Arab Academy for Science, Technology and Maritime Transport
The International Maritime and Logistics Conference "Marlog 8"
Towards Global Competitiveness in Maritime Industry
"Investing in Ports"
The Trends, The Future
17 – 19 March 2019

Performance assessment of alternative Mediterranean transport networks by combining KPIs and Factor-Cluster Analysis

Keywords: Maritime Transport Networks; Factor-Cluster Analysis; Performance Assessment.

ABSTRACT: Performance assessment is a fundamental tool to successfully monitor and manage logistics and transport systems. In this study, the performance of a newly designed Mediterranean ro-ro transport network will be investigated by providing a valid framework of performance measurement capable of describing its functioning and comparing it with the existing transport option. Performance benchmarking of the two alternative network schemes 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. The methodology is applied to two data samples, each including 72 Mediterranean ro-ro liner services, referring respectively to the existing transport option and to the newly proposed network set-up. Quantitative results mostly confirm the overall better performance of the newly designed network and prove that using a combination of KPIs and factor-cluster analysis to investigate the performances of maritime transport networks can serve as a useful support tool for decision-makers and transport planners when assessing and comparing the performances of alternative transport schemes.

1. INTRODUCTION

Interest in performance assessment of logistics systems has significantly grown in recent years. Performance measurement takes on relevant importance especially when involving the key sectors of the economy, such as the maritime transport sector due to its crucial role in local and global economies. If on the one hand the study of port performances has received a great deal of attention in the literature (Wang and Cullinane, 2015), on the other hand, only a few studies seem to have focused on the performance assessment of maritime transport chains. In this regard, the present study intends to provide a contribution to the literature in the field by presenting a case study focused on the performance evaluation of a Mediterranean transport network. Specifically, the performance of a newly designed Mediterranean ro-ro network developed in the framework of a past Euro-Mediterranean cooperation project are assessed in order to investigate the potential margin of improvement that would result from its entry into operation in place of the existing system.

The Mediterranean basin has always been a desirable market for shipping operators, mainly because of its geographical location at the centre of the major international trade routes. Moreover, not only does it play a key role in international East-West trade but, following the development of MENA (Middle-East and North-Africa) countries, it is gaining increasing importance as a trade area for intra-regional Mediterranean traffic. Note that MENA countries have seen their GDP increase by 4.4% per year during the period 1995-2016, while in the same period the average increase in the EU28 was 1.9% (EUROSTAT statistics). The 2001-2014 traffic data further confirm this growth trend, showing an increase of about 160% in north-south maritime freight flows from the Mediterranean to the Middle- and the Far East- Gulf, and a 92% increase in the opposite direction. Such a seamless flow of goods across the Mediterranean basin clearly requires a well-functioning maritime transport system.

However, despite such growth trends, integration among the countries on the northern and southern shores still appears to be inadequate in terms of stable and sustainable commercial relationships, and of maritime connections able to support such development (Fadda et al., 2017). In line with the above, in recent years an increasing number of studies and projects promoted by several international programs have been focusing on the design of effective solutions to support this development.

In particular, the focus of this paper is on the outcomes of a project funded under the last 2007/2013 ENPI CBC MED - European multilateral Cross-Border Cooperation Programme, the so-called OPTIMED project, whose primary aim was to optimize the trade network between the north-western and the south-eastern shores of the Mediterranean (Fadda et al., 2017). The objectives to be achieved with the OPTIMED project 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 in relation to its ability to attract new demand and improve commercial relations and trade between the countries on the two shores. This project scenario arose from the need to overcome the limitations and weaknesses of the existing maritime ro-ro transport supply: poor reliability and high vulnerability; irregularity of service provision; lengthy journey times (because of a large number of intermediate stops of current lines); low frequencies and uncertain departure and arrival dates. To overcome such limits, the OPTIMED project designed a new topological structure of the shipping network connecting the two Mediterranean shores and proposed an optimized organization of its transport services.

Although it is universally recognized that more efficient transport chains can enhance seamless logistics and promote efficiency, sustainability and interconnectivity of trade networks in the Mediterranean area, quantifying the effectiveness of such initiatives can be very hard, unless they can be checked against a set of performance indicators closely related to what has been implemented (Morales-Fusco et al., 2016). With this idea in mind, the present study aims at analyzing the performance of the newly designed Mediterranean ro-ro transport network by providing a valid framework of efficiency measurement capable of describing its functioning and comparing it with that of the existing transport option. The idea is to systematically compare the performances of the two network schemes, existing and optimized, first on a global level and then considering sub-groups of homogeneous services. The application involves two data samples, including 72 maritime ro-ro services each, referring respectively to the existing transport option and to the newly proposed network set-up. A comparative analysis of the services that make up the two network schemes is performed using a set of operational and sustainability Key Performance Indicators (KPIs) and applying a factor-cluster analysis to produce clusters of services based on the relevant KPIs.

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

2. BACKGROUND LITERATURE

Performance assessment is a fundamental tool to successfully monitor and manage supply chains and the lack of a suitable assessment can represent an important obstacle to an efficient Supply Chain Management - SCM (Lai et al., 2002). The importance of performance assessment in SCM to support decision makers in the management of their supply chains is witnessed by a large number of studies in the field of tools and instruments to supply chain performance measurement. Performance measurement is essential for an efficient planning and monitoring of activities within the decision-making process (Neely et al., 2001) and can help companies to improve the level of service offered. The crucial role played by performance measures for enhancing the efficiency of logistics and business systems has been deeply investigated during the last decades (Beamon, 1999; Shepherd and Günter, 2006) and several methodologies have been suggested for their evaluation and their management (Gunasekaran et al., 2004; Agami et al., 2012). Looking at the literature, it seems possible to classify existing performances measurement studies into three main categories depending on the approach they use (Gunasekaran and Kobu, 2007): perspective-based; process-based; hierarchical-based. The first category is the most diffused as it allows to investigate the performance of a supply chain from a specific product-oriented perspective. Perspective-based studies involve, among the others: food supply chains (Aramyan et al., 2007), high-tech supply chains (Lin and Li, 2010), textile supply chains (Charkha and Jaju, 2014), automotive supply chains (Cuthbertson and Piotrowicz, 2011), intermodal transport chains (Fancello et al., 2018). The second category focuses on the various processes that take place in a supply chain (Parkan and Wang, 2007; Lin and Li, 2010) while the third category differentiates performance measures based on planning levels: strategic, tactical and operational.

As for the methods used to analyse performances, they include, among the others: KPIs (Lauras et al., 2011; Gunasekaran and Kobu, 2007), fuzzy techniques (El-Baz, 2011, Theeranuphattana and Tang, 2008), DEA – Data Envelopment Analysis (Tavana et al., 2015; Wang and Chin, 2010), multicriteria methods (Chan et al., 2013; Galankashi et al.; 2014), balanced scorecard methods (Bhagwat and Sharma, 2007; Varma et al., 2008), and SCOR - Supply Chain Operations Reference models (Liepina and Kirikova, 2011; Ramaa et al., 2009). In particular, KPIs are among the most used models for the measurement of logistics performance (Paddeu, 2016) to understand the extent to which an area or process is working against the objectives that the company is responsible to achieve. 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 have to be taken for their enhancement. KPIs are also among the main tools used to carry out comparative analyses between different logistics chains and allow to understand and monitor the quality of the performances in relation to fixed strategic objectives, such as the quality of the services provided (Morales-Fusco et al., 2016). 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. KPIs 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.

Generally, Supply Chains are considered in their entire product life cycle, starting from material procurements until to final customers (Guide et al., 2003). Woxenius (2012) proposes an interesting classification of chains distinguishing 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 and extends from when it is created until it is dissolved;
- transport chains that focus upon a consignment and extends over movement, physical handling and 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 to customers. It means that whatever the approach is used to analyze the efficiency of supply chains, transport variables need always to be considered as key performances measures of logistics processes (Fancello et al., 2018). Despite the use of performance indicators in the maritime industry appears really widespread, it seems to be limited almost exclusively to the port area (Morales Fusco et al., 2016; Owino et al., 2006; Bichou and Gray, 2004), while, as far as the authors are aware, a very few studies deal with performance assessment of maritime transport chains (Fancello et al., 2018). In this regard, the present study aims to provide a contribution to the literature in the field by presenting a case study focused on the performance evaluation and comparison of two alternative maritime networks. Specifically, following the chosen transport-based approach, this study aims at investigating the operational and sustainability performances of a newly designed Mediterranean ro-ro transport system, by providing a valid framework of efficiency measurement capable of describing its functioning and comparing it with the existing transport option. The idea is to compare the performances of the two network schemes, existing and optimized, by means of a set of relevant KPIs. In this regard, it should be noticed that if on the one side a good use of KPIs requires to compare them in order to be able to determine who is doing best by simply comparing the numbers, on the other side their direct use can yield to wrong performance assessment 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 (Morales-Fusco et al., 2016) and a number of studies have tried to address this drawback. In particular, the study by Tovar and Rodriguez-Déniz (2015) 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 main idea is that service efficiency benchmarking can benefit from the combination of assessment measures with cluster analysis, especially when the sample is heterogeneous. Following this principle, in this application, a comparative analysis of the services that make up the two network schemes is performed using a set of operational and sustainability KPIs and applying a factor-cluster analysis to produce clusters of services based on the relevant KPIs. 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 services into a number of well-defined groups to facilitate a better comparative analysis.

3. PROBLEM SETTING

The area of interest concerns the Mediterranean basin and specifically the system of maritime connections that offer regular ro-ro services between the main ports of its north-western and south-eastern coastal slopes. Countries involved include France, Italy, and Spain for the north-western part and Cyprus, Egypt, Lebanon, Syria, and Turkey for the south-eastern one. As the problem in study concerns the assessment and comparison of the performances of two alternative Mediterranean ro-ro networks, one of which related to the current transport scenario and the other to a project scenario, it was first necessary to rebuild the system of connections that characterize both scenarios.

3.1. The characterization of the existing scenario

Within the context of reference there are a significant number of maritime connections that offer ro-ro services between the main ports of the two coastal slopes of interest: the north-western side, with the ports of Valencia, Sagunto, Castellon, Barcelona, Tarragona, Marseille, Sète, Toulon, Savona, Genoa, La Spezia, Livorno, Civitavecchia, Naples, Salerno and the south-eastern part with the ports of Mersin, Lattakia, Tartous, Beirut, Tripoli, Alexandria, Damietta, Port Said, Limassol.

The reconstruction of the existing network has been realized with the support of the port authorities of interest, which have provided us with the list of ro-ro shipping companies regularly calling at their ports, and then using the information contained in the official websites of the above companies to select and characterize the services of interest in terms of routes, sequence of ports of call, frequency of the service, features of the ships operating the service, and service timetables, when available. This process made it possible to count 16 Mediterranean ro-ro liner services providing at least one service per month, and connecting at least two ports on opposite shores.

Despite the number of existing ro-ro lines may appear "consistent" in size and diffusion, a more in-depth analysis showed that these services lack any distinctive element for which they can actually be considered a proper 'Mediterranean system'. In the majority of cases, the services appear fragmented and not integrated, a large number of routes overlap as they have been conceived singularly and sized only on the basis of shipping companies' fleet availability rather than to meet actual demand and customers needs. In this context, it can be difficult to quantify the attributes and performances of the service offered. In order to simplify the analysis of the supply context, a graph of the liner connections offered by the main shipping companies operating in the corridor of interest was reconstructed using the data and information available. The network graph was reconstructed by identifying a single centroid node (node of generation and attraction of demand) for each area of origin and destination of the goods. Each of these areas can comprise more than one port in the portion of the coastal arch in which maritime services of the corridor of interest are available (Table 1).

Table 1: Network centroids.

	Country	*Centroid*	*Ports belonging to 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	Lattakia	Lattakia, Tartous
	Lebanon	Beirut	Beirut, Tripoli
	Egypt	Alexandria	Alexandria
		Port Said	Port Said
		Damietta	Damietta
	Cyprus	Limassol	Limassol

The final graph of the network in analysis consists of seven 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). Between two centroids there can be as many arches as the number of available services that connect them. This representation is useful for evaluating the minimum routes based on the length of the itinerary identifying the minimum path that uses the same line, excluding the possibility of interchange between different lines that use the same ports. In fact, many of these lines are offered by different companies that have uncoordinated service schedules. Moreover, the calculation of the route using the same line allows to also determine the number of stops to be made before reaching the final destination. The possibility of interchange between lines is considered only when no single line allowing the direct connection between a pair of ports on the two shores is available, and therefore the combination of minimum two lines is necessary to connect them. In this case, in the interchange port the goods need to be first disembarked and then loaded on another ship, with an increase in travel time.

3.2. The characterization of the optimized scenario

This study examines the performance of the ro-ro Mediterranean network designed within the OPTIMED project (ENPI CBC MED Programme 2007-2013). The proposed network has a "two-hub-based" configuration. Two hubs are identified, one serving the western side and one for the eastern part. Each hub serves a set of origin/destination ports according to the hub and spoke distribution paradigm in which all traffic volumes move along spokes through scheduled, reliable and cost competitive shipping services. The location of the two hubs was identified with reference to their barycentric position with respect to the respective coastal arches and the availability of port and backport areas capable of accommodating a platform for handling goods. The proposed structure of the services is completed with the connections between these two hubs and the ports along the coastal arch of reference. The proposed 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 final destination port using the existing short-haul shipping services, systemically reorganized. Figure 1 illustrates the topological structure of the network. It consists of the 14 centroids plus the 2 hubs and allows the same 98 potential O/D connections. The various services result fully characterized concerning optimal service frequencies, capacities and schedules.

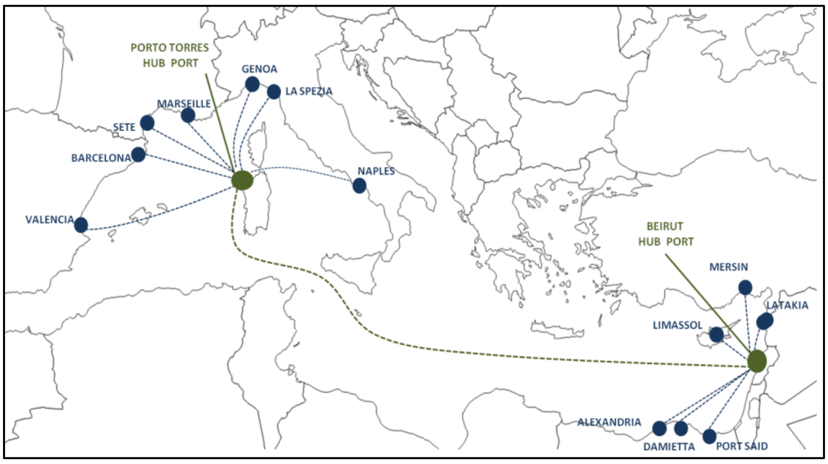

Figure 1: The topological structure of the analyzed project network.

The services characterization was performed using a two-step optimization approach based on two interconnected Mixed Integer Linear Programming Models. With the first model, the optimal services frequencies and capacities were determined, while with the second an optimal feasible timetable for the organization of the above services was identified (Fadda et al., 2017).

4. DATA AND KPI$_S$ DEFINITION

Each O/D service that makes up the two networks (existing and optimized) is characterized through the following variables:

1. Weekly demand. It is expressed in terms of linear meters of freight that weekly move along the service. The weekly demand is the same for the two networks. It has been estimated using the O/D matrices at the port level for the five-year period 2008-2012, thus before the political crisis that has long characterized the Eastern Mediterranean region. Of the 98 potential west-east connections composing the network only 72 have a demand greater than zero and are considered in the application.
2. Service frequency. Number of travels on a given O/D service (moving in the same direction) within a week. For the existing scenario, the frequency indicated by the shipping line for a given route is considered. In the case of interline shipment, it is taken as the lowest. For the project scenario, 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.
3. Distances. Nautical distances from origin to destination ports expressed in nautical miles (nm). For the existing scenario, the distances between each O/D pair are those for the shortest route operated by an existing shipping line (or interlines, should no connection exist operated by a single company). For the project scenario, the distances between each O/D pair are 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.
4. Intermediate stops. Number of intermediate stops from origin to destination port.
5. Sailing times. Navigation times from origin to destination ports expressed in hours (h). For the existing situation, when not available from the service sheet, sailing times are calculated on the basis of the distance travelled assuming an average sailing speed of 18 knots. For the project scenario, they are calculated considering a sailing speed of 21 knots along the inter-hub leg and 18 knots between each hub and the ports of origin or destination.
6. Hotelling times in port. They are expressed in hours (h). For the existing scenario, when not available from the service information sheet, an average hotelling time of 10 hours is considered. When the O/D route requires interline shipment, a hotelling time of 20 hours is considered for each port of call where freight is transferred from one carrier to another. For the project scenario, hotelling times are taken for granted from the project timetables.
7. Manoeuvring times in port. They are expressed in hours (h). For the existing situation, when not available from the service information, an average time of 1 hour is considered for manoeuvring into or out of the port. For the project scenario, manoeuvring times are taken for granted from the project timetables.
8. Emissions. Weekly emissions of CO_2 related to each O/D service. They are expressed in terms of kg of CO_2 and are taken from the study of Serra et al. (2018).

In order to compare the performance of the two networks, a set of KPIs have been identified from the above variables and classified into two main categories: operational and sustainability.

Operational KPIs include:

- WF – Average Weekly Frequency of the services that make up the network (times per week);
- WD – Average Weekly Demand of the services that make up the network (lm per service);
- SD – Average Sailing Distance of the routes that make up the network (nm per travel);

- NS – Average Number of intermediate Stops from origin to destination of the services that make up the network (n. of stops per travel);
- ST - Average Sailing Time of the services that make up the network (h/travel);
- HT – Average Hotelling Time of the services that make up the network (h/travel);
- MT – Average Manoeuvring Time of the services that make up the network (h/travel);
- PT - Average Port Time (h/travel). It includes manoeuvring and hotelling time assigned to each port of call along the route;
- WT - Average Waiting Time (h/travel). It accounts for the availability or not of the service in relation to its frequency. It is calculated as a function of frequency, as the time between successive sailings divided by two as shown by the following equation:

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

  where: 168 are the hours in a week. By so doing it is possible to account for the inconvenience of there not being a regular, frequent and reliable service.

  For the current scenario, the reference frequency has been taken as the frequency indicated by the shipping line for a given route. In the case of interline shipment, it is taken as the lowest. For the project scenario, it has been taken as the minimum frequency between the three legs.
- TT – Average Travel Time (h/travel). It includes Sailing + Port Time;
- TJT – Average Total Journey Time (h/travel), calculated as the sum of Sailing, Port, and Waiting Times;
- RWTJ – Average Ratio between Waiting and Total Journey Time. It is a dimensionless indicator. The lower the value, the more efficient the network.

Sustainability KPIs combine more than one variable and refer to the external sustainability of the network and its services, they include:

- UE – Average Unitary Emission of CO_2 (kg CO_2/lm) per linear meter of transported goods along the services that make up the network. It provides a measure of the environmental efficiency of the network. The lower the value, the more efficient the network.
- UR – Average Utilization of the Route (lm/h). It gives an indication of the performance of the route in terms of linear meters of goods transported per each hour of travel (including waiting times). The greater the value, the more efficient the network.

Moreover, a TJTR – Total Journey Time Regression has been estimated for both network scenarios in the attempt to provide a tool to estimate the Total Journey Time of a given a service (y) based on a multiple regression model with two predictors: services weekly frequency (x_1) and number of intermediate stops along the route (x_2). Table 2 and 3 show the summary of the two multiple linear regression models developed for the two samples of data together with the goodness-of-fit statistics. In both models, the size of the sample is large enough to obtain a good estimate of the strength of the regression model (after eliminating the outliers both samples count 70 observations). The analyzed models explain respectively 92.2% and 85.2% of the variation in the response. An R-sq value like this indicates that the model provides an adequate fit to the data. As for the R-sq(pred), values of 91,8% and 84%, each very near to the related R-sq, indicates that both models can predict quite well the response for new observations. In both models, both predictors have p-values that are less than the significance level of 0.05. Table 4 summarizes mean values and standard deviations assumed by each indicator for the existing layout and the proposed optimized design.

Table 2: Model summary (interception value equal to zero) – TJTR for the existing network.

Term	*Coef*	*SE Coef*	*T-Value*	*P-Value*	*Adj SS*	*Adj MS*	*F-Value*
x_1	-76.70	9.98	-7.69	<0.005	632378	632378	59.11
x_2	117.85	4.72	24.99	<0.005	6681607	6681607	624.53

- Goodness-of-fit statistics: R-sq = 0.922; R-sq(adj) = 0.920; R-sq(pred) = 0.918

Table 3: Model summary – TJTR for the optimized network.

Term	*Coef*	*SE Coef*	*T-Value*	*P-Value*	*Adj SS*	*Adj MS*	*F-Value*
Constant	229.35	4.24	54.11	<0.005	-	-	-
x_1	-42.78	2.88	-14.88	<0.005	6816	6815.93	221.27
x_2	25.58	1.77	14.44	<0.005	6425	6425.29	208.59

- Goodness-of-fit statistics: R-sq = 0.852; R-sq(adj) = 0.848; R-sq(pred) = 0.836

Table 4: Performance Indicators.

KPI	*Unit of measure*	*Existing scenario*		*Optimized scenario*		*Desired trend*	*Best performing scheme*	*Variation (%)*
		Mean	StDev	Mean	StDev			
WF	times/week	1.3	1.2	1.1	0.6	>	Existing	-15.4
WT	h/week	167.5	135.3	80.6	12.6	<	Optimized	-51.9
NS	Stops/travel	3.6	0.7	1.8	0.4	<	Optimized	-50.0
SD	nm/travel	2016.4	561.2	1883.7	126.7	<	Optimized	-6.6
ST	h/travel	106.1	29.5	93.4	7.0	<	Optimized	-12.0
HT	h/travel	56.1	7.4	50.2	4.3	<	Optimized	-10.5
MT	h/travel	9.2	1.5	5.7	0.7	<	Optimized	-38.0
PT	h/travel	65.3	8.9	55.8	5.1	<	Optimized	-14.5
TT	h/travel	171.4	31.3	149.2	10.9	<	Optimized	-13.0
TJT	h/travel	338.9	139.9	229.9	16.4	<	Optimized	-32.2
RWTJ	-	0.41	0.23	0.34	0.04	<	Optimized	-17.1
UR	lm/h	1.1	2.2	1.3	2.4	>	Optimized	+18.2
UE	kgCO$_2$/lm	1781	2673	429.7	155.4	<	Optimized	-75.9
TJTR	h/travel	326.0	133.3	230.9	13.1	<	Optimized	-29.2

The desired trend column uses the major (>) or minor (<) symbols to indicate whether a higher or a lower value is more desirable for the 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 scheme is in the last column. Looking at the data shown in Table 4, the optimized scheme clearly appears to be more performing than the existing scenario. The only exception is represented by the WF indicator, for which the existing scheme seems to show a slightly more favourable value. Anyway, looking at the standard deviation values it emerges that, especially for the existing network, in the majority of cases data are very spread out from the mean indicating a substantial dispersion of data and a significant heterogeneity of the sample. In these cases, as previously mentioned, 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, in this application a comparative analysis of the services that make up the two network schemes is performed applying a factor-cluster analysis to produce clusters of services 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 $\mathrm{Y_1, Y_2, \dots Y_n}$ into a smaller number of latent unrelated factors $\mathrm{F_1, F_2, \dots F_k}$. Each generic factor $\mathrm{F_i (i = 1, \dots k)}$ is a linear function of the original variables and can be written as shown in the equation following:

$$\mathrm{F_i = \delta_{i0} + \delta_{i1}\,Y_1 + \delta_{i2}\,Y_2 + \dots + \delta_{ik}\,Y_n + \mathcal{E}_i} \qquad (2)$$

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

In the proposed application, the number of factors to extract have been preliminary defined by performing the analysis using the principal components method of extraction, without rotation, and then using the percentage of variance to determine the amount of variance explained by the factors. The factor analysis is 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. Clustering is one of the most popular statistical tools with a plethora of applications in many fields, including the maritime transport sector (Fancello et al., 2014). The existing wide variety of clustering techniques can be roughly classified into two main methods: hierarchical and divisive (Abonyi and Feil, 2007). Hierarchical methods start with n classes, representing the n statistical units, and then use iterative processes of merging, 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 by means of 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 we use a hierarchical method for partitioning a set of observations into groups so as maximize both within cluster homogeneity and heterogeneity among clusters. The similarity between two clusters i and j is calculated as shown in the following equation:

$$\mathrm{S_{ij} = \frac{100\,(1 - d_{ij})}{d_{max}}} \qquad (3)$$

where: $\mathrm{S_{ij}}$ is similarity between clusters i and j; $\mathrm{d_{ij}}$ is distance between clusters i and j; $\mathrm{d_{max}}$ is 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 allows to obtain 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. In this application we use as a linkage method the Ward's Method (Ward, 1963), whose merging criterion is based on the analysis of the – within clusters variance.

6. APPLICATION

The described methodology has been applied to the two data samples, referring respectively to the existing transport option and to the newly proposed network set-up, in order to:

- identify, within each sample, well-defined groups of services that can be benchmarked against one another, in order to put into light inefficiencies and/or proper functioning.
- assess on a network level the performance benchmarks between the two samples.

The following paragraphs describe and discuss the application performed for the two data samples.

6.1. Factor-Cluster analysis for the existing network

The analyzed sample is made up of 72 observations corresponding to the 72 shore-to-shore O/D services composing the existing network. Before applying the factor-cluster analysis data have been preprocessed and outliers eliminated using Minitab statistical software.

Table 5 shows unrotated factor loadings and communalities using the 7 following variables/KPIs: weekly demand, weekly frequency, number of intermediate stops, sailing distance, port time, total journey time, and unitary emission of CO_2. The first four factors have eigenvalues higher than 1 and explain 92% of the total variance. The factor analysis is then repeated using the Varimax rotation to extract only the first four factors. Rotated factor loadings and communalities for the first four factors using Varimax rotation are shown in Table 6.

Table 5: Unrotated factor loadings and communalities.

Variable	*Factor1*	*Factor2*	*Factor3*	*Factor4*	*Factor5*	*Factor6*	*Factor7*	*Communality*
WD - Weekly Demand	-0.096	-0.357	-0.830	0.180	0.377	0.010	0.000	1.000
WF - Weekly Frequency	-0.704	-0.632	-0.031	0.051	-0.197	-0.250	0.000	1.000
NS - N. of intermediate Stops	0.746	-0.650	0.116	-0.079	-0.021	0.017	0.000	1.000
SD - Sailing Distance	0.134	-0.035	-0.036	0.964	-0.216	0.064	0.000	1.000
PT - Port Time	0.746	-0.650	0.116	-0.079	-0.021	0.017	0.000	1.000
TJT - Total Journey Time	0.788	0.494	0.035	0.197	0.165	-0.259	0.000	1.000
UE – Unitary Emission of CO_2	-0.415	-0.255	0.717	0.275	0.416	0.011	0.000	1.000
Eigenvalue	2.431	1.682	1.234	1.091	0.428	0.134	0.000	7.000
% Var	0.347	0.240	0.176	0.156	0.061	0.019	0.000	1.000

Table 6: Rotated factor loadings and communalities using Varimax rotation.

Variable	*Factor1*	*Factor2*	*Factor3*	*Factor4*	*Communality*
WD - Weekly Demand	-0.300	-0.048	-0.851	0.204	0.858
WF - Weekly Frequency	-0.945	0.039	-0.041	0.058	0.899
NS - N. of intermediate Stops	0.091	-0.995	-0.031	0.016	0.999
SD - Sailing Distance	0.084	-0.019	-0.034	0.970	0.949
PT - Port Time	0.091	-0.995	-0.031	0.016	0.999
TJT - Total Journey Time	0.913	-0.171	0.026	0.205	0.906
UE – Unitary Emission of CO_2	-0.485	0.020	0.721	0.266	0.827
Eigenvalue	2.075	2.013	1.249	1.099	6.438
% Var	0.297	0.288	0.179	0.157	0.920

Using the rotated factor loadings higher than 0.7, the factors can be interpreted as follows:

- WF (-0.945) and TJT (0.913) have respectively negative and positive loadings on Factor 1, this factor can represent the time component of a service;

- NS (-0.995) and PT (-0.995) have large negative loadings on Factor 2, this factor describes the port component of a service;
- WD (-0.851) and UE (0.721) have respectively large negative loadings on Factor 3, this factor describes the extent to which a service is used;
- SD (0.970) has a large positive loading on Factor 4, it describes length of a service.

In a second step, a cluster analysis has been performed, using as input variables the four factors, to join services that share common characteristics into homogeneous groups. The dendrogram in Figure 2 illustrates the final partition in 5 clusters while Table 7 shows its characteristics. The average performances of the 5 clusters are in Table 8.

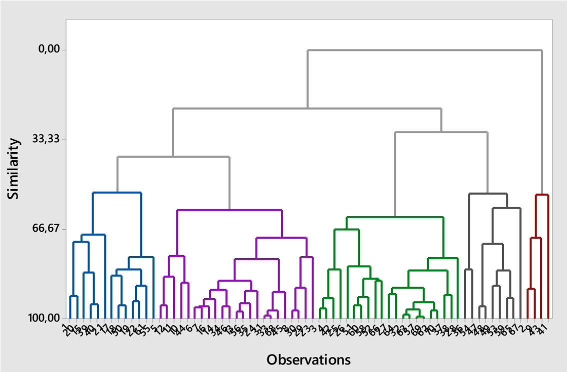

Fig. 2: Dendrogram existing network – Complete linkage **-** Euclidean Distance.

Cluster 1 (13 services): it includes services with the lowest frequencies (WF) and highest waiting times (WT) and sailing distances (SD). These services are characterized by the highest travel times (TT, TJT) and a high number of intermediate stops (NS). These services appear to be among the most inefficient also in terms of sustainability, showing a low utilization rate of the route (UR) and a high value of emissions per unit of freight transported (UE).

Cluster 2 (4 services): it is the smallest cluster. Services belonging to this cluster are characterized by high frequencies (WF), lowest waiting (WT) and total journey times (TJT). These services appear to be also the best performing ones in terms of both utilization rate of the route (UR) and of environmental efficiency (UE).

Cluster 3 and Cluster 4 include together about 2/3 of the services analyzed. Features of the 44 services belonging to these two clusters are very similar to each other and can be considered representative of the sample under investigation. The main element of distinction between the two clusters is represented by the number of intermediate stops (NS) made along the route: the services belonging to cluster 3 are characterized by the lowest number of stops, while those belonging to cluster 4 by the highest.

Cluster 5 (9 observations): services belonging to cluster 4 are among the most efficient from a user’s perspective as they are characterized by high frequencies (WF), low waiting (WT) and total journey times (TJT), low number of intermediate stops (NS). Conversely, if analyzed from a sustainability perspective, these services appear to be the most inefficient ones being characterized by the highest unitary value of CO_2 emission (UE) and by the lowest UR value.

Table 7: Final partition.

	Number of observations	*Within cluster Sum of squares*	*Average distance from centroid*	*Maximum distance from centroid*
Cluster1	13	28.6597	1.41039	2.15616
Cluster2	4	8.7905	1.39737	2.09318
Cluster3	21	25.4171	1.05710	1.77274
Cluster4	23	28.2685	1.03436	1.73960
Cluster5	9	19.1887	1.37573	2.21444

Table 8: Final partition – Existing 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*
WF	times/week	1.3	1.2	0.3	0.1	2.7	0.5	1.1	1.0	1.1	1.1	2.6	0.9
WT	h/week	167.5	135.3	284.3	80.7	31.5	7.0	181.8	141.9	174.4	130.2	37.6	18.8
NS	Stops/travel	3.6	0.7	3.8	0.9	3.7	0.5	2.9	0.2	4.3	0.4	3.2	0.4
SD	nm/travel	2016.4	561.2	2804.6	271.6	2258.3	194.9	1613.5	272.0	1706.0	207.5	2330	563
ST	h/travel	106.1	29.5	147.6	14.3	118.9	10.3	84.9	14.3	89.8	10.9	122.6	29.6
HT	h/travel	56.1	7.4	57.7	9.3	57.5	5.0	49.5	2.2	62.6	4.5	52.2	4.4
MT	h/travel	9.2	1.5	9.5	1.8	9.5	1.0	7.9	0.4	10.5	0.9	8.4	0.8
PT	h/travel	65.3	8.9	67.2	11.1	67.0	6.0	57.4	2.6	73.1	5.4	60.7	5.3
TT	h/travel	171.4	31.3	214.8	15.5	185.9	5.2	142.3	15.2	162.9	14.0	183.3	29.4
TJT	h/travel	338.9	139.9	499.1	85.6	217.4	11.2	324.1	134.5	337.3	131.8	220.9	42.4
RWTJ	-	0.41	0.23	0.56	0.08	0.14	0.02	0.47	0.24	0.44	0.21	0.2	0.05
UR	lm/h	1.1	2.2	0.4	0.5	8.4	4.1	0.9	1.3	0.6	0.5	0.2	0.1
UE	kgCO$_2$/lm	1781	2673	1297	1658	704	1135	1009	1046	1005	880	6938	4302
TJTR	h/travel	326.0	133.3	419.1	114.8	231.0	20.6	260.3	78.0	415.4	110.1	181.6	87.6
N. of observations		70		13		4		21		23		9	

6.2. Factor-Cluster analysis for the optimized network

In order to perform a comparative analysis between the two scenarios (existing and optimized), the same methodology has been applied to the optimized instance. The analyzed sample counts 72 observations corresponding to the same set of O/D pairs that make up the existing scenario. Even in this case, before applying the factor-cluster analysis, data have been pre-processed and outliers eliminated using Minitab statistical software. Table 9 shows unrotated factor loadings and communalities using the principal components method of extraction, without rotation, for the following set of variables/KPIs: weekly demand, weekly frequency, number of intermediate stops, sailing distance, port time, total journey time, and unitary emission of CO$_2$. The first three factors have high eigenvalues and account for most of the total variability in data (86.1%), rotated factor loadings and communalities using Varimax rotation are in Table 10.

Using the rotated factor loadings higher than 0.7, the three factors can be interpreted as follows:

– NS (0.929), SD (0.854), PT (0.923), and TJT (0.735) have large positive loadings on Factor 1, so this factor describes the operating structure of the service;

- WF (-0.945) and WD (-0.776) have large negative loadings on Factor 2, this factor can be representative of the attractiveness of the service;
- UE (-0.935) has a large negative loading on Factor 3, so this factor describes the environmental footprint of the service.

The results of the cluster analysis performed using as input variables the three factors above are graphically illustrated in the dendrogram in Figure 3 featuring 4 main clusters.

Table 9: Unrotated factor loadings and communalities.

Variable	*Factor1*	*Factor2*	*Factor3*	*Factor4*	*Factor5*	*Factor6*	*Factor7*	*Communality*
WD - Weekly Demand	-0.265	-0.770	0.200	0.473	0.272	-0.001	0.000	1.000
WF - Weekly Frequency	-0.210	-0.899	-0.224	-0.195	-0.241	-0.025	0.000	1.000
NS - N. of intermediate Stops	0.883	-0.343	0.044	-0.216	0.162	0.167	0.000	1.000
SD - Sailing Distance	0.820	-0.223	0.130	0.270	-0.434	0.007	0.000	1.000
PT - Port Time	0.873	-0.333	0.068	-0.250	0.195	-0.147	0.000	1.000
TJT - Total Journey Time	0.869	0.389	0.244	0.180	0.020	-0.032	0.000	1.000
UE – Unitary Emission of CO_2	0.497	0.092	-0.826	0.231	0.093	-0.005	0.000	1.000
Eigenvalue	3.331	1.840	0.855	0.529	0.394	0.051	0.000	7.000
% Var	0.476	0.263	0.122	0.076	0.056	0.007	0.000	1.000

Table 10: Rotated factor loadings and communalities using Varimax rotation.

Variable	*Factor1*	*Factor2*	*Factor3*	*Communality*
WD - Weekly Demand	0.046	-0.776	0.314	0.703
WF - Weekly Frequency	0.035	-0.945	-0.098	0.903
NS - N. of intermediate Stops	0.929	-0.067	-0.177	0.899
SD - Sailing Distance	0.854	0.041	-0.085	0.739
PT - Port Time	0.923	-0.057	-0.152	0.878
TJT - Total Journey Time	0.735	0.652	-0.029	0.966
UE – Unitary Emission of CO_2	0.230	0.108	-0.935	0.938
Eigenvalue	3.0418	1.9398	1.0442	6.0259
% Var	0.435	0.277	0.149	0.861

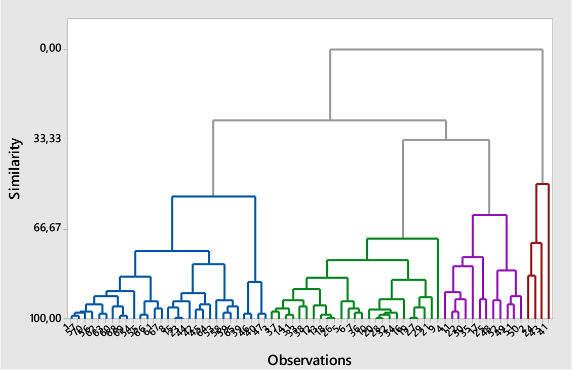

Fig. 3: Dendrogram optimized network – Complete linkage - Euclidean Distance.

General characteristics of each cluster in the final partition are in Table 11. Mean and standard deviation values of KPIs for the 4 clusters are in Table 12.

Table 11: Final partition.

	Number of observations	*Within cluster sum of squares*	*Average distance from centroid*	*Maximum distance from centroid*
Cluster1	29	21.2	0.698	2.135
Cluster2	4	7.32	1.239	1.964
Cluster3	25	6.92	0.443	1.460
Cluster4	12	9.62	0.838	1.416

Table 12: Final partition – Optimized network.

KPI	*Unit of measure*	*Whole network*		*Cluster 1*		*Cluster 2*		*Cluster 3*		*Cluster 4*	
		Mean	*StDev*	*Mean*	*StDev*	*Mean*	*StDev*	*Mean*	*StDev*	*Mean*	*StDev*
WF	times/week	1.1	0.6	1.0	0.0	2.0	0.0	1.0	0.0	1.0	0.0
WT	h/week	80.6	12.6	84.0	0.0	42.0	0.0	84.0	0.0	84.0	0.0
NS	Stops/travel	1.8	0.4	2.0	0.0	2.0	0.0	2.0	0.0	1.6	0.5
SD	nm/travel	1883.7	126.7	1923.6	97.4	1912.0	117.8	1929.0	99.6	1836.2	151.4
ST	h/travel	93.4	7.0	95.6	5.4	94.9	6.5	95.9	5.53	90.7	8.4
HT	h/travel	50.2	4.3	52.0	0.0	52.0	0.0	52.0	0.0	47.6	5.9
MT	h/travel	5.7	0.7	6.0	0.0	6.0	0.0	6.0	0.0	5.3	0.9
PT	h/travel	55.8	5.1	58.0	0.0	58.0	0.0	58.0	0.0	52.9	6.9
TT	h/travel	149.2	10.9	153.6	5.41	152.9	6.5	153.9	5.5	143.6	14.2
TJT	h/travel	229.9	16.4	237.6	5.41	194.9	6.5	237.9	5.5	227.6	14.2
RWTJ	-	0.34	0.04	0.35	0.01	0.22	0.01	0.35	0.01	0.37	0.02
UR	lm/h	1.3	2.4	0.5	0.5	6.1	5.5	1.1	1.2	1.3	1.4
UE	$kgCO_2/lm$	429.7	155.4	575.5	119.0	386.7	106.6	323.7	46.0	316.3	75.2
TJTR	h/travel	230.9	13.1	237.7	0.0	195.0	0.0	237.7	0.0	212.2	0.0
N. of observations		70		29		4		25		12	

At a glance, the dendrogram in Figure 3 features two high-level groups that clearly correspond to services with a weekly frequency (clusters 1, 3 and 4, for a total of 66 observations) and services with a double weekly frequency (cluster 2, including only 4 observations).

Services belonging to cluster 2 are characterized by the lowest waiting (WT) and total journey times (TJT), and by the highest utilization rate of the route (UR). Compared to services of clusters 1 and 3, services belonging to cluster 4 appear more efficient both from a user's and sustainability point of view. In fact, these services are characterized by both lower journey times (TJT) and number of intermediate stops (NS). As for the latter aspect, it is strongly due to the presence in the cluster of a number of services for which the origin (or destination) port coincides with the hub of reference. As regards the services belonging to clusters 1 and 3, they appear to be very similar in terms of frequency (WF), waiting time (WT, RWTJ), number of stops (NS), travel (TT, TJT) and port times (PT). The main distinctive element between the two clusters is represented by the sustainability KPIs, with cluster 3 that appears more performing than cluster 1 in terms of both utilization rate of the route (UR) and of environmental efficiency (UE).

6.3. Results and Discussion

The clustering of the sample representing the optimized network yields to four clusters significantly more homogeneous than those characterizing the existing network. This is not surprising as it directly depends on the layout of the new network itself. In fact, the double hub and spoke structure causes that the main portion of each O/D connection, the so-called inter-hub leg, is shared among all the services that make up the newly designed network. As for the analyzed KPIs, the new network appears to be on overall better performing than the existing scenario. Nevertheless, looking at the data, a number of considerations are necessary to better understand the results:

- if for a number of operational KPIs (NS, MT, UE) the new network option always appears to be more performing when compared with the existing scenario, on the other hand, a number of KPIs seem to slightly worsen when the new network scheme is considered. That is the case of WF, WT, and RWTJ for which clusters 2 and 5 appear to be more performing than all the clusters characterizing the optimized configuration;
- from an environmental perspective the new network appears to be clearly more efficient than the existing scheme: all clusters of the optimized sample show UE values that are significantly lower than those of the existing sample, thus confirming the potential effectiveness of the newly designed network in reducing the emissions of Mediterranean transport chains;
- looking at the utilization rate of the services, the UR indicator appears to be the most heterogeneous variable within both samples. In fact, even if the optimized sample appears to be on average better performing than the existing one, when single clusters are analyzed it emerges that there is a numerous group of observations (cluster 1 – optimized network) for which the UR indicator assumes a lower and less desirable value than some clusters in the existing network (clusters 2, 3, and 4);
- the TJTR perfectly fits TJT values for each cluster of the optimized sample, thus confirming the goodness of the regression model to provide a good estimate of the total journey time for all the clusters. As for the existing sample, the most significant differences between the two indicators are in clusters 1, 3, and 4.

What clearly emerges from the performed application is that the resulting clusters are characterized by different dimensions, and hence the interpretation of results may not be straightforward. Each cluster has to be analyzed carefully, since its classification might not be explained by a single variable, but only by a combination of them, and might vary depending on the perspective considered. In this regard, it should be noted that in the performed application it is assumed that all variables have equal weight and thus contribute equally to the final cluster structure. However, as weights can heavily influence the determination of the clusters (Gnanadesikan et al., 1995), 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.

7. CONCLUSIONS

The goal of the research presented was to evaluate the performance of a newly designed Mediterranean ro-ro transport system by providing a valid framework of efficiency measurement capable of describing its functioning and comparing it with the existing transport option. To this end, a comparative analysis of the services that make up the two network schemes was performed using a set of quantitative KPIs and applying a factor-cluster analysis to produce homogeneous clusters of services based on the relevant KPIs, while accounting for sample heterogeneity. The methodology was applied to two data samples, including 72 maritime services each, referring respectively to the existing transport option and to the newly proposed network set-up. The applied methodology allowed to:

– assess on a network level the performance benchmarks between the two samples, showing the better overall performance of the newly designed network compared to the existing scenario;
– identify, within each sample, well-defined groups of services that can be benchmarked against one another, in order to put into light inefficiencies and/or proper functioning within the analyzed network. The clustering of the optimized network yielded to four clusters of services that are significantly more homogeneous in terms of performance than those characterizing the existing network. This was not surprising and easily justifiable in the light of the double hub-and-spoke layout of the new network, which causes that the main portion of each O/D connection, the so-called inter-hub leg, is shared among all the services that make up the network. The performed analysis not only allowed to identify groups of services that are likely to improve their performance with the implementation of the new transport scheme, but it also put into light the presence of groups of services for which some indicator seems to slightly worsen when the new network set-up is considered. Because of the different 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 support the idea that combining KPIs and factor-cluster analysis can serve as a useful analytical support tool when assessing and comparing the performance of alternative transport schemes. It allows for a more detailed analysis and identification of performance benchmarks and it can provide decision-makers with quantitative knowledge elements that can help them in setting sharper targets for improvement of transport services as a function of the detected needs. However, because of the different dimensions that typically characterize clustering, the analysis of results may sometimes not be straightforward and may raise some interpretative doubts. 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.

REFERENCES

Abonyi, J. and Feil, B., 2007. Cluster analysis for data mining and system identification. Springer Science & Business Media.

Agami, N., Saleh, M. and Rasmy, M., 2012. Supply chain performance measurement approaches: Review and classification, Journal of Organizational Management Studies, 1-20.

Aramyan, L.H., Oude Lansink, A.G., Van Der Vorst, J.G., Van Kooten, O., 2007. Performance measurement in agri-food supply chains: a case study. SCM: An International Journal 12.4, 304–315.

Bhagwat, R., Sharma, M.K., 2007. Performance measurement of SCM: a balanced scorecard approach. Comp. Ind. Eng. 53.1,43–62.

Beamon, B.M., 1999. Measuring supply chain performance. Int. Journal of Operations & Production Manag., 19.3,275–292.

Bichou, K. and Gray, R., 2004. A logistics and supply chain management approach to port performance measurement. Maritime Policy & Management, 31(1), pp.47-67.

Chan, T., Nayak, A., Raj, R., Chong, A. Y. L., Manoj, T., 2013. An innovative supply chain performance measurement system incorporating research and development (R&D) and marketing policy. Comput. Ind. Eng. 69, 64–70.

Charkha, P. G., Jaju, S. B., 2014. Designing innovative framework for supply chain performance measurement in textile industry. Int. J. Logist. Syst. Manage. 18.2, 216–230.

Cuthbertson, R., Piotrowicz, W., 2011. Performance measurement systems in supply chains: a framework for contextual analysis. Int. J. Product. Perform. Manage. 60.6, 583–602.

El-Baz, M. A., 2011. Fuzzy performance measurement of a supply chain in manufacturing companies. Expert Syst. Appl. 38.6, 6681–6688.

Fadda P., Fancello G., Pani C., Serra P. (2017). The OPTIMED project: A new Mediterranean hub-based ro-ro network. Transport Infrastructure and Systems: Proceedings of the AIIT International Congress on Transport Infrastructure and Systems. ISBN 978 1138030091; 2017.

Fancello, G., Pani, C., Serra, P., & Fadda, P. (2014). Port cooperation policies in the Mediterranean Basin: An experimental approach using cluster analysis. Transportation Research Procedia, 3, 700-709.

Fancello, G., Schintu, A. and Serra, P., 2018. An experimental analysis of Mediterranean supply chains through the use of cost KPIs. Transportation Research Procedia, 30, pp.137-146.

Galankashi, M. R., Memari, A., Anjomshoae, A., Ma'aram, A., Helmi, S. A., 2014. Selection of supply chain performance measurement frameworks in electrical supply chains. Int. J. Ind. Eng. Manage. 3.5, 131–137.

Gnanadesikan, R., Kettenring, J.R. and Tsao, S.L., 1995. Weighting and selection of variables for cluster analysis. Journal of Classification, 12(1), pp.113-136.

Guide, V. D. R., Jayaraman, V., Linton, J. D., 2003. Building contingency planning for closed-loop supply chains with product recovery. J. Oper. Manage. 21.3, 259–279.

Gunasekaran, A., Patelb, C., Mc Gaughey, R. E., 2004. A framework for supply chain performance measurement. Int. J. Prod. Econ. 87, 333–347.

Gunasekaran, A., Kobu, B., 2007. Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. Int. Journal of production research 45.12, 2819-2840.

Lauras, M., Lamothe, J., Pingaud, H., 2011. A business process oriented method to design supply chain performance measurement systems. Int. J. Bus. Perform. Manage. 12.4, 354–376.

Liepina, L., Kirikova, M., 2011. SCOR based ISS requirements identification, Business Information Systems Workshops, Springer, Berlin Heidelberg, 232– 243.

Lin, L. C., Li, T. S., 2010. An integrated framework for SC performance measurement using six-sigma metrics. Softw. Qual. J. 18.3, 387–406.

Morales-Fusco, P., Saurí, S., Lekka, A. M., Karousos, I., 2016. Assessing customs performance in Mediterranean ports. KPI selection and best practices identification as part of the MEDNET project. Transp. Res. Procedia. 18. 201, 374 – 383.

Neely, A., Adams, C. and Crowe, P., 2001. The Performance Prism in Practice. Journal of Measuring Business Excellence, 5(2), 6-13.

Owino, E.L., Wang, T.F. and Pasukeviciute, I., 2006, July. Performance measurement in EU container terminal industry: an empirical investigation. Proceedings of International Association of Marine Economists Conference (pp. 12-14).

Paddeu, D., 2016. How do you evaluate logistics and supply chain performance? A review of the main methods and indicators. European Transport/Trasporti europei, 61 (4). pp. 1-16. ISSN 1825-3997.

Parkan, C., Wang, J., 2007. Gauging the performance of a supply chain, Int. J. Product. Qual. Management 2.2, 141–176.

Ramaa, A., Rangaswamy, T.M., Subramanya, K.N., 2009. A review of literature on performance measurement of supply chain network, Emerging Trends in Engineering and Technology (ICETET), 2009 2nd Intern.Conf., IEEE 802–807.

Serra, P., Fadda, P., Fancello, G., 2018. Investigating the potential mitigating role of network design measures for reducing the environmental impact of maritime chains: the Mediterranean case. Conference proceedings of the Siga2 Conference - The Port and Maritime Sector: Key Developments and Challenges. Antwerp, May, 2018.

Shepherd, C. and Günter H., 2006. Measuring SC performance: current research and future directions. International Journal of Productivity and Performance Management, 55.3/4, 242–258.

Tavana, M., Kaviani, M. A., Di Caprio, D., Rahpeyma, B., 2015. A two-stage data envelopment analysis model for measuring performance in three-level supply chains, Measurement 78, 322–333.

Theeranuphattana, A., Tang, J. C. S., 2008. A conceptual model of performance measurement for supply chains alternative considerations. J. Manuf. Technol. Manage. 19.1, 125–148.

Tovar, B. and Rodríguez-Déniz, H., 2015. Classifying ports for efficiency benchmarking: A review and a frontier-based clustering approach. Transport Reviews, 35(3), pp.378-400.

Varma, S., Wadhwa, S., Deshmukh, S. G, 2008. Evaluating petroleum supply chain performance: application of analytical hierarchy process to balanced scorecard. Asia Pac. J. Mark. Logist. 20.3, 343–356.

Wang, T. and Cullinane, K., 2015. The efficiency of European container terminals and implications for supply chain management. In Port management (pp. 253-272). Palgrave Macmillan, London.

Wang, Y. M., Chin, K. S., 2010. Some alternative DEA models for two-stage process. Expert Syst. Appl. 37.12, 8799–8808.

Woxenius, J., 2012. Directness as a key performance indicator for freight transport chains. Research in transportation economics, 36(1), pp.63-72.