Maritime Economics & Logistics (2020) 22:218–238
https://doi.org/10.1057/s41278-019-00144-4

ORIGINAL ARTICLE

A fuzzy AHP classification of container terminals

B. Adenso-Díaz[1] · N. García Álvarez[2] · J. A. Lago Alba[2]

Published online: 29 November 2019

Abstract
This article proposes a methodology for the classification of container terminals aiming to identify groups of terminals with similar management characteristics. Based on physical and terminal operations data and the subjective judgment of experts in port management, we show that it is possible to identify the main factors affecting the management of container terminals and produce a classification of these facilities, allowing determination of their strengths, weaknesses, and place within their port system and in relation to their competitors. The methodology is based on the fuzzy analytic hierarchy process (F-AHP). As a case study to validate the procedure, the Spanish port system is selected, and the results are compared with other classification methods not including subjectivity criteria, namely cluster analysis. By assigning more weight to expert judgments, results differ and become more trustworthy, since expert knowledge can go beyond simple variables such as TEUs moved or number of available cranes.

Keywords Container terminals · Port management · Fuzzy AHP · Clustering · Port classification

1 Introduction

Maritime transport currently represents more than 90% of the volume of international trade, involving the world's maritime routes and multimodal exchange networks composed among others by ports and their host cities (Ducruet et al. 2018).

Although throughout history developing countries have been the main suppliers of raw materials to developed countries, since 2014 an important change of trend has been detected: for the first time the goods unloaded in developing countries have surpassed the goods loaded, which implies the importance of world maritime trade,

✉ B. Adenso-Díaz
adenso@uniovi.es

1 Engineering School, University of Oviedo, Campus Gijón, 33204 Gijón, Spain

2 Port Authority of Gijon, Gijón, Spain

as well as the importance of all kinds of countries in global value chains (UNCTAD 2018).

Since its first documented appearance in 1956, the container has been a technological revolution of continuous innovation to minimize costs and delivery times. Forklifts have been used since the 1920s and utilized to a large extent in the 1950s to move pallets from the warehouse to the vessel side (Levinson 2016). From that moment on, the use of the container has undergone processes of continuous improvement and technological innovations that have meant a revolution in the way goods are moved on a global scale.

It is almost impossible to quantify how much the container contributes to the global economy. It is estimated that 752.2 million TEUs were handled at container ports worldwide in 2017. For the management of such an immense number of boxes, the adoption of IT developments and the large-scale application of automation processes have become mandatory. Also, because of the growing demands of the sector, the capacity of container terminals has increased considerably in recent years and research efforts have focused on automating processes as much as possible.

Even though container terminals differ considerably in size, function, and geometrical layout, they all share the need to offer their customers competitive conditions, involving a reduction in the length of stay of ships in port and the completion of port operations in the shortest possible time at the lowest possible cost.

In this global context, a well-developed transport infrastructure network is a prerequisite for access to economic activities and services worldwide, while effective modes of transport allow corporations to meet their objectives (Torres and Rendón 2013). These modes of transport usually end at container terminals, which are "logistics points included in a global chain that can provide added value to their users as elements of wider systems of circulation" (Rodrigue and Notteboom 2009). Therefore, a container terminal is a port facility that constitutes the interface between the different modes of transport, enabling transfer of cargo between ships and trucks, or railroads, pipelines, etc. (Estrada Llaquet 2007).

Considering this wide diversity of factors and the high competitiveness of the sector, it becomes interesting to establish a classification system that takes into account the most important variables defining container terminals, thus providing an understanding of the different types of such facilities from the viewpoint of management requirements. This could help to better understand the challenges facing different types of terminals, as well as the most suitable way to manage each one.

1.1 Managing container terminals

An integrated container terminal is a very complex system including official agents, inspection agencies (foreign and veterinary health, phytosanitary inspection, and foreign trade inspection services) as well as private agents (moorers, shipowners, operators, tugboats, stevedores, customs agents, freight forwarders, transport companies, etc.). Dealing with all these agents is part of the daily management of any container terminal. A terminal's main mission is to provide the means and organization necessary for the exchange of containers between different modes of transport, under the best conditions of speed, efficiency, safety, respect for the environment, and economy (Monfort et al. 2001).

Container terminals differ considerably in size, function, and geometrical layout, but they are principally made up of four subsystems: ship to shore, transfer, storage, and delivery/reception (Sauri and Martin 2011). It is apparent that differences in the size, infrastructure, or arrangements of different container terminals may result in different management practices which are worth understanding further. It is highly probable for instance that a small, specialized, reefer container terminal will require a different management approach than a large transhipment terminal located on major trade routes.

This paper aims to determine the information necessary to enable a categorization of container terminals and thus reveal the management characteristics they share or those that make each one unique. The intention is to offer a methodology that allows one to classify and group container terminals according to the factors or variables that affect their management, or make such management especially singular. We systematize the subjective criteria of port managers and apply mathematical models that allow us to weight the physical and operational characteristics of terminals, thus enabling their classification according to how these variables affect their efficient management.

2 Relevant literature

In scientific literature, there is no agreed method for the classification of container terminals. Not even a consensual conventional terminology exists for such a classification. The existing literature on the functions of ports and their organization is very extensive, but although there is a large number of proposals for the classification of ports, there is no single framework or even an accepted terminology (Bichou and Gray 2005).

Multiple studies on port economics, performance, governance, and management have appeared in scientific literature in the past few years (Pallis et al. 2010). Vieira et al. (2014) identified a total of 63 main articles related to these subjects in the period 2004–2013, focusing on various aspects of port management and concluding that the relationship between governance models and port performance does not seem to have been sufficiently studied. Neither governance nor performance describes the aspects that differentiate the management of port terminals, in a way that contributes to achieving excellence in the management of container terminals (Vieira et al. 2014).

However, other aspects such as efficiency in the container industry have been widely studied using various approaches, such as data envelopment analysis (DEA) or stochastic frontier analysis (SFA) (Lampe and Hilgers 2015; Lu and Wang 2017). The strong commercial competition in the sector has driven research efforts to improve the competitiveness of port terminals (see, for instance, the early papers of Rios and Maçada 2006; Wu et al. 2010).

There are numerous cases of the use of DEA for benchmarking container terminals using public data, but certain disadvantages have also been detected in the use of this method, such as the low reliability of the source data, or the actual lack of (predominantly port labor) data, given the fact that much of this information might be considered confidential and therefore impossible to access (Cullinane et al. 2006). The above authors also conclude that the information obtained can be used to assist governments and authorities that manage container ports in making management decisions at the port authority or terminal operator level. In addition, studies have tended to mix ports with container terminals and fail to take into account the differences between very large terminals and specialized terminals (De Koster et al. 2009). The most likely explanation for this would be the lack of a systematic method to classify terminals beyond the differences in magnitude of the physical and operational variables of the terminals themselves.

Another frequently used methodology, according to reviews and systematic analysis of the state of the art, is the analytic hierarchy process (AHP) and its evolution, fuzzy AHP (F-AHP), both used in 25.84% of the 89 papers reviewed for the whole transportation system, with 5 of the papers reviewed focusing on the shipping industry (Mardani et al. 2016).

The AHP is also widely used in the port environment, although not directly to categorize terminals as in our case, but to assist decision-making in transhipment port selection (Lirn et al. 2004). Ugboma et al. (2006) highlight that "AHP is able to assist port managers in obtaining a detailed understanding of the criteria that shippers deem important in port selection decisions and the strength of their preferences."

Among multicriteria decision-making (MCDM) techniques, F-AHP has been used in a vast number of applications, actually being the second most widely used methodology, behind AHP (Kubler et al. 2016). Since human decision-making involves fuzziness and vagueness, F-AHP has proven to have great potential for resolution of MCDM problems, as can be observed in the 190 scientific articles published in international journals between 2004 and 2016 (Kubler et al. 2016).

Multiple examples of the use of AHP for decision-making in the port environment can be found, such as the analysis of the competitiveness of Chinese container ports (Song and Yeo 2004) or the use of F-AHP to express the opinions from experts in the pairwise comparison stage (Ung et al. 2006). Other papers have focused on transhipment port selection from a carrier's perspective (Lirn et al. 2003). Seaport competitiveness models (Da Cruz et al. 2013) or the location of international distribution centers in the global logistics of multinational corporations (Chou and Yu 2013) are just some of the multiple applications of AHP and F-AHP to assist decision-making within the port environment.

The large number of examples in scientific literature on port efficiency contrasts with the low presence of port clustering and the lack of robust methodologies for the classification of seaports (Tovar and Rodríguez-Déniz 2015).

The categorization of terminals is important to understand the possible ways of collaboration between them, since the size of terminals does not seem to have a significant impact on the most important factors for collaboration and coopetition (Song et al. 2015). Although the F-AHP has been designed to aid decision-making, in this case it will be used to categorize terminals, by considering the variables that, according to industry experts, are the most appropriate for classifying them in regard to their management practices.

3 Proposed methodology

The analytic hierarchy process (AHP) is a general theory of measurement used to draw conclusions from discrete and continuous pair comparisons (Saaty 1987). These comparisons can be based on actual measurements or on a fundamental scale that can reflect preferences. To perform the comparisons, a hierarchical structure must be defined, complex enough to capture the situation yet small enough to be sensitive to changes. This process has been extensively studied and standardized in seven basic steps (Vaidya and Kumar 2006), including the statement of the problem, definition of the objective, identification of the influencing criteria, definition of the hierarchy, pairwise comparison of elements, calculation of the weights of each criteria and alternatives, and the consistency of the judgments, and if consistency is nor guaranteed, repetition of the process (Guy and Urli 2006).

To capture the fuzzy nature of human reasoning, the AHP was extended by creating a fuzzy version to choose among a number of alternatives expressing the opinion of a decision-maker on the importance of a pair of factors, using triangular fuzzy numbers instead of crisp numbers (Van Laarhoven and Pedrycz 1983). Fuzzy versions of consistency testing and weighting calculations have been defined for triangular fuzzy numbers, mimicking the logic of the crisp version (Chang 1996). The F-AHP method has found multiple applications in decision-making, both in cases of a single decision-maker as well as in cases where the decision must be made by consensus by a group of decision-makers. In our case, the aim consists of determining which weights correspond to each variable in the hierarchy to achieve a meaningful categorization of port terminal management in a given context.

The relevance of using fuzzy numbers in this process comes from the fact that, when experts are making pairwise comparisons, it becomes very difficult to provide specific answers. Individuals' feelings and opinions are not devoid of subjectivity. If asked whether automation or equipment is more important for management categorization, for example, it is very unlikely that an expert would state that one is exactly 20% more important than the other. It would be more accurate for them to define a range that would indicate the importance of one component over the other. To reflect this subjectivity, fuzzy numbers and the logic of F-AHP methodology results are more convenient. In addition, to ensure that the responses are consistent, use is made of mechanisms to check consistency and reach consensus on the opinion of all the experts.

As a prerequisite for applying this methodology, some information and resources must be available. First, it is important to have access to consistent information from all terminals to be included in a study. Often, this is easier said than done due to confidentiality concerns in today's competitive environment of the port sector. Second, it is necessary to ensure access to experts of proven prestige, able to provide well-founded and consistent answers during the surveying process.

3.1 Logic of the procedure

Based on the principles of the F-AHP methodology, the most relevant factors in the management of container terminals must be initially identified, and a hierarchical structure developed considering these factors. It is very important to design a survey that is easy to understand by the experts, allowing the introduction of intervals (fuzzy numbers) representing the importance of each pair of factors. Once the experts' answers have been processed, the weight of each variable in the container terminal management hierarchy is determined.

Although the classic F-AHP method would end at this point, the information about the influential weight of each variable is used to establish a ranking of the container terminals by using the data available for each of the surveyed ports. Thus:

3.1.1 Step 1: identification of the relevant variables that best define the categorization of a container terminal in terms of its management

It is necessary to identify variables that are proven to have an impact on the categorization. These variables must be numerical and available for all terminals. A review of extant literature identifies such variables as total terminal surface, linear meters of berth, terminal draft, number of reefer connections, yard equipment, TEUs moved, etc.

3.1.2 Step 2: expert verification of these variables and elimination of correlated ones

With the twofold aim of minimizing the number of variables that can best categorize port terminals and eliminating the variables that have a residual weight, a survey among a limited number of well-trained experts could endorse the correct selection of the variables.

3.1.3 Step 3: grouping the variables into a hierarchical structure

Following the F-AHP methodology, a hierarchical structure must be designed to group the variables, preparing the survey for the evaluation.

3.1.4 Step 4: survey delivery

To obtain consistent data, it is very important to correctly explain to the experts the motivation and the importance of adequately answering each question, to avoid receiving spurious information. The experts will have to perform the pairwise comparisons of the factors identified at each level of the hierarchy, using triangular numbers.

3.1.5 Step 5: processing the results

The survey results received are processed according to the F-AHP methodology, and the weights of each factor calculated.

3.1.6 Step 6: transfer of the weighting of the variables to the data of each terminal and calculation of the final results

Once the weight of each variable is obtained, it is necessary to calculate the weighted sum score for each terminal based on the available data for the facility. This requires the standardization of the input data by setting a fixed maximum value for each variable according to the input data. These final scores are used in our categorization of container terminals.

Regarding the last step (global score calculation for each terminal), further clarification might be needed. For each of the final variables, each port will receive a gross score from 0 to 10, depending on the facilities and characteristics of that terminal. For instance, 10 points could be assigned to a specific terminal if it has more than four railway tracks; 6 points for one to four railway tracks, and 0 points if it lacks this service. These scores are weighted using the weights obtained in the previous fuzzy procedure to obtain a final score for the terminal.

4 Case study: the Spanish port system

To validate the methodology, we choose the Spanish port system, consisting of 28 port authorities managing 46 ports of general interest, moving—in 2017—nearly 16 million TEUs (Table 1). Although the first Spanish port to appear in the Lloyds List (2018) "most important ports in 2017" is Valencia (29th place), the Spanish case could be interesting to consider, given the different sizes and management models found in this country. To focus this study on "relevant" container terminals, terminals with throughput of less than 60,000 TEUs per annum (11 ports) are excluded.

4.1 Application of the Classification Method

4.1.1 Step 1

Our initial set of variables was selected from sets previously used in similar studies, such as Orive et al. (2016), who categorized Spanish ports using cluster analysis; Sharma and Yu (2009), who worked in benchmarking of container terminals; or Cabral and Sousa Ramos (2014), who studied the competitiveness of container ports in Brazil. Another source used to define the initial set of variables was the "Permanent Observatory of the Port Services Market" report, published by the Spanish

Table 1 Thousands of TEUs moved in 2017 by Spanish port authorities (Puertos del Estado 2017)

Port authority	Container terminals	TEU (× 1000)
VALENCIA	TCV, MSC, NOATUM	4832
BAHÍA DE ALGECIRAS	TTI, APM	4380
BARCELONA	BEST, TCB, PORT NOU	3006
LAS PALMAS	LA LUZ, OPCSA	1174
BILBAO	NOATUM	604
SANTA CRUZ DE TENERIFE	CAPSA, TCT	466
CASTELLÓN	TPC	240
VIGO	TERMAVI	183
ALICANTE	TMS	164
SEVILLA	TCON	105
MARÍN Y RÍA DE PONTEVEDRA	TERMARIN	88
MÁLAGA	NOATUM	86
BAHÍA DE CÁDIZ	TTI	82
GIJÓN	TCG	76
TARRAGONA	DP WORLD	62
BALEARES	Diversified in five different small ports	120
CARTAGENA	Variable data	84
HUELVA		58
MELILLA		36
VILAGARCÍA		34
CEUTA		16
SANTANDER		6
ALMERÍA		6
MOTRIL		1
FERROL-SAN CIBRAO		0.45
PASAIA		0
A CORUÑA		0
AVILÉS		0

authorities (Puertos del Estado 2018). Other more infrequently used variables in this type of studies were discarded (for instance, "ice production," "liquid bulk traffic," "number of passengers," or "length of fishing docks").

Based on this literature review, an initial selection of 18 variables (Table 2) was made. Note that data corresponding to the Spanish ports in relation to these variables are not always available for public viewing, and specific figures had to be gathered by direct requests to port managers.

4.1.2 Step 2

A previous analysis was carried out, calling upon five local experts (directors of Spanish port authorities) to validate the suitability of the initial variable selection.

Table 2 Preselected and final variables considered

Preselected variables from literature		Variables added by experts (F-AHP)
1. Total terminal area	2. Linear meters of berth	14. Access gates automatization
3. Number of gates	4. Average TEUs	15. Crane automatization
5. Panamax	6. Post-Panamax	16. Yard equipment automatization
7. Super Post-Panamax	8. Reach stacker	17. Railway tracks
9. Front lifts/fork lifts	10. Tractor heads	18. Import/export % (transhipment)
11. Straddle carrier	12. Chassis/platforms	
13. RTGs	(Feeder cranes)	
(Automobile cranes)	(Number of reefer connections)	
(Storage area)	(Terminal draft)	

Variables in parentheses were disregarded by the team of experts

Considering the feedback from these pretests, we decided to eliminate five variables (Table 2), in some cases because it was considered that they represented nearly the same concept (for instance "Total terminal area" and "Storage area"). For another variable ("Number of reefer connections"), it was considered that, although this may be an indicator of the type of traffic handled at the terminal, it is not significant for our study as the installation of connections is relatively quick when needed for new traffic.

Five new variables were added by the experts, namely gates, cranes, and yard equipment automatization, number of railway tracks, and import/export percentage. Although these variables were not included in earlier literature, the experts agreed that these aspects are key to determining differences for the categorization of the Spanish port system. As mentioned above, this will help to identify the variables for use in this research, that is, the relevant factors affecting the classification of container terminals and thus also their management, given their specific characteristics.

4.1.3 Step 3

With the feedback of the experts, the final variables were grouped according to the hierarchical structure shown in Fig. 1, with the three main categories being "Automation," "Operations and Installations," and "Equipment."

4.1.4 Step 4

To design the survey, the previously mentioned hierarchy was described, and the process of the pairwise comparisons explained to the experts. The final variables were grouped into eight categories and subcategories; thus, the experts had to evaluate nine matrices to compare the importance of the variables that were part of these groupings.

The survey was distributed and answered by 14 experts, consisting of operations directors, port directors, port infrastructure managers, and researchers within the port sector. Aiming for a heterogeneous profile in the answers, the

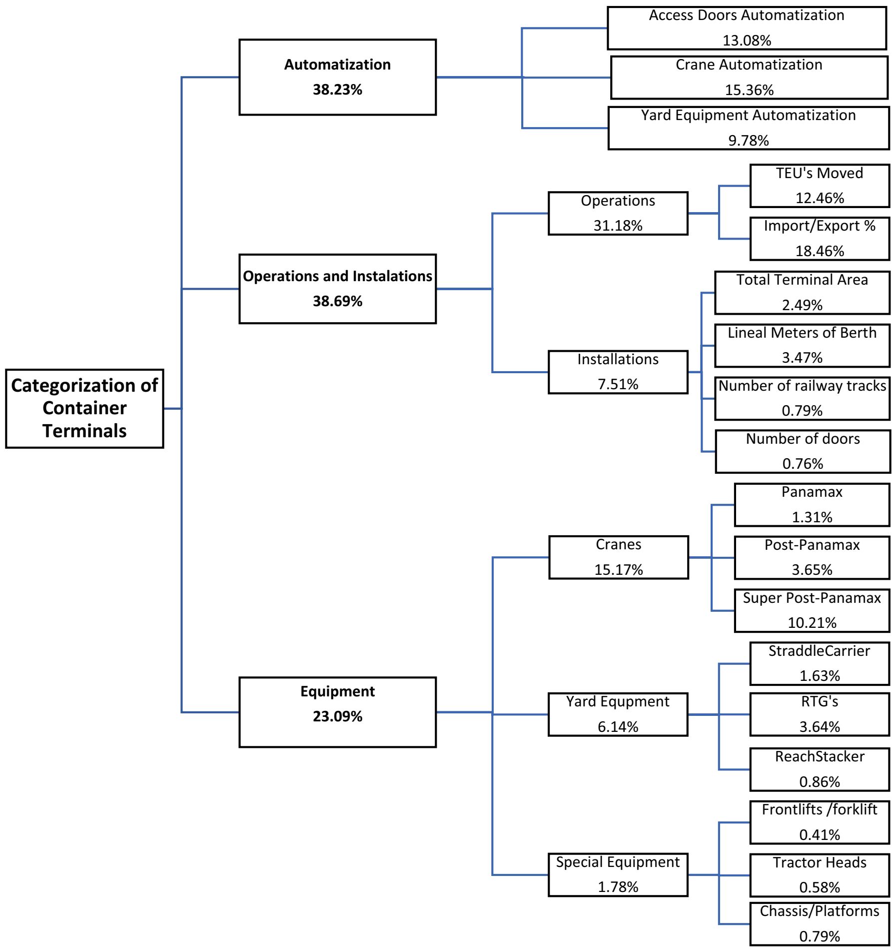

Fig. 1 Structure for classification of terminals, including 8 categories and 18 final variables. Percentages represent the final weight of each variable obtained after using F-AHP

experts came from the central governmental agency of the Spanish ports, five different Spanish port authorities, three private companies, and two universities.

Note that the survey was designed to encourage experts to choose from a range of values (fuzzy numbers), which will be addressed following the F-AHP methodology in the next steps. As an example, Fig. 2 shows the answers to the first comparison matrix of the survey. In this case, the expert indicated that the “Operations and installations” category is slightly more important than the “Automatization” category, that “Automation” is more important (from strongly to weakly) than the “Equipment” category, and finally that “Operations and installations” is of far more importance than the “Equipment” category.

Based on your experience, which of the following categories is more important for the categorization of container terminals according to the complexity of their management										
	Absolute	Very Strong	Strong	Weak	Equal	Weak	Strong	Very Strong	Absolute	
	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	
Automatization						X				Operations and installations
Automatization			X	X						Equipment
Operations and installations	X	X	X							Equipment

Matrix pairwise comparison	Crisp Matrix
$\begin{pmatrix} (1,1,1) & \left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right) & (3,4,5) \\ (3,3,3) & (1,1,1) & (5,7,9) \\ \left(\frac{1}{5},\frac{1}{4},\frac{1}{3}\right) & \left(\frac{1}{9},\frac{1}{7},\frac{1}{5}\right) & (1,1,1) \end{pmatrix}$	$\begin{pmatrix} 1 & \frac{1}{3} & 4 \\ 3 & 1 & 7 \\ \frac{1}{4} & \frac{1}{7} & 1 \end{pmatrix}$

Fig. 2 Example of survey response for the upper level in the hierarchy. Fuzzy matrix gathers the fuzzy information in the survey [for instance, element (2, 3) comparing "Operations and installations" versus "Equipment" goes from 5 to 9, representing the range 5:1 to 9:1 shown in the survey answer]. The corresponding crisp matrix is used for consistency checking

4.1.5 Step 5: processing of the results

With the data received from each of the 14 experts consulted, each matrix's answers were converted into a matrix made up of fuzzy numbers (see Fig. 2 and Palacio et al. 2015; Goepel 2013). Answers were checked for consistency using standard consistency methods (Demirel et al. 2008). For this purpose, fuzzy matrices were converted into crisp ones (Kwong and Bai 2003) and the mechanisms for consistency verification in the AHP methodology were applied (Saaty 1987).

At this point, there are 9 sets of 14 consistent matrices containing the answers of the 14 experts. Before proceeding with the calculation of weights, it is necessary to reach a consensus on all individual responses received to obtain a "group consensus matrix" on the importance of the variables and categories surveyed (Dong and Saaty 2014). For each set, calculating the geometric mean of the 14 values that occupy the same position generates the first consensus matrix. Then, the process iterates measurement of the global distance from the current "consensus matrix" to each matrix, until convergence is guaranteed in the final consensus matrix (Wu and Xu 2012).

The weights of each of the variables of the final consensus matrix define the importance of each variable in the management of container terminals according to the experts consulted. These data were consolidated in the hierarchical structure of the F-AHP, to obtain the weights for each category (Fig. 1).

In our specific case of the Spanish terminals, the importance of the automatization variables (38.23%) should be noted. In other environments with a different degree of development (such as countries in Africa and Latin America, where terminals are not likely to be automated according to UNCTAD 2018), perhaps this structure would not be the most appropriate and experts might give different importance to this variable; therefore it is critical to highlight the importance of having the support of local experts to create a hierarchical structure suitable to the reality of the case study.

4.1.6 Step 6

As mentioned above, due to the necessity of normalization of the final variables, a scale from 0 to 10 was defined by our experts, taking into account the characteristics of the Spanish terminals and each variable (Table 3); For example, 0 points are assigned to a terminal with no "Crane automation," while 10 points are assigned otherwise. In the case of the "% Transhipment" variable, a terminal receives 0 points for values lower than 10%, 7 points for 10–30%, and 10 points for transhipment figures higher than 30%.

To illustrate how the final score of each terminal was calculated, a real example is presented in Table 4. Variables have been categorized according to the criteria in Table 3, and these values are listed in the "Categorization" column. The "Gross points" column shows the numerical equivalent of this categorization, while the "Weighting" column contains the weights of each of the variables, calculated in the previous steps of the F-AHP. Finally, by weighting the gross points with their corresponding weight, it is possible to obtain the weighted points for each variable, listed in the last column of Table 4. The final classification of the 22 port terminals in this study is presented in Table 5.

Note that weighting can change the ranking of the assessed terminals. For instance, the BEST-Barcelona terminal occupies the second position in the classification considering the gross points (105) but falls to fourth position (5.34) after considering the variables' weights. On the other hand, it is important to note that the terminal that occupies the sixth position in a classification using only the gross points (TTI–Algeciras) rises to first position due to the fact that it presents very high values for the variables with greater specific weight (mainly those related to automation).

5 Comparison of the results with cluster analysis

To compare the results obtained using the F-AHP methodology with another methodology not based on the subjectivity of experts, we carried out a study using cluster analysis. Comparing the two approaches, it is interesting to note how the results can vary when information received from experts is considered.

Cluster analysis has been widely used in maritime research; For instance, Cabral and Sousa Ramos (2014) used it for the classification of 17 Brazilian container ports, which were grouped into three different clusters, based on competitiveness criteria. With the aim of identifying homogeneous groups of ports in the Mediterranean region through clustering techniques, Gianfranco et al. (2014) focused on the possible strategic relations between 34 ports of the Mediterranean Basin, aiming to promote possible collective actions among ports with similar characteristics. In that study, nine groups of ports were created, according to different factors including

Table 3 Standardization criteria and scoring of each variable

Points: variable	0	4	5	6	7	10
1. Total terminal area	Small < 107,496	Medium < 322,489				Large > 322,489
2. Linear meters of berth	Small < 660		Medium ≤ 1333			Large > 1333
3. Number of gates	Few (≤ 4)		Medium (< 8)			High (≥ 8)
4. Average TEUs moved	Small < 500,000		Medium ≤ 1,500,000			Large > 1,500,000
5. Panamax	Few (≤ 1)		Medium (≤ 4)			High (> 4)
6. Post-Panamax	No (0)		Few (< 6)			High (≥ 6)
7. Super-Post-Panamax	No (0)		Few (< 6)			High (≥ 6)
8. Reach stacker	Few (≤ 3)		Medium (< 6)			High (≥ 6)
9. Front lifts/fork lifts	Few (≤ 8)		Medium (≤ 16)			High (> 60)
10. Tractor heads	Few (≤ 30)		Medium (≤ 60)			High (> 60)
11. Straddle carrier	Few (≤ 3)		Medium (< 6)			High (≥ 6)
12. Chassis/platforms	Few (< 25)		Medium (≤ 50)			High (> 50)
13. RTGs	Few (≤ 5)		Medium (≤ 20)			High (> 20)
14. Access gates automat.	No					Yes
15. Crane automatization	No					Yes
16. Yard equipment automat.	No					Yes
17. Number of railway tracks	No (0)			Few (1–4)		Many (> 4)
18. % Transshipment	Few (< 0.1)				Medium (≤ 0.3)	High (> 0.3)

Table 4 Example of score evaluation for BEST-Barcelona Port Terminal

Variable	Categorization	Gross points	Weighting (%)	Weighted points
1. Total terminal area	Big	10	2.49	0.249
2. Linear meters of berth	Big	10	3.47	0.347
3. Number of gates	High	10	0.76	0.076
4. Average TEUs moved	Medium	5	12.46	0.623
5. Panamax	Few	0	1.31	0
6. Post-Panamax	No	0	3.65	0
7. Super-Post-Panamax	High	10	10.21	1.021
8. Reach stacker	High	10	0.86	0.086
9. Front lifts/fork lifts	Few	0	0.41	0
10. Tractor heads	Few	0	0.58	0
11. Straddle carrier	High	10	1.63	0.163
12. Chassis/platforms	Few	0	0.79	0
13. RTGs	Few	0	3.64	0
14. Access gates automat.	Yes	10	13.08	1.308
15. Crane automatization	No	0	15.36	0
16. Yard equipment automat.	Yes	10	9.78	0.978
17. Number of railway tracks	Many	10	0.79	0.079
18. % Transshipment	High	10	18.72	1.872
Total		105		6.80

their yard organization, type of traffic, geographic area, and what the authors call the set of three factors (dimensional factor, precrisis growth factor, and postcrisis growth factor). Those ports included several ones in our case, i.e., Alicante, Barcelona, Valencia, and Algeciras, which were compared with 30 other ports in the Mediterranean Basin such as Genoa, Cagliari, Tangier, Beirut, Naples, Livorno, or Venice among others. Within the geographical scope of our own research, cluster analysis has already been used previously for the categorization of port authorities of the Spanish port system, instead of container terminals as herein (Orive et al. 2016).

Given that cluster analysis does not introduce subjective factors like the F-AHP, the variables considered here were those preselected prior to the consultation of the experts (i.e., variables 1 to 13 and variables in parentheses in Table 2). To simplify the variables used, all cranes were grouped into a single variable (adding variables 5–7, feeder cranes, and automobile cranes in Table 2), and the same was done for "yard equipment" (variables 8–13 in Table 2). Using cluster analysis techniques (Rousseeuw and Kaufman 1990), the selection of the variables was checked, and the *z*-scores calculated, for the standardization of the TEU average variable (Milligan and Cooper 1988).

Statistical software R was used for the computations, given the number of alternatives it provides for the grouping of the selected variables (Hothorn and Everitt 2014). In our case, the "Average" method for clustering was selected (Wilks 2011). The method defines cluster-to-cluster distance as the average distance between all

Table 5 Final score of port terminals using F-AHP, sorted by weighted sum. Gross points are also shown

Container terminal	Weighted sum	Weighted ranking	Gross points sum	Gross points ranking
TTI—Algeciras	8.37	1	101	6
NOATUM—Valencia	6.98	2	130	1
APM TERMINALS—Algeciras	6.94	3	105	2
BEST—Barcelona	6.80	4	105	2
TCB—Barcelona	5.34	5	102	5
LA LUZ—Las Palmas	5.32	6	59	11
TCV—Valencia	5.06	7	103	4
TCT—Tenerife	4.65	8	44	13
MSC—Valencia	4.41	9	60	9
OPCSA—Las Palmas	4.09	10	80	8
NOATUM—Bilbao	3.36	11	81	7
TERMAVI—Vigo	2.66	12	60	9
NOATUM—Málaga	2.51	13	43	14
CAPSA—Tenerife	2.24	14	35	16
PORT NOU—Barcelona	1.85	15	45	12
TMS—Alicante	1.72	16	35	16
TCON—Sevilla	1.47	17	30	19
DP WORLD—Tarragona	1.15	18	40	15
TPC—Castellón	0.99	19	31	18
TCG—Gijón	0.15	20	16	20
TERMARIN—Marín	0.15	20	16	20
TTI—Cádiz	0.06	22	5	22

possible pairs of points in the two groups being compared. As seen in the dendrogram in Fig. 3, terminals were grouped into five clusters, with the last three groups made up of a single terminal (namely APM–Algeciras, BEST–Barcelona, and NOATUM–Valencia). These three are the largest facilities in the country and have very similar physical and operating characteristics, thus representing the "large terminals."

6 Discussion of the results

To identify a company's strengths, some of the competitive assets that could be considered are superior technological skills, economies of scale, and the learning and experience curve advantages over rivals (Thompson et al. 2018). In our case, comparison with other terminals may help to identify the competitive advantages of terminals and, if necessary, adapt their management practices.

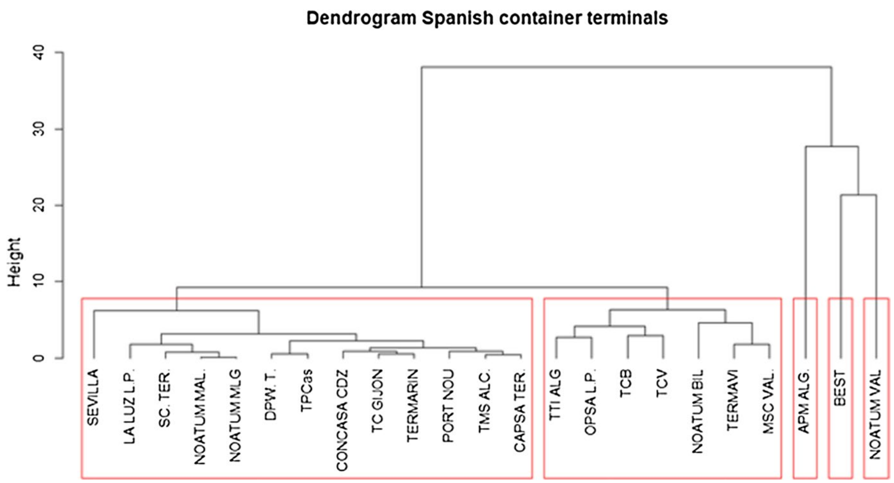

Fig. 3 Dendrogram showing results of cluster analysis

In view of the results obtained by the cluster analysis, the container terminals can be grouped into three main groups, namely “small terminals” (12 terminals named cluster 1 in Table 6), “medium terminals” (seven terminals named cluster 2), and “large terminals” (the remaining three terminals). Note that this classification, based only on some physical variables as required by the cluster methodology, does not consider the complexity in the management of these terminals, but rather the mere observations and processing of the variables used for their classification.

On the other side, the final classification, taking into account the complexity of terminal management using the F-AHP (Table 5), singles out a first group, led by TTI–Algeciras, comprising three other terminals (NOATUM–Valencia, APM–Algeciras, and BEST–Barcelona). This group is characterized by a high degree of terminal automation. Highly automated terminals are expected to be managed using a functional approach based on the automating technologies, with business process reengineering (BPR) as the action tool (Martín-Soberón et al. 2014). This should involve the reduction of human resource intervention in operations, thus focusing on task automation, information flow, and decision-making.

The F-AHP classification proves the predominance of the Mediterranean coast of Spain versus the Atlantic coast, not only in the physical and operating variables but also in the classification, weighted according to the criteria of the experts. It can also be noted that a second group of terminals, separated by less than two weighted points, made up of seven terminals (positions 5 to 11 in Table 5) is characterized by a medium degree of automation (usually the access gates), medium size, and inhomogeneous characteristics in the rest of the variables studied. Finally, in the opinion of the experts, the third group, made up of 11 terminals from different geographical locations, represents a lower level of management complexity, whose main characteristics are small size, limited TEU movements, and a low degree of automation.

The lower degree of automation of the latter groups means that most operations involve manual work carried out in places with difficult access, with strong

Table 6 Results after using cluster analysis, and comparison with the groups formed using F-AHP

Container terminal	Cluster	Gross points rank	Weighted rank
NOATUM—Valencia	5	1	2
BEST—Barcelona	4	2	4
APM—Algeciras	3	2	3
TCV—Valencia	2	4	7
TCB—Barcelona	2	5	5
TTI—Algeciras	2	6	1
NOATUM—Bilbao	2	7	11
OPCSA—Las Palmas	2	8	10
MSC—Valencia	2	9	9
TERMAVI—Vigo	2	9	12
LA LUZ—Las Palmas	1	11	6
PORT NOU—Barcelona	1	12	15
TCT—Tenerife	1	13	8
NOATUM—Málaga	1	14	13
DP WORLD—Tarragona	1	15	18
CAPSA—Tenerife	1	16	14
TMS—Alicante	1	16	16
TPC—Castellón	1	18	19
TCON—Sevilla	1	19	17
TCG—Gijón	1	20	20
TERMARIN—Marín	1	20	20
TTI—Cádiz	1	22	22

involvement of heavy machinery, hazardous cargoes, and dense traffic, thereby making port work a dangerous job (Hinkka et al. 2016). For these terminals, human resource management and training is a relevant asset, considering the high labor costs which make manpower management a crucial activity (Di Francesco et al. 2016). It is therefore to be expected that the management of these terminals will focus on the management of human resources, as this is one of their main assets.

There are multiple views addressing management styles. According to contingency theory, there is no one best way to structure the activities of an organization in all circumstances. Some contextual factors determine the nature of the structure of the organization, which is viewed by contingency theory as a center of mutual influence and interaction between four subsystems (goal, human, technical, and managerial) that should be optimally coordinated (Jackson 2007). Container terminals, like any other organization, are exposed to certain conditions such as legal mandates, trade union culture, and traditions that can limit their autonomy and flexibility in adopting more efficient management models (Marios 2006). However, one would expect terminals with a high degree of automation (namely TTI–Algeciras) to have an IT approach to management, that is, a strong focus on employee training, continuous improvement processes, and process automation. Other terminals could take a contingent approach and focus their management on the most important subsystems of the terminal.

Terminals located in the middle part of the table, such as NOATUM–Bilbao, have some feasible opportunities for improvement, regarding the automation of their facilities, and should therefore focus their management on upgrading their technical subsystem. Finally, terminals listed in the last positions (namely TCG–Gijón) would be more likely to focus their management on improving their human resources system, since automation must be implemented at a gradual pace.

Our results show the significance of grouping port terminals without considering the opinion of experts, for the calculation of the complexity of their management. Despite the fact that, for the gross points calculation in the F-AHP methodology, different variables were taken into account than those in the cluster analysis (which did not include, for example, variables related to the automation of port terminals), the results obtained in the classification taking into account the gross points of the F-AHP methodology (without weighting) and the results of grouping the terminals by cluster analysis are very similar, as presented in Table 6. This result shows that our nonsubjective analysis could serve as a starting point for the subjective approach, introducing the fuzzy opinion of the experts to better capture the pursued classification.

7 Conclusions

Characteristics of container terminals (such as the degree of automation, number of TEUs moved, or terminal area) differ greatly and have a great influence on terminal management practices. Therefore, knowing how to assess those variables and how they can affect the way decisions are made can help in developing new management tools; For instance, in the aforementioned case of the TTI–Algeciras terminal, the set of automation variables—especially the most weighted variable (i.e., “Crane automatization” with importance of 15.36%)—makes this terminal reach the top of the global ranking. This means that automation characteristics are critical in our classification, requiring the use of a technological approach in management practices.

This paper proposes a classification system for terminals based on the subjective opinions of a group of experts. The classification should be understood as a still photo, taken at a given moment, and may vary depending on improvements made to the terminal, especially regarding the features that have more weight in the classification according to the criteria of the experts.

To the best of the authors’ knowledge, this paper proposes for the first time a systematic method of applying knowledge, based on expert views, to classify container terminals according to criteria that determine their special management characteristics. Expert opinions are collected via surveys designed to capture fuzzy answers. By filling this gap in the scientific literature, it is hoped that this classification system will serve to identify opportunities to improve terminal management, with the understanding that those terminals have special characteristics, such as ABC, and they perhaps need ad hoc management systems. Results of the F-AHP approach were compared with nonsubjective classification techniques such as cluster analysis, yielding some variations in the classification due to the weighting of some variables that the experts considered more relevant.

As further research, other case studies for different sets of port terminals could be considered as well. Checking the opinions of experts in different environments could provide information on different weights and changes in the final ranking of the terminals. With several case studies, a comparative study could be carried out of the variables that most affect the management of port terminals in different geographical areas, including in this comparison the physical variables that define their traffic and thus check, for example, whether, in environments with a lower degree of automation, these variables have a lower weight. A longitudinal study carrying out a similar analysis in the future could allow a comparison of the evolution of container terminals.

Acknowledgements This research was carried out with partial financial support from the Spanish Ministry of Science and the European Regional Development Fund (ERDF) grant DPI2017-85343-P. The authors would like to thank Prof. Montes Peón and all personnel at the Spanish port authorities and different container terminals who contributed to the verification of terminal data and served as experts in the survey. We are especially grateful to *MEL* reviewers, whose comments were very useful in improving the manuscript and are greatly appreciated.

References

Bichou, K., and R. Gray. 2005. A critical review of conventional terminology for classifying seaports. *Transportation Research Part A Policy and Practice* 39: 75–92.

Cabral, A.M.R., and F. Sousa Ramos. 2014. Cluster analysis of the competitiveness of container ports in Brazil. *Transportation Research Part A Policy and Practice* 69: 423–431.

Chang, D.-Y. 1996. Applications of the extent analysis method on Fuzzy AHP. *European Journal of Operational Research* 95: 649–655.

Chou, C.-C., and K.-W. Yu. 2013. Application of a new hybrid Fuzzy AHP Model to the location choice. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2013/592138.

Cullinane, K., T.-F. Wang, D.-W. Song, and P. Ji. 2006. The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A Policy and Practice* 40: 354–374.

Da Cruz, M.R.P., J.J. Ferreira, and S.G. Azevedo. 2013. Key factors of seaport competitiveness based on the stakeholder perspective: An analytic hierarchy process (AHP) model. *Maritime Economics & Logistics* 15: 416–443.

De Koster, M.B.M., B.M. Balk, and W.T.I. Van Nus. 2009. On using DEA for benchmarking container terminals. *International Journal of Operations & Production Management* 29: 1140–1155.

Demirel, T., N.Ç. Demirel, and C. Kahraman. 2008. Fuzzy analytic hierarchy process and its application. In *Fuzzy multi-criteria decision making*, ed. C. Kahraman, 53–83. Boston: Springer.

Di Francesco, M., A. Manca, S. Zanda, and P. Zuddas. 2016. Planning and optimising manpower management in a transshipment container terminal. *European Journal of Industrial Engineering* 10: 777–793.

Dong, Q., and T.L. Saaty. 2014. An analytic hierarchy process model of group consensus. *Journal of Systems Science and Systems Engineering* 23: 362–374.

Ducruet, C., S. Cuyala, and A. El Hosni. 2018. Maritime networks as systems of cities: The long-term interdependencies between global shipping flows and urban development (1890–2010). *Journal of Transport Geography* 66: 340–355.

Estrada Llaquet, J. L., 2007. *Mejora de la competitividad de un puerto por medio de un nuevo modelo de gestión de la estrategia aplicando el cuadro de mando integral*. Doctoral thesis.

Gianfranco, F., P. Claudia, S. Patrizia, and F. Paolo. 2014. Port cooperation policies in the Mediterranean Basin: An experimental approach using cluster analysis. *Transportation Research Procedia* 3: 700–709.

Goepel, K.D. 2013. Implementing the analytic hierarchy process as a standard method for multi-criteria decision making in corporate enterprises—A new AHP excel template with multiple inputs. *Conference Paper*. https://doi.org/10.13033/isahp.y2013.047.

Guy, E., and B. Urli. 2006. Port selection and multicriteria analysis: An application to the Montreal–New York alternative. *Maritime Economics & Logistics* 8: 169–186.

Hinkka, V., J. Eckhardt, A. Permala, and H. Mantsinen. 2016. Changing training needs of port workers due to future trends. *Transportation Research Procedia* 14: 4085–4094.

Hothorn, T., and B.S. Everitt. 2014. *A handbook of statistical analyses using R*. Boca Raton: Chapman and Hall/CRC.

Jackson, M.C. 2007. *Systems approaches to management*. Boston: Springer.

Kubler, S., et al. 2016. A state-of the-art survey & testbed of fuzzy AHP (FAHP) applications. *Expert Systems with Applications* 65: 398–422.

Kwong, C.-K., and H. Bai. 2003. Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach. *IIE Transactions* 35: 619–626.

Lampe, H.W., and D. Hilgers. 2015. Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA. *European Journal of Operational Research* 240: 1–21.

Levinson, M. 2016. *The box: How the shipping container made the world smaller and the world economy bigger-with a new chapter by the author*. Princeton: Princeton University Press.

Lirn, T.-C., H.A. Thanopoulou, and A.K.C. Beresford. 2003. Transhipment port selection and decision-making behaviour: analysing the Taiwanese case. *International Journal of Logistics: Research and Applications* 6: 229–244.

Lirn, T.C., H.A. Thanopoulou, M.J. Beynon, and A.K.C. Beresford. 2004. An application of AHP on transhipment port selection: A global perspective. *Maritime Economics & Logistics* 6: 70–91.

Lloyds List. 2018. *Lloyd's List.* https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2018. Accessed 18 January 2019.

Lu, B., and Wang, S. 2017. DEA conceptual exposition and literature review. In *Container Port Production and Management*, 7–17. Singapore: Springer.

Mardani, A., et al. 2016. Multiple criteria decision-making techniques in transportation systems: A systematic review of the state of the art literature. *Transport* 31: 359–385.

Marios, K. 2006. *Strategic management, global cultural perspectives for profit and non-profit organizations*. Burlington, MA: Elsevier Butterworth-Heinemann.

Martín-Soberón, A.M., A. Monfort, R. Sapiña, N. Monterde, and D. Calduch. 2014. Automation in port container terminals. *Procedia-Social and Behavioral Sciences* 160: 195–204.

Milligan, G.W., and M.C. Cooper. 1988. A study of standardization of variables in cluster analysis. *Journal of Classification* 5: 181–204.

Monfort, A., et al. 2001. *Terminales marítimas de contenedores: el desarrollo de la automatización*. Valencia: Fundación Instituto Portuario de Estudios y Cooperación de la Comunidad Valenciana.

Orive, A.C., et al. 2016. Metodología para la clasificación de los puertos mediante indicadores de explotación utilizando análisis de conglomerados. *INGE CUC* 12: 41–49.

Palacio, A., Adenso-Díaz, B., and Lozano, S. 2015. A decision-making model to design a sustainable container depot logistic network: The case of the port of Valencia. *Transport* 1–12.

Pallis, A.A., T.K. Vitsounis, and P.W. De Langen. 2010. Port economics, policy and management: Review of an emerging research field. *Transport Reviews* 30: 115–161.

Puertos del Estado. 2017. *Corporate web site.* http://www.puertos.es/es-es/estadisticas/Paginas/estadistica_mensual.aspx. Accessed 3 January 2019.

Puertos del Estado. 2018. *Observatorio Permanente de los Servicios Portuarios.* http://observatorio.puertos.es/. Accessed 9 January 2019.

Rios, L.R., and A.C.G. Maçada. 2006. Analysing the relative efficiency of container terminals of Mercosur using DEA. *Maritime Economics & Logistics* 8: 331–346.

Rodrigue, J.-P., and T. Notteboom. 2009. The terminalization of supply chains: Reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management* 36: 165–183.

Rousseeuw, P.J., and L. Kaufman. 1990. Finding groups in data. *Series in Probability & Mathematical Statistics* 34 (1): 111–112.

Saaty, R.W. 1987. The analytic hierarchy process—What it is and how it is used. *Mathematical Modelling* 9: 161–176.

Sauri, S., and E. Martin. 2011. Space allocating strategies for improving import yard performance at marine terminals. *Transportation Research Part E Logistics and Transportation Review* 47: 1038–1057.

Sharma, M.J., and S.J. Yu. 2009. Performance based stratification and clustering for benchmarking of container terminals. *Expert Systems with Applications* 36: 5016–5022.

Song, D.-W., S. Cheon, and C. Pire. 2015. Does size matter for port coopetition strategy? Concept, motivation and implication. *International Journal of Logistics Research and Applications* 18: 207–227.

Song, D.-W., and K.-T. Yeo. 2004. A competitive analysis of Chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics* 6: 34–52.

Thompson, A., M. Peteraf, J. Gamble, and A. Strickland. 2018. *Crafting & Executing Strategy 21/e: The Quest for Competitive Advantage: Concepts and Cases*. McGraw-Hill Education.

Torres, A.I.Z., and O.H.P. Rendón. 2013. El transporte internacional como factor de competitividad en el comercio exterior. *Journal of Economics Finance and Administrative Science* 18: 108–118.

Tovar, B., and H. Rodŕiguez-Déniz. 2015. Classifying ports for efficiency benchmarking: A review and a frontier-based clustering approach. *Transport Reviews* 35: 378–400.

Ugboma, C., O. Ugboma, and I.C. Ogwude. 2006. An analytic hierarchy process (AHP) approach to port selection decisions—Empirical evidence from Nigerian ports. *Maritime Economics & Logistics* 8: 251–266.

UNCTAD. 2018. *Review of maritime transport 2018*. Geneva: UNCTAD.

Ung, S.T., et al. 2006. Human error assessment and management in port operations using fuzzy AHP. *Marine Technology Society Journal* 40: 73–86.

Vaidya, O.S., and S. Kumar. 2006. Analytic hierarchy process: An overview of applications. *European Journal of Operational Research* 169: 1–29.

Van Laarhoven, P.J.M., and W. Pedrycz. 1983. A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems* 11: 229–241.

Vieira, G.B.B., F.J. Kliemann Neto, and F.G. Amaral. 2014. Governance, governance models and port performance: A systematic review. *Transport Reviews* 34: 645–662.

Wilks, D.S. 2011. Cluster analysis. *International Geophysics* 100: 603–616.

Wu, Z., and J. Xu. 2012. A consistency and consensus based decision support model for group decision making with multiplicative preference relations. *Decision Support Systems* 52: 757–767.

Wu, J., H. Yan, and J. Liu. 2010. DEA models for identifying sensitive performance measures in container port evaluation. *Maritime Economics & Logistics* 12: 215–236.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.