limassol, Valencia-Latakia, Valencia-Alexandria, Valencia-Damietta, Valencia-Port Said, Barcelona-Limassol, Barcelona-Mersin, Barcelona-Latakia, Barcelona-Alexandria, Barcelona-Damietta, Barcelona-Port Said, Marseille-Latakia, Marseille-Alexandria, Marseille-Damietta, Marseille-Port Said, Sète-Mersin, Genoa-Alexandria, Genoa-Damietta, Genoa-Port Said, Spezia-Mersin, Spezia-Alexandria, Spezia-Damietta, Spezia-Port Said, Naples-Mersin, Naples-Alexandria, Naples-Damietta, Naples-Port Said, Mersin-Barcelona, Mersin-Spezia, Mersin-Naples, Alexandria-Valencia, Alexandria-Barcelona, Alexandria-Genoa, Alexandria-Spezia, Alexandria-Naples, Damietta-Valencia, Damietta-Barcelona, Damietta-Genoa, Damietta-Spezia, Damietta-Naples, Port Said-Valencia, Port Said-Genoa, Port Said-Naples |
| 2 | 12 | Valencia-Mersin, Valencia-Beirut, Marseille-Mersin, Marseille-Beirut, Genoa-Mersin, Genoa-Beirut, Mersin-Valencia, Mersin-Marseille, Mersin-Genoa, Beirut-Valencia, Beirut-Marseille, Beirut-Genoa |
| 3 | 7 | Barcelona-Beirut, Sète-Beirut, Spezia-Beirut, Naples-Beirut, Beirut-Barcelona, Beirut-Spezia, Beirut-Naples |
| 4 | 28 | Marseille-Limassol, Sète-Limassol, Sète-Latakia, Sète-Alexandria, Sète-Damietta, Sète-Port Said, Genoa-Limassol, Genoa-Latakia, Spezia-Limassol, Spezia-Latakia, Naples-Limassol, Naples-Latakia, Limassol-Valencia, Limassol-Barcelona, Limassol-Genoa, Limassol-Spezia, Limassol-Naples, Latakia-Valencia, Latakia-Barcelona, Latakia-Genoa, Latakia-Spezia, Latakia-Naples, Beirut-Sète, Alexandria-Marseille, Damietta-Marseille, Port Said-Barcelona, Port Said-Marseille, Port Said-Spezia |
| 5 | 8 | Limassol-Marseille, Limassol-Sète, Mersin-Sète, Latakia-Marseille, Latakia-Sète, Alexandria-Sète, Damietta-Sète, Port Said-Sète |

appear highly performing from a user's point of view may turn out to be inefficient if analyzed from a different perspective, for example, the environmental one. In this regard it is worth pointing out that this application assumes that all variables have equal weight and contribute equally to the final cluster structure. However, as weights can influence the determination of the clusters [27], for the future can be interesting to investigate the extent to which the cluster structure may vary when different weights, depending on different decision perspectives, are given to the various variables.

## 8 Conclusion

This study has proposed a quantitative methodology based on the combination of KPIs and factor-cluster analysis to be used as a decision-support tool when preliminarily assessing and comparing the transport performance of alternative SSS networks. The research was executed via a Mediterranean case study that compared a hypothetical hub-based Mediterranean ro-ro SSS network with the network of existing multi-port-calling ro-ro services operating in the area. The 98 O/D connections that make up the two networks were analyzed using operational, economic and environmental KPIs and applying a factor-cluster analysis to produce homogeneous clusters of observations based on the relevant variables. The applied methodology aimed to:

- assess on a global level the performance benchmarks between the two networks, showing the better overall performance of the newly designed network compared to the existing one;
- identify, within each network, well-defined groups of O/D connections that can be benchmarked against one another to put into light inefficiencies and/or proper functioning. The analysis evidenced groups of O/D pairs that are likely to improve their performance if the new network option enters into operation,

**Table 16** Descriptive features of the final partition – Optimized network

| KPI | Unit of measure | Whole network | | Cluster 1 | | Cluster 2 | | Cluster 3 | | Cluster 4 | | Cluster 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev | Mean | StDev |
| WD | lm/week | 269.5 | 775.0 | 212.8 | 242.6 | 1292.8 | 1922.1 | 142.4 | 127.3 | 22.1 | 9.5 | 15.0 | 0.0 |
| WF | times/week | 1.2 | 0.8 | 1.0 | 0.0 | 3.0 | 1.5 | 1.0 | 0.0 | 1.0 | 0.0 | 1.0 | 0.0 |
| NS | stops/travel | 1.8 | 0.3 | 2.0 | 0.0 | 1.5 | 0.5 | 1.0 | 0.0 | 2.0 | 0.2 | 2.0 | 0.0 |
| SD | NM/travel | 1865.1 | 123.3 | 1939.9 | 98.5 | 1788.3 | 137.1 | 1684.1 | 36.6 | 1831.0 | 87.7 | 1856.3 | 100.8 |
| TT | h/travel | 225.9 | 23.4 | 238.5 | 5.5 | 171.7 | 21.0 | 208.3 | 2.0 | 231.9 | 6.5 | 233.9 | 5.6 |
| RWT | – | 0.3 | 0.1 | 0.4 | 0.0 | 0.2 | 0.1 | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 |
| OC | €/lm | 1089 | 1027 | 439.8 | 322.0 | 268.6 | 415.1 | 579.4 | 679.7 | 2019.9 | 536.4 | 3001.6 | 757.3 |
| TC | €/lm | 429.2 | 44.5 | 453.2 | 10.4 | 326.2 | 39.8 | 395.8 | 3.9 | 440.6 | 12.3 | 444.3 | 10.6 |
| UE | kgCO$_2$/lm | 465.5 | 212.6 | 398.5 | 104.3 | 359.5 | 117.2 | 303.7 | 95.7 | 505.3 | 167.7 | 987.2 | 180.8 |
| N. of observations | | 98 | | 43 | | 12 | | 7 | | 28 | | 8 | |

**Table 17** Summary table

| KPI | Unit of measure | EXISTING NETWORK | | | | | | | OPTIMIZED NETWORK | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Whole network | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Whole network | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
| WD | lm/week | 269.5 | 212.0 | 2802.0 | 249.3 | 23.0 | 15.0 | 46.8 | 269.5 | 212.8 | 1292.8 | 142.4 | 22.1 | 15.0 |
| WF | times/ week | 1.0 | 0.3 | 2.6 | 2.1 | 0.4 | 0.3 | 2.7 | 1.2 | 1.0 | 3.0 | 1.0 | 1.0 | 1.0 |
| NS | stops/ travel | 3.8 | 3.6 | 3.8 | 3.6 | 4.1 | 4.8 | 3.3 | 1.8 | 2.0 | 1.5 | 1.0 | 2.0 | 2.0 |
| SD | NM/ travel | 2102.6 | 1898.8 | 2451.0 | 1797.6 | 2152.7 | 2940.3 | 2195.6 | 1865.1 | 1939.9 | 1788.3 | 1684.1 | 1831.0 | 1856.3 |
| TT | h/travel | 392.1 | 458.1 | 237.4 | 208.2 | 463.2 | 579.0 | 214.4 | 225.9 | 238.5 | 171.7 | 208.3 | 231.9 | 233.9 |
| RWT | – | 0.5 | 0.6 | 0.1 | 0.2 | 0.6 | 0.6 | 0.1 | 0.3 | 0.4 | 0.2 | 0.4 | 0.4 | 0.4 |
| OC | €/lm | 1976.0 | 502.6 | 93.2 | 706.9 | 3119.5 | 5536.6 | 3847.4 | 1089 | 439.8 | 268.6 | 579.4 | 2019.9 | 3001.6 |
| TC | €/lm | 745.0 | 870.3 | 451.0 | 395.6 | 880.1 | 1100.0 | 407.4 | 429.2 | 453.2 | 326.2 | 395.8 | 440.6 | 444.3 |
| UE | kg$CO_2$/ lm | 5733.0 | 1563.6 | 261.3 | 2076.4 | 8861.3 | 15,494.0 | 12,019.5 | 465.5 | 398.5 | 359.5 | 303.7 | 505.3 | 987.2 |
| N. of observations | | 98 | 31 | 5 | 19 | 25 | 10 | 8 | 98 | 43 | 12 | 7 | 28 | 8 |

but also groups of O/D pairs for which some indicators slightly worsen when the new network set-up is considered. Because of the multiple dimensions that characterize the clusters, results must necessarily be analyzed carefully, since they cannot be explained by a single variable, but only by a combination of them, and might also vary depending on the perspective considered.

Outcomes of the study generally support the idea that combining KPIs and factor-cluster analysis can support decision-making when assessing and comparing the performance of alternative transport networks. In the decision-making context of SSS initiatives, factor-cluster analysis can support a preliminary comparison of the network alternatives at hand and provide decision-makers with additional knowledge elements that can help in setting targeted policy initiatives as a function of the detected needs and political priorities (reduction of the environmental impact, improvement of the level of service, cost reduction, etc.). However, because of the different dimensions that typically characterize clustering, the analysis of results may sometimes not be straightforward. As a future development, the introduction of appropriate weighting criteria of the relevant clustering variables would likely improve and sharpen the results obtained and the strength of the conclusions derived.

**Table 18** Average deviations (whole network – clustering) in absolute value

| KPI | Unit of measure | EXISTING NETWORK | | | OPTIMIZED NETWORK | | |
|---|---|---|---|---|---|---|---|
| | | Whole network [mean] | 6-class clustering [mean] | Deviation [%] | Whole network [mean] | 5-class clustering [mean] | Deviation [%] |
| WD | lm/week | 269.5 | 558.0 | 51.7 | 269.5 | 337.0 | 20.1 |
| WF | times/ week | 1.0 | 1.4 | 28.6 | 1.2 | 1.4 | 14.3 |
| NS | stops/ travel | 3.8 | 3.9 | 1.7 | 1.8 | 1.7 | 5.9 |
| SD | NM/travel | 2102.6 | 2239.3 | 6.1 | 1865.1 | 1819.9 | 2.5 |
| PT | h/travel | 68.0 | 68.3 | 0.5 | 55.7 | 53.1 | 4.9 |
| TT | h/travel | 392.1 | 360.0 | 8.9 | 225.9 | 216.9 | 4.2 |
| RWT | – | 0.5 | 0.4 | 36.4 | 0.3 | 0.4 | 16.7 |
| OC | €/lm | 1976.0 | 2301.0 | 14.1 | 1089 | 1261.9 | 13.7 |
| TC | €/lm | 745.0 | 684.1 | 8.9 | 429.2 | 412.0 | 4.2 |
| UE | kg$CO_2$/lm | 5733.0 | 6712.7 | 14.6 | 465.5 | 510.8 | 8.9 |

## 1 Appendix 1

**Table 19** General features of the existing network

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 1 | Valencia - Limassol | 0.25 | 4 | 2362 | 537.2 |
| 2 | Valencia - Mersin | 3 | 4 | 2070 | 213.0 |
| 3 | Valencia - Latakia | 2.5 | 3 | 1994 | 202.4 |
| 4 | Valencia - Beirut | 3 | 3 | 1894 | 191.2 |
| 5 | Valencia - Alexandria | 3 | 4 | 1554 | 184.3 |
| 6 | Valencia - Damietta | 0.5 | 4 | 1554 | 324.3 |
| 7 | Valencia - Port Said | 0.5 | 4 | 1554 | 324.3 |
| 8 | Barcelona - Limassol | 0.25 | 5 | 1980 | 528.0 |
| 9 | Barcelona - Mersin | 3 | 4 | 2252 | 223.1 |
| 10 | Barcelona - Latakia | 2.5 | 5 | 2158 | 235.5 |
| 11 | Barcelona - Beirut | 3 | 4 | 2058 | 212.3 |
| 12 | Barcelona - Alexandria | 3 | 4 | 1718 | 193.4 |
| 13 | Barcelona - Damietta | 2 | 4 | 1718 | 207.4 |
| 14 | Barcelona - Port Said | 1 | 4 | 1718 | 249.4 |
| 15 | Marseille - Limassol | 0.25 | 5 | 2968 | 582.9 |
| 16 | Marseille - Mersin | 2 | 4 | 3222 | 291.0 |
| 17 | Marseille - Latakia | 0.5 | 4 | 1752 | 335.3 |
| 18 | Marseille - Beirut | 0.5 | 3 | 3046 | 395.2 |
| 19 | Marseille - Alexandria | 0.5 | 3 | 2706 | 376.3 |
| 20 | Marseille - Damietta | 0.25 | 3 | 2706 | 544.3 |
| 21 | Marseille - Port Said | 0.25 | 4 | 2706 | 556.3 |
| 22 | Sète - Limassol | 0.25 | 5 | 3140 | 592.4 |
| 23 | Sète - Mersin | 0.25 | 5 | 3185 | 594.9 |
| 24 | Sète - Latakia | 0.25 | 5 | 3109 | 590.7 |
| 25 | Sète - Beirut | 0.25 | 3 | 3009 | 561.2 |
| 26 | Sète - Alexandria | 0.25 | 4 | 2669 | 554.3 |
| 27 | Sète - Damietta | 0.25 | 3 | 2669 | 542.3 |
| 28 | Sète - Port Said | 0.25 | 4 | 2669 | 554.3 |
| 29 | Genoa - Limassol | 0.25 | 5 | 1574 | 505.4 |
| 30 | Genoa - Mersin | 1.25 | 4 | 1962 | 246.2 |
| 31 | Genoa - Latakia | 0.25 | 4 | 1752 | 503.3 |
| 32 | Genoa - Beirut | 1.75 | 3 | 1652 | 197.8 |
| 33 | Genoa - Alexandria | 1.75 | 3 | 1312 | 178.9 |
| 34 | Genoa - Damietta | 0.25 | 3 | 1312 | 466.9 |
| 35 | Genoa - Port Said | 0.25 | 2 | 1312 | 454.9 |
| 36 | Spezia - Limassol | 0.25 | 5 | 1786 | 517.2 |
| 37 | Spezia - Mersin | 0.25 | 5 | 2040 | 531.3 |
| 38 | Spezia - Latakia | 0.25 | 5 | 1964 | 527.1 |
| 39 | Spezia - Beirut | 0.25 | 5 | 1864 | 521.6 |
| 40 | Spezia - Alexandria | 0.25 | 4 | 1524 | 490.7 |
| 41 | Spezia - Damietta | 0.25 | 3 | 1524 | 478.7 |
| 42 | Spezia - Port Said | 0.25 | 4 | 1524 | 490.7 |
| 43 | Naples - Limassol | 0.25 | 5 | 1653 | 509.8 |

**Table 19** General features of the existing network *(Continued)*

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 44 | Naples - Mersin | 0.5 | 4 | 1675 | 331.1 |
| 45 | Naples - Latakia | 0.5 | 4 | 1599 | 326.8 |
| 46 | Naples - Beirut | 1.25 | 4 | 1499 | 220.5 |
| 47 | Naples - Alexandria | 2.75 | 3 | 1159 | 152.9 |
| 48 | Naples - Damietta | 0.5 | 3 | 1159 | 290.4 |
| 49 | Naples - Port Said | 0.25 | 3 | 1159 | 458.4 |
| 50 | Limassol - Valencia | 0.25 | 5 | 2544 | 559.3 |
| 51 | Limassol - Barcelona | 0.25 | 5 | 2380 | 550.2 |
| 52 | Limassol - Marseille | 0.25 | 5 | 2889 | 578.5 |
| 53 | Limassol - Sète | 0.25 | 5 | 2934 | 581.0 |
| 54 | Limassol - Genoa | 0.25 | 5 | 1900 | 523.6 |
| 55 | Limassol - Spezia | 0.25 | 5 | 1965 | 527.2 |
| 56 | Limassol -Naples | 0.25 | 5 | 1538 | 503.4 |
| 57 | Mersin - Valencia | 3 | 4 | 2183 | 219.3 |
| 58 | Mersin - Barcelona | 3 | 3 | 2019 | 198.2 |
| 59 | Mersin - Marseille | 2 | 3 | 2528 | 240.4 |
| 60 | Mersin - Sète | 0.25 | 4 | 2573 | 548.9 |
| 61 | Mersin - Genoa | 1.25 | 5 | 1452 | 229.9 |
| 62 | Mersin - Spezia | 0.25 | 4 | 1622 | 496.1 |
| 63 | Mersin - Naples | 0.5 | 4 | 1457 | 318.9 |
| 64 | Latakia - Valencia | 2.5 | 4 | 2277 | 230.1 |
| 65 | Latakia - Barcelona | 2.5 | 4 | 2113 | 221.0 |
| 66 | Latakia - Marseille | 0.5 | 3 | 2622 | 371.7 |
| 67 | Latakia - Sète | 0.25 | 5 | 2667 | 566.2 |
| 68 | Latakia - Genoa | 0.25 | 4 | 1856 | 509.1 |
| 69 | Latakia - Spezia | 0.25 | 4 | 1670 | 498.8 |
| 70 | Latakia - Naples | 0.5 | 4 | 1363 | 313.7 |
| 71 | Beirut - Valencia | 3 | 3 | 2377 | 218.1 |
| 72 | Beirut - Barcelona | 3 | 3 | 2213 | 208.9 |
| 73 | Beirut - Marseille | 0.5 | 3 | 2722 | 377.2 |
| 74 | Beirut - Sète | 0.25 | 4 | 2767 | 559.7 |
| 75 | Beirut - Genoa | 1.75 | 3 | 1733 | 202.3 |
| 76 | Beirut - Spezia | 0.25 | 4 | 1798 | 505.9 |
| 77 | Beirut - Naples | 1.25 | 3 | 1371 | 201.4 |
| 78 | Alexandria - Valencia | 3 | 3 | 2717 | 236.9 |
| 79 | Alexandria - Barcelona | 3 | 3 | 1992 | 196.7 |
| 80 | Alexandria - Marseille | 0.5 | 3 | 3063 | 396.2 |
| 81 | Alexandria - Sète | 0.25 | 5 | 3108 | 590.7 |
| 82 | Alexandria - Genoa | 1.75 | 4 | 1640 | 209.1 |
| 83 | Alexandria - Spezia | 0.25 | 3 | 1562 | 480.8 |
| 84 | Alexandria - Naples | 2.75 | 3 | 1711 | 183.6 |
| 85 | Damietta - Valencia | 2 | 3 | 2717 | 250.9 |
| 86 | Damietta - Barcelona | 2 | 3 | 1992 | 210.7 |
| 87 | Damietta - Marseille | 0.25 | 3 | 3063 | 564.2 |

**Table 19** General features of the existing network *(Continued)*

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 88 | Damietta - Sète | 0.25 | 5 | 3108 | 590.7 |
| 89 | Damietta - Genoa | 0.25 | 3 | 1640 | 485.1 |
| 90 | Damietta - Spezia | 0.25 | 3 | 1562 | 480.8 |
| 91 | Damietta - Naples | 0.5 | 3 | 1711 | 321.1 |
| 92 | Port Said - Valencia | 2 | 3 | 2717 | 250.9 |
| 93 | Port Said - Barcelona | 1 | 3 | 1992 | 252.7 |
| 94 | Port Said - Marseille | 1 | 3 | 3063 | 312.2 |
| 95 | Port Said - Sète | 0.25 | 5 | 3108 | 590.7 |
| 96 | Port Said - Genoa | 0.25 | 4 | 1640 | 497.1 |
| 97 | Port Said - Spezia | 0.25 | 3 | 1562 | 480.8 |
| 98 | Port Said - Naples | 0.25 | 3 | 1711 | 489.1 |

# 9 Appendix 2

## 9.1 Features of the optimized network

**Table 20** Leg 1 - Western feeder services: frequencies and capacities

| Feeder service | Feeder ship category (lm) | | | Weekly frequency | West to East | | East to West | |
|---|---|---|---|---|---|---|---|---|
| | 1350 | 2520 | 3320 | | Weekly demand (lm) | Used capacity (%) | Weekly demand (lm) | Used capacity (%) |
| Barcelona – Porto Torres - Barcelona | 0 | 1 | 0 | 1 | 2188 | 0.87 | 819 | 0.33 |
| Genoa – Porto Torres - Genoa | 2 | 0 | 0 | 2 | 2197 | 0.81 | 1065 | 0.39 |
| Spezia – Porto Torres – Spezia | 1 | 0 | 0 | 1 | 879 | 0.65 | 669 | 0.50 |
| Marseille – Porto Torres - Marseille | 5 | 1 | 0 | 6 | 8250 | 0.89 | 1959 | 0.21 |
| Naples – Porto Torres - Naples | 1 | 0 | 0 | 1 | 615 | 0.46 | 1093 | 0.81 |
| Sète – Porto Torres - Sète | 1 | 0 | 0 | 1 | 1102 | 0.82 | 105 | 0.08 |
| Valencia – Porto Torres - Valencia | 1 | 0 | 1 | 2 | 1970 | 0.42 | 3460 | 0.74 |

**Table 21** Leg 2 – Mother services: frequencies and capacities

| Mother service | Mother ship category (lm) | | | Weekly frequency | West to East | | East to West | |
|---|---|---|---|---|---|---|---|---|
| | 4600 | 6350 | 7700 | | Weekly demand (lm) | Used capacity (%) | Weekly demand (lm) | Used capacity (%) |
| Porto Torres – Beirut – Porto Torres | 5 | 0 | 0 | 5 | 17,231 | 0.75 | 9170 | 0.40 |

**Table 22** Leg 3 - Eastern feeder services: frequencies and capacities

| Feeder service | Feeder ship category (lm) | | | Weekly frequency | East to West | | West to East | |
|---|---|---|---|---|---|---|---|---|
| | 1350 | 2520 | 3320 | | Weekly demand (lm) | Used capacity (%) | Weekly demand (lm) | Used capacity (%) |
| Mersin – Beirut - Mersin | 1 | 4 | 1 | 6 | 6600 | 0.45 | 11,013 | 0.75 |
| Latakia – Beirut - Latakia | 1 | 0 | 0 | 1 | 148 | 0.11 | 550 | 0.41 |
| Damietta – Beirut - Damietta | 0 | 1 | 0 | 1 | 914 | 0.36 | 1304 | 0.52 |
| Alexandria – Beirut - Alexandria | 1 | 0 | 0 | 1 | 533 | 0.39 | 774 | 0.57 |
| Port Said – Beirut – Port Said | 1 | 0 | 0 | 1 | 393 | 0.29 | 525 | 0.39 |
| Limassol – Beirut - Limassol | 1 | 0 | 0 | 1 | 143 | 0.11 | 224 | 0.17 |

**Table 23** Operational features of the optimized network

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 1 | Valencia - Limassol | 1 | 2 | 1969 | 240 |
| 2 | Valencia - Mersin | 2 | 2 | 2014 | 201 |
| 3 | Valencia - Latakia | 1 | 2 | 1938 | 238 |
| 4 | Valencia - Beirut | 2 | 1 | 1838 | 175 |
| 5 | Valencia - Alexandria | 1 | 2 | 2178 | 252 |
| 6 | Valencia - Damietta | 1 | 2 | 2078 | 246 |
| 7 | Valencia - Port Said | 1 | 2 | 2066 | 246 |
| 8 | Barcelona - Limassol | 1 | 2 | 1846 | 233 |
| 9 | Barcelona - Mersin | 1 | 2 | 1891 | 236 |
| 10 | Barcelona - Latakia | 1 | 2 | 1815 | 232 |
| 11 | Barcelona - Beirut | 1 | 1 | 1715 | 210 |
| 12 | Barcelona - Alexandria | 1 | 2 | 2055 | 245 |
| 13 | Barcelona - Damietta | 1 | 2 | 1955 | 239 |
| 14 | Barcelona - Port Said | 1 | 2 | 1943 | 239 |
| 15 | Marseille - Limassol | 1 | 2 | 1760 | 229 |
| 16 | Marseille - Mersin | 5 | 2 | 1805 | 164 |
| 17 | Marseille - Latakia | 1 | 2 | 1729 | 227 |
| 18 | Marseille - Beirut | 5 | 1 | 1629 | 138 |
| 19 | Marseille - Alexandria | 1 | 2 | 1969 | 240 |
| 20 | Marseille - Damietta | 1 | 2 | 1869 | 235 |
| 21 | Marseille - Port Said | 1 | 2 | 1857 | 234 |
| 22 | Sète - Limassol | 1 | 2 | 1822 | 232 |
| 23 | Sète - Mersin | 1 | 2 | 1867 | 234 |
| 24 | Sète - Latakia | 1 | 2 | 1791 | 230 |
| 25 | Sète - Beirut | 1 | 1 | 1691 | 209 |
| 26 | Sète - Alexandria | 1 | 2 | 2031 | 244 |
| 27 | Sète - Damietta | 1 | 2 | 1931 | 238 |
| 28 | Sète - Port Said | 1 | 2 | 1919 | 237 |
| 29 | Genoa - Limassol | 1 | 2 | 1765 | 229 |
| 30 | Genoa - Mersin | 2 | 2 | 1810 | 189 |
| 31 | Genoa - Latakia | 1 | 2 | 1734 | 227 |
| 32 | Genoa - Beirut | 2 | 1 | 1634 | 164 |
| 33 | Genoa - Alexandria | 1 | 2 | 1974 | 240 |
| 34 | Genoa - Damietta | 1 | 2 | 1874 | 235 |
| 35 | Genoa - Port Said | 1 | 2 | 1862 | 234 |
| 36 | Spezia - Limassol | 1 | 2 | 1763 | 229 |
| 37 | Spezia - Mersin | 1 | 2 | 1808 | 231 |
| 38 | Spezia - Latakia | 1 | 2 | 1732 | 227 |
| 39 | Spezia - Beirut | 1 | 1 | 1632 | 205 |
| 40 | Spezia - Alexandria | 1 | 2 | 1972 | 240 |
| 41 | Spezia - Damietta | 1 | 2 | 1872 | 235 |
| 42 | Spezia - Port Said | 1 | 2 | 1860 | 234 |
| 43 | Naples - Limassol | 1 | 2 | 1833 | 233 |

**Table 23** Operational features of the optimized network *(Continued)*

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 44 | Naples - Mersin | 1 | 2 | 1878 | 235 |
| 45 | Naples - Latakia | 1 | 2 | 1802 | 231 |
| 46 | Naples - Beirut | 1 | 1 | 1702 | 209 |
| 47 | Naples - Alexandria | 1 | 2 | 2042 | 244 |
| 48 | Naples - Damietta | 1 | 2 | 1942 | 239 |
| 49 | Naples - Port Said | 1 | 2 | 1930 | 238 |
| 50 | Limassol - Valencia | 1 | 2 | 1969 | 240 |
| 51 | Limassol - Barcelona | 1 | 2 | 1846 | 233 |
| 52 | Limassol - Marseille | 1 | 2 | 1760 | 229 |
| 53 | Limassol - Sète | 1 | 2 | 1822 | 232 |
| 54 | Limassol - Genoa | 1 | 2 | 1765 | 229 |
| 55 | Limassol - Spezia | 1 | 2 | 1763 | 229 |
| 56 | Limassol -Naples | 1 | 2 | 1833 | 233 |
| 57 | Mersin - Valencia | 2 | 2 | 2014 | 201 |
| 58 | Mersin - Barcelona | 1 | 2 | 1891 | 236 |
| 59 | Mersin - Marseille | 5 | 2 | 1805 | 164 |
| 60 | Mersin - Sète | 1 | 2 | 1867 | 234 |
| 61 | Mersin - Genoa | 2 | 2 | 1810 | 189 |
| 62 | Mersin - Spezia | 1 | 2 | 1808 | 231 |
| 63 | Mersin - Naples | 1 | 2 | 1878 | 235 |
| 64 | Latakia - Valencia | 1 | 2 | 1938 | 238 |
| 65 | Latakia - Barcelona | 1 | 2 | 1815 | 232 |
| 66 | Latakia - Marseille | 1 | 2 | 1729 | 227 |
| 67 | Latakia - Sète | 1 | 2 | 1791 | 230 |
| 68 | Latakia - Genoa | 1 | 2 | 1734 | 227 |
| 69 | Latakia - Spezia | 1 | 2 | 1732 | 227 |
| 70 | Latakia - Naples | 1 | 2 | 1802 | 231 |
| 71 | Beirut - Valencia | 2 | 1 | 1838 | 175 |
| 72 | Beirut - Barcelona | 1 | 1 | 1715 | 210 |
| 73 | Beirut - Marseille | 5 | 1 | 1629 | 138 |
| 74 | Beirut - Sète | 1 | 1 | 1691 | 209 |
| 75 | Beirut - Genoa | 2 | 1 | 1634 | 164 |
| 76 | Beirut - Spezia | 1 | 1 | 1632 | 205 |
| 77 | Beirut - Naples | 1 | 1 | 1702 | 209 |
| 78 | Alexandria - Valencia | 1 | 2 | 2178 | 252 |
| 79 | Alexandria - Barcelona | 1 | 2 | 2055 | 245 |
| 80 | Alexandria - Marseille | 1 | 2 | 1969 | 240 |
| 81 | Alexandria - Sète | 1 | 2 | 2031 | 244 |
| 82 | Alexandria - Genoa | 1 | 2 | 1974 | 240 |
| 83 | Alexandria - Spezia | 1 | 2 | 1972 | 240 |
| 84 | Alexandria - Naples | 1 | 2 | 2042 | 244 |
| 85 | Damietta - Valencia | 1 | 2 | 2078 | 246 |
| 86 | Damietta - Barcelona | 1 | 2 | 1955 | 239 |

**Table 23** Operational features of the optimized network *(Continued)*

| ID | O/D Route | Weekly Frequency (travels/week) | N. of stops | O/D distance (NM) | Total Time (h/journey) |
|---|---|---|---|---|---|
| 87 | Damietta - Marseille | 1 | 2 | 1869 | 235 |
| 88 | Damietta - Sète | 1 | 2 | 1931 | 238 |
| 89 | Damietta - Genoa | 1 | 2 | 1874 | 235 |
| 90 | Damietta - Spezia | 1 | 2 | 1872 | 235 |
| 91 | Damietta - Naples | 1 | 2 | 1942 | 239 |
| 92 | Port Said - Valencia | 1 | 2 | 2066 | 246 |
| 93 | Port Said - Barcelona | 1 | 2 | 1943 | 239 |
| 94 | Port Said - Marseille | 1 | 2 | 1857 | 234 |
| 95 | Port Said - Sète | 1 | 2 | 1919 | 237 |
| 96 | Port Said - Genoa | 1 | 2 | 1862 | 234 |
| 97 | Port Said - Spezia | 1 | 2 | 1860 | 234 |
| 98 | Port Said - Naples | 1 | 2 | 1930 | 238 |

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### Authors' contributions
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### Availability of data and materials
The main data generated or analyzed during this study are included in this article and its appendices. The full datasets are available from the corresponding author on reasonable request.

### Competing interests
The authors declare that they have no competing interests.

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