Georgoulas *et al.*
Journal of Shipping and Trade (2023) 8:16
https://doi.org/10.1186/s41072-023-00144-x

Journal of Shipping and Trade

ORIGINAL ARTICLE

Open Access

An AHP enabled port selection multi-source decision support system and validation: insights from the ENIRISST project

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Abstract

Analytical Hierarchy Process (AHP) is a robust procedure for ranking options and supporting multi-criteria decision making that determine the port that a shipping operator will select, while designing the most cost-effective route. An important decision that may turn out to be decisive for a company's survival. We developed an AHP based decision support system, as part of a wider Research and data Infrastructure system, that enables practitioners' decision making based on their subjective experience and within realistic time constraints. We test the approach using two regional ports and the throughput results confirmed the initial expectations.

Keywords: AHP, Port selection, Decision support system, DSS, Greek ports

Introduction

Globalization has led the largest companies in the world to expand to other parts of the world by creating global networks, which impose competition not only at the level of the company but also throughout the entire supply chain (Christopher 1998). In this kind of competition, liner shipping plays a special role. About 90% of world trade by volume and 70% by value are carried by sea. Therefore, it is evident that maritime transport and by extension the liner shipping industry are the main pillar of international trade and therefore support the global economy.

Liner shipping is widely recognized as a business sector with intense competitive pressure. Innovations and turbulence in the balance of international stakeholders render survival in the sector difficult, while informed stakeholders are staying competitive compared to their peers. In a volatile environment like the one in the maritime ecosystem, priorities are never the same and decisions have greater impact (Mittal and McClung 2016). Hence, interpreting decision-making behaviour is of paramount importance.

Ports, which are considered the centre of the maritime supply chain, take decisions that become more difficult day by day. As regional competition intensifies, port operators are losing control because of the competitive dynamics. This is apparent in the reduced monopolistic position of ports and the dominant influence of shipping lines' global operations on port development. Ports performance is also of great importance

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for the regional and national economy, especially for the developing countries (Munim and Schramm 2018).

One can ponder that decisions in liner shipping have not only direct and obvious impact on the supply chain stakeholders but also an indirect and subtle impact on the port hinterland as well as on the short sea shipping providers (Papadimitriou et al. 2018). One vital question both for container operators and port authorities concerns the criteria that are being considered during the port choice (Yuen et al. 2012). Understanding the key factors that render a port competitive is a matter of survival for the port and has ensuing ramifications on all the stakeholders involved. Consequently, a robust approach plays a crucial role in maintaining the consistency of competitive strategy for both port and liner shipping operators. The need to develop simple, yet robust decision-making tools was a guiding principle in developing an Analytical Hierarchy process (AHP) based decision support system using open sources, as well as developing the necessary data repositories to support efficient, timely and accurate decision making. In parallel, we highlight the usefulness of the AHP as a method to solve the problem of port selection by scrutinizing the literature and summing the studies that incorporated as main tool. The accuracy of the decisions and the reduction of time spending on it, were also two key elements that inspired this research.

Our suggested Decision Support System (DSS) is one of the few that addresses the complicated and time-consuming problem of port choice. In essence it bridges the academic knowledge with the application in business, providing a method for the improvement of the management of global trade activities for practioners.

The research is part of a wider research to build robust Research Infrastructures, as a fundamental element of building resilient clusters (Stavroulakis et al. 2020), which will be available to interested parties, will include open data and ultimately will improve decision making at different levels, from business, to public, to research and beyond.

This paper is structured as follows: a literature review covering the background information, a description of the Research Infrastructure, a methodological part explaining the approach, an analysis part and conclusions.

Literature review

Port choice decision making

The maritime industry is an established sector that has long relied on human expertise to make decisions, including critical functions. However, in recent times, the introduction of DSSs in ports and maritime shipping to improve operational efficiency, increasing throughput, and reduce overall costs. These systems are designed to assist decision-making and enable the industry to keep pace with modern advances in technology.

One of the main purposes of a decision support system (DSS) is to assist top-level managers or executives who may lack expertise in mathematical modelling and analysis. When these decision makers need to handle complex, multi-objective problems, they require systematic support from an information system that can present optimization results visually. This helps to simplify the decision-making process and ensures that important factors are taken into account.

A number of problems have been addressed through DSS in various sections of maritime shipping. More specifically, there have been developed DSS for sustainable efficient decisions (Mansouri et al. 2015; Bruzzone et al. 2010), for the optimization of port operations (Zhou et al. 2021; Legato and Mazza 2018) or of liner shipping companies (Wong et al. 2015; Lee et al. 2018). The dominant method used in DSS frameworks is what-if analysis. There is only a limited number of studies that incorporate qualitative decisions (Mansouri et al. 2015).

The question of port choice criteria in liner shipping is a core subject for scientific and commercial reasons alike. Moya and Valero (2017) grouped them into two fundamental categories, factors under control (FC) and factors beyond control (PA). The first group of decision making (DM) criteria incorporates factors that can be determined for the port itself or port authorities like the charging policy, while the latter encompasses factors that are not able to be influenced by a port authority, like the distance from a maritime trade route or the local connections in the hinterland and/or with short sea shipping routes (Papadimitriou et al. 2018).

Practitioners approach DM by numerous perspectives, while motivations, goals, and strategies vary based on the individual decision maker. Hence, there are three searching pillars which are determined from the position of the decision maker in the (international) supply chain, namely freight forwarders, Shippers, and Shipping lines. From the freight forwarders' point of view, criteria associated with time are substantial in selecting the appropriate port (Slack 1985; Bird 1988; Tongzon 1995, 2002). The most prevailing criteria include the frequency of service provided and the port's efficiency. From the shippers' perspective, the priorities emphasise factors related to the selected route like distance, the costs of port and service factors, the variety and the reliability (McGinnis 1979; Meyrick and D'Este 1989; Wilson et al. 1986; Malchow and Kanafani 2001, 2004). Shipping lines are also affected by similar port characteristics, albeit to a different extent. Some distinctive properties that attract them are the port's throughput, infrastructure, and connectivity (Mulder and Dekker 2017).

The literature covers geographical criteria also, specifically, dependence on the nature of exports/imports (in a regional, national or continental level) or the gross domestic product (GDP) (Souza et al. 2021). Furthermore, political stability with a strong regional focus plays a decisive role in the port selection (Ugboma et al. 2002). Furthermore, cargo owners and exporters focus on cargo theft risk while importers on taxation (Souza et al. 2021).

The process for understanding the factors that affect stakeholders' port selection include both quantitative and qualitative elements, thus our understanding is that the methodological approach is pertinent to the trade, the geography/region and even the seasonality among other factors (Moya and Valero 2017). A key takeaway is that a robust, simple and open multi-criteria decision-making process is the preferred approach by the scientific and practitioner community and the Analytical Hierarchy Process AHP is a satisfying option (Lam and Dai 2012).Therefore, we have accumulated all the researches that are oriented in finding the appropriate criteria for port selection in Table 1. From our analysis, one can conclude the existence of many lacunas in the use of AHP for the port decision problem. Regions like America, Australia have not been covered by research using the aforementioned method. Also, the perspective of the port operators has been underestimated in the most cases. Lastly, the

Table 1 Literature regarding AHP methods for port selection

Region	Perspective	Source
Africa	Shipper	Ugboma et al. (2006)
Asia	Shipper	Lirn et al. (2004), Chou (2010), Park and Min (2011), Rahman et al. (2019) and Lirn et al. (2003) and Yuen et al. (2012)
	Port operator	Lirn et al. (2004) and Park and Min (2011)
Europe	Shipper	Cruz et al. (2013)
	Port operator	Cruz et al. (2013)
Americas	Shipper	Mittal and McClung (2016)
Meditereanean	Shipper	Baştuğ et al. (2022)
	Port operator	Baştuğ et al. (2022)

combination of AHP with DSS for solving the port choice in multiple regions quickly and robustly is absent.

There is only one case where DSS and AHP is combined in the literature. Lam and Dai (2012) suggested a model that the user should first evaluate the importance of the port choice criteria using pairwise comparisons. The model formulates then an AHP based on the user's comparison and calculates the score of every candidate port by retrieving ports information from a database. Rahman et al. (2019) develop a technique for port choice which is based on a survey that they conducted among experts. The latter graded the criteria for port selection through an AHP. The final score was determined through Evidential Reasoning. This model was applicable on Malaysia ports and expanding it to further regions would entail the recruitment of additional experts.

It could be argued that a DSS model incorporating the knowledge from the existing academic literature is missing. More specifically, a model that will produce more robust results, cover different perspectives and regions, be less time consuming and allowed sensitivity analysis is absent. Our suggested model fulfills the aforementioned prerequisites, while is the first DSS that concentrates the results from more than one AHP of studies regarding port decision criteria. Additionally, the results are rewarding also for port operators, while our DSS allow them to be compared and benchmarked with their rivals, leading them to more informed decisions based on literature.

The ENIRISST research infrastucture as a basis for a decision support system

ENIRISST ("Intelligent Research Infrastructure for Shipping, Supply Chain, Transport and Logistics") is a project implement through the Action "Reinforcement of the Research and Innovation Infrastructure" and funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014–2020) and co-financed by Greece and the European Union (European Regional Development Fund). The main objective of the proposed RI is to create a center of excellence for research in shipping and transport in Greece providing the necessary services (data, modeling, planning, user and agencies' related applications and consulting) to support existing and future research in the maritime, land and air, passenger and freight sectors. This RI aims to be the first intelligent research infrastructure in the field of shipping and transport in Greece and Europe, formulating an intelligent platform combining business analytics along visualization techniques and technology (e.g., dashboards) to support smart specialization across regions involved. This RI will collect, process and make available data, information, and intelligence on a number of different elements like commodities, passengers' flows, port infrastructure and beyond.

ENIRISST envisages to develop an integrated, interoperable environment (e-infrastructure) that will support, enable and improve decision making. ENIRISST develops common user interfaces, application interfaces, standardization for future extensions and virtualization. Towards this end, standardized dictionaries/ontology and software interfaces will be defined and consistently developed and applied (McGuinness et al. 2009) whereas improved simulation and decision making software (Hornbæk 2006) will be co-developed with and for practitioners offering better web-based visualization(Bizer 2009). ENIRISST utilises the experience of previous attempts to develop information collection and dissemination systems using for example freight e-waybills (Cane et al. 2012), Maritime Single Windows (Koliousis et al. 2014) and eMaritime based automation (Morrall et al. 2016) in order to develop centralised and decentralised/distributed data sharing systems.

ENIRISST will go beyond static data and will be scalable for future extensions and additions for example regularly updated data to be used through a multi-objective decision-making model for port selection, as is this case or on the route optimization problem both for shipping and land transport (Robu et al. 2011). The RI will also develop web services to allow users to access the services/applications/databases and will also develop technical specifications for developers to enable future extensions.

Methodology

The concept of our DSS is simple in the design and execution. At first we construct a database with the studies dealing with port selection issue by utilizing AHP. This database encompasses all the weights of criteria proposed in the literature categorized by region and decision-maker perspective. The related literature summarizing the aforementioned studies is described in Moya and Valero (2017). We supplement this study with the newest studies on port selection using AHP and we present the whole database on the table below. Hence, we visualize the frequency of the methods wide use and contribution on the port selection problem.

Our novel tool includes information for a number of ports that are published. Based on these two sources our model will visualize the comparison of the neighbouring ports from a selected geographical area by the user following the rules that are described below.

We should initially familiarize the reader with the concept of AHP. The AHP is a method to decompose problems associated with decisions (Zahedi 1986) entailing a 4-step process:

1. Analysing the decision process into key elements, which in our example are the criteria.
2. Comparing the different elements in pairs through judgments.
3. Calculating relative weights for each criterion using eigenvalues.

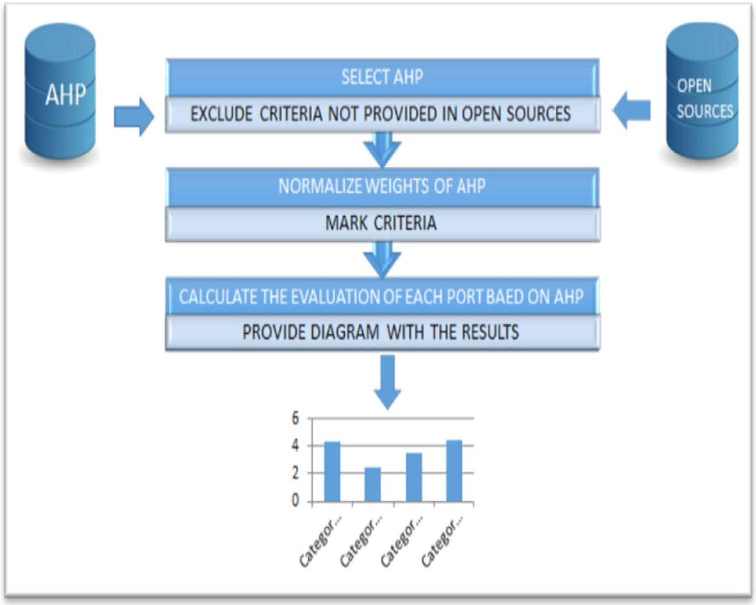

Fig. 1 The architecture of DSS (*Source*: Authors)

4. Summing weights, in order to formulate a set of ratings for each criterion.

After calculating the weights, the criteria can be hierarchically categorized. Nevertheless, it must be noted that the (relative) importance is hard to be obtained considering the fast-paced commercial environment and the requirement for quick decisions. Our proposal thus, is practitioner-oriented and entails an initial step which clusters neighbouring ports together as potential candidates for consideration. The proposed architecture of our system (Figs. 1, 2) is as follows:

1. The user selects geographical area (e.g. Mediterranean Sea) decision-maker perspective (shipper, freight forwarder, shipping line).
2. Our model visualizes the AHPs conducted with the criteria selected by user. The user selects one study for the evaluation to take place.
3. From the AHP selected, system excludes criteria that are difficult to find information about (e.g., closed, fee based sources)
4. Normalize the weights of the rest criteria so as their sum would equal to one.
5. Quantify the qualitative criteria using predefined rules or policies. For example, 'variety of services' may sum the number of different services provided by different options, or 'cost of services' may average the cost of each service that is provided by all options. Similarly, binary logic based on quantification can be used to compare every criterion with its average value and assign one or zero to the candidate port that provides above or below the average cost of services or additionally, assign 1 to the port that offers more than the average number of services (service availability/proliferation) following the equation below (Fig. 3).

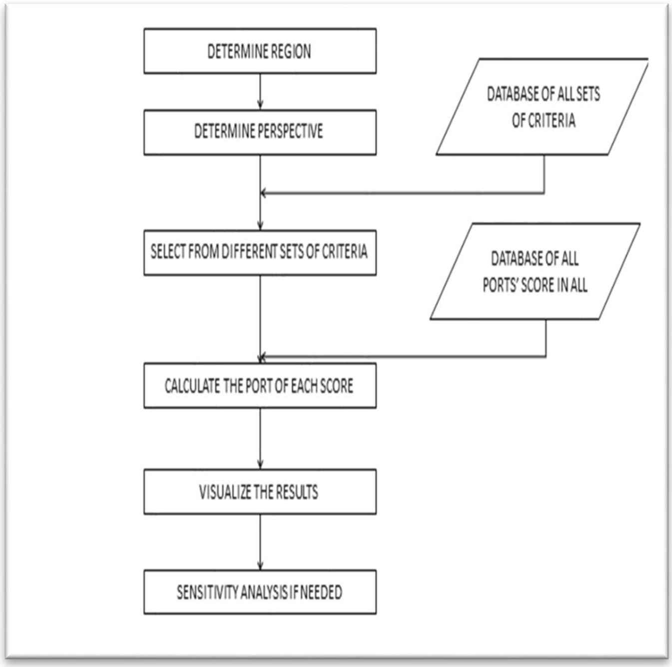

Fig. 2 The DSS procedures (*Source*: Authors)

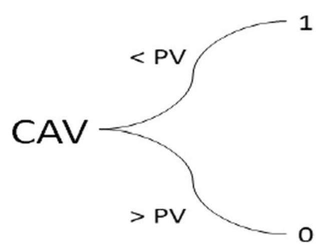

Fig. 3 Criteria evaluation (*Source*: Authors)

Where CAV is the average value of the criterion and PV is the port value of the specific criterion

6. Similarly, assign one or zero to the rest of the criteria based on their comparison with the mean.
7. Substitute the numbers for quantitative and qualitative criteria in the equation produced by AHP.
8. Calculate the results and evaluate port options.

The user is able to perform comparisons based on all of the AHP that are contained in the model and referred to geographical area and decision maker perspective selected. Hence, he is able to obtain in order a more holistic image about the port choice and the alternatives based on different studies.

Application and analysis

For testing our novel proxy for port evaluation, we will compare two neighbouring ports (with similar hinterland) and compare the results with their actual visits. Our candidate ports will be ports of Piraeus and Thessaloniki from the perspective of liner shipping. We used weights from Cruz et al. (2013) which address decision making geographically focused to Europe and addresses both liner shipping and seaport service providers. Table 2 reports the core decision making criteria and their factors that contribute to port choices from line shipping.

Additional criteria collected by open sources, considering time-constraints for quick turnaround decision making, are reported on Table 3.

For the Seaport facilities we used the facilities and equipment asset value as reported on annual fillings (figures in €). The Depth was calculated in meters from the port websites. Connectivity is a dummy classification variable (0, 1, 2, 3) considering the number of intermodal connections (Airport, National High Way, Train) each port has. Case in point, the vessel time at port was not found.

The final values of the criteria were calculated by averaging the values of the two ports and comparing their values to the mean. For each criterion, ports with prices higher than the average are assigned the value 1, 0 otherwise (Table 4).

Table 2 Weights of core selection criteria

Criteria	Weights
Seaport facilities and equipment	20.86
Depth	14.57
Connectivity	21.11
Vessel time at port	25.75
Proximity to import/export area	17.71

Source: Cruz et al. (2013)

Table 3 Additional operational criteria

Criteria	Piraeus	Thessaloniki
Seaport facilities and equipment	293,677,764.81	147,748,000.00
Depth	18	12
Connectivity	3	3
Vessel time at port	–	–

Sources: www.olp.gr, www.thpa.gr

Table 4 Criteria calibrations

Criteria	Piraeus	Thessaloniki
Seaport facilities and equipment	1	0
Depth	1	0
Connectivity	1	1
Vessel time at port	-	-

Source: Authors' calculations

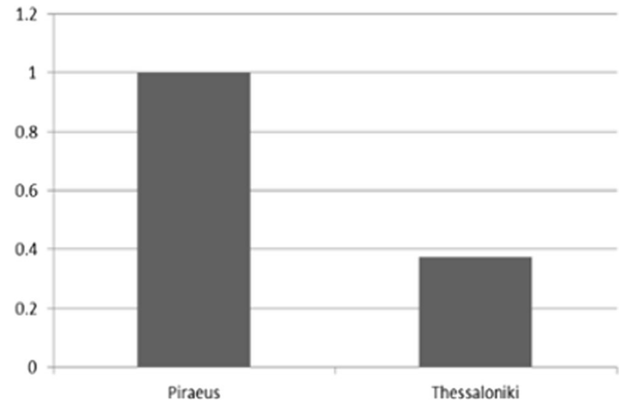

Fig. 4 Ports evaluation (*Source*: Authors)

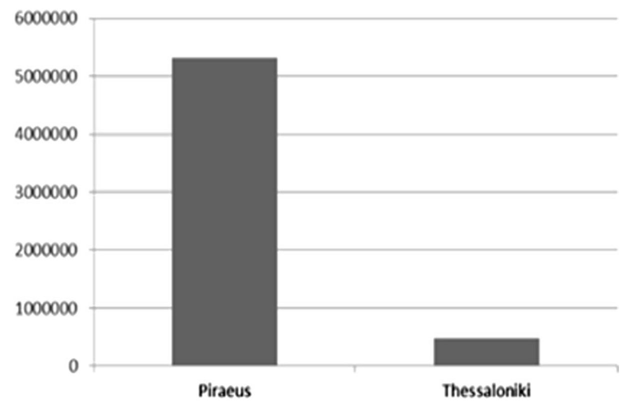

Fig. 5 Ports trade volumes in TEUS (*Source*: Port websites)

Lastly, we normalized the weights after a number of inconclusive or data-less criteria were excluded. The calculations for the evaluation of the two ports are:

- Piraeus Port: $(0.3689)X(1) + (0.2576)X(1) + (0.3733)X(1) = 1$
- Thessaloniki Port: $(0.3689)X(0) + (0.2576)X(0) + (0.3733)X(1) = 0.37$

The total relative weight for each port is presented in the following figures (Figs. 4, 5):

The results from our evaluation are aligned with the yearly throughput of the candidate ports, while the choice of Piraeus trade volumes of TEUS is undisputedly higher compared to that of Port of Thessaloniki. This confirms our expectations that more shipping lines selected in 2021 as part of their route Piraeus port instead of Thessaloniki port.

Conclusion

We developed a Decision Support System that compares and evaluates ports, as part of a greater portfolio of data-rich evaluative services within a Research Infrastructure context. It provides fast, quick-turnaround decision making based on the (subjective) experience of specialists and practitioners but using all available information. Using a robust technique, AHP, we support shipping executives by facilitating a quicker but equally robust decision making and port operators by allowing them to be compare their offerings to those of their competitors.

The proposed approach is scalable, especially considering the growing demand and expectations from a modern Research Infrastructure. In essence, the proposed DSS can be applied in any relevant decision making context, evaluating maritime logistics options. Similarly, the Research Infrastructure, ENIRISST, is scalable and envisages to collect and disseminate data and information for practitioners, researchers and policy makers alike, encompassing a number of transport related data needs.

Our model also fulfills the salient criteria of results visualization and user-friendly environment. It is the first of its kind that transforming the added value from academics to added value for the practitioners. It provides solutions to one of the most researched problems in the literature of maritime trade and improves shipping management.

Finally, our study emphasizes the efficacy of the AHP methodology in facilitating port selection decision and raises awareness of the availability of this methodology as a viable alternative for decision-making among marine stakeholders. For future work we suggest the expansion of AHP to regions and perspectives that are not covered by the current literature. Hence, our suggested model will become more globally applicable.

Abbreviations

AHP	Analytic Hierarchy Process
CAV	Criterion average value
DM	Decision making
DSS	Decision support system
FC	Full control
PV	Port value

Acknowledgements
None.

Author contributions
GD: code model, initial testing, writing. KI: develop initial model, review, testing, writing and proof reading. PS: develop initial model, review, testing. All authors read and approved the final manuscript.

Funding
We acknowledge support of this work by the project EN.I.R.I.S.S.T. (Intelligent Research Infrastructure for Shipping, Supply Chain, Transport and Logistics) (MIS 5027930) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014–2020) and co-financed by Greece and the European Union (European Regional Development Fund). The authors would also like to acknowldege that the article processing charge of this work is supported by China Merchants Energy Shipping

Availability of data and materials
These are available upon request. An open access repository will be available at www.enirisst.gr

Declaration

Competing interests
None.

Received: 3 January 2023 Revised: 10 April 2023 Accepted: 28 April 2023
Published online: 18 May 2023

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