Journal of Cleaner Production 268 (2020) 122156

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Identifying the appropriate governance model for green port management: Applying Analytic Network Process and Best-Worst methods to ports in the Indian Ocean Rim

Ziaul Haque Munim [a, *], Henrik Sornn-Friese [b], Mariia Dushenko [a]

[a] Faculty of Technology, Natural and Maritime Sciences, University of South-Eastern Norway, Norway
[b] Department of Strategy and Innovation, Copenhagen Business School, Denmark

A R T I C L E I N F O

Article history:
Received 4 October 2019
Received in revised form
5 May 2020
Accepted 9 May 2020
Available online 21 May 2020

Handling editor: Yutao Wang

Keywords:
Analytic network process
Best-worst method
Environmental performance
Port governance
Multi-criteria decision making

A B S T R A C T

This study investigates the appropriate port governance model for implementation of green port management (GPM) practices. Relying on social systems engineering principles, we propose a multi-criteria decision-making (MCDM) framework considering four port governance models and five major GPM practice indicators. We validate the MCDM framework using survey data collected from top management executives of three ports in the Indian Ocean Rim — Bangladesh, Sri Lanka and Tanzania. We compare the Analytic Network Process (ANP) method with more recently developed Best-Worst Method (BWM) in analysis of the MCDM problem of finding the right port governance model for GPM. We collect data using the ANP and BWM survey in January 2019 and August 2019, respectively, from the same respondents. While participating in the study in January 2019, the respondents did not know that they would respond to the same MCDM problem using a different model, which corresponds to a repeated measures experimental design. In both analyses, we find that increasing privatization in port governance would enhance the implementation of GPM practices. Our study furthermore suggests that BWM is a reliable MCDM method with greater applicability than ANP, as it requires significantly lower number of judgement comparisons.

1. Introduction

Ports play a significant role in fostering economic growth, in developing as well as developed countries (Munim and Schramm, 2018). Meanwhile, the role of modern ports extends beyond cargo handling to also facilitate agility and flexibility in global supply chains (Paixao and Bernard Marlow, 2003; Panayides, 2006), while balancing the triple bottom lines of port operation, that is, economic, environmental and social performance (Dushenko et al., 2019). This is also evident in the conceptual characterization of port development stages (generations), where the role of ports is seen to have evolved over time to become increasingly oriented towards addressing environmental impacts, even beyond compliance (Lee and Lam, 2015). Sustainability, a multidisciplinary concept, has been defined by researchers in different ways although the key tenet has been in line with the original Brundtland Report on sustainable development published by the United Nations in 1987, that is, securing the well-being of future generations while preserving the natural resources (Kates et al., 2001; Kuhlman and Farrington, 2010). Ports that balance the three dimensions of sustainability are often referred to as green ports (Cheon and Deakin, 2010; Chang and Wang, 2012; Lam and Notteboom, 2014; Bergqvist and Monios, 2018).

While ports are indispensable for the economy of a country, they do have adverse environmental impacts, as also recognized with the charter to implement the United Nation's 17 sustainable development goals (SDGs) that members of the World Port's Sustainability Program (previously known as the World Port's Climate Initiative) have recently signed, committing them to action programs in future-proofing infrastructure, climate and energy, social integration, safety and security, and ethical policy.

Previous research on the environmental and climate impact of maritime activity has focused more on analyzing and quantifying emissions from shipping than from ports (Bergqvist and Monios, 2018). According to Smith et al. (2014), the international shipping

* Corresponding author.
E-mail addresses: ziaul.h.munim@usn.no (Z.H. Munim), hs.si@cbs.dk (H. Sornn-Friese), Mariia.Dushenko@usn.no (M. Dushenko).

https://doi.org/10.1016/j.jclepro.2020.122156
0959-6526/

industry was responsible for 2.8% of the global greenhouse gas (GHG) emission during 2007–2012. Shipping also causes considerable local air pollution, accounting for approximately 5–8% of sulphur oxides (Sox) emission and 15% of nitrogen oxides (NOx) emission worldwide (Zis et al., 2016). According to the European Commission (n.d.), among all transport modes, maritime transport accounted for 13% of greenhouse gas (GHG) emission in Europe in 2014. Meanwhile, ports are facing growing pressure to minimize their environmental impact (Davarzani et al., 2016; Fenton, 2017). In 2018 the International Maritime Organization (IMO) adopted an ambitious GHG strategy for shipping and noted that ports would play a key role to achieve the set emission reduction targets. According to an earlier IMO commissioned study, community and public pressure, local and regional regulation, national and supranational legislation, and corporate social responsibility (CSR) are the primary environmental improvement drivers for reducing emissions at the ship-port interface (Anderson et al., 2015). It has also been argued that green port management (GPM) initiatives can contribute to raising the operational and economic performance of a port (Dushenko et al., 2019).

The level of adoption of environmental initiatives by ports differ from country to country and from port to port (Sornn-Friese and Poulsen, 2016). While there could be many reasons for the varying level of environmental initiatives taken by ports, the geographical, economic, regulatory and political contexts are crucial (Lam and Notteboom, 2014). In addition to these contextual factors, a port's governance model has a significant influence on its environmental initiatives (Faulin et al., 2018; Munim et al., 2020).

Port governance is a focal issue in port research, and several attempts have been made with the aim to categorize port governance models (Brooks, 2004; Monios, 2019). In the following, we apply the port governance typology developed by the World Bank (2007), which is one of the one most widely used classification (e.g. Munim et al., 2019). The World Bank (2007) distinguishes among four port governance models, based on port functions and with an increasing level of privatization: (1) service port, (2) tool port, (3) landlord port, and (4) private port (as depicted in Table 1). Among the port functions, (1) port infrastructure includes management of, e.g. quays, jetties, basins, land, (2) superstructure includes, e.g. buildings, port equipment, warehouses, (3) port labor simply refers to people working at ports, and (4) other functions include ancillary activities such as towage, pilotage, linesmen service etc.

Previous studies suggest that the landlord model yields maximum economic surplus on an aggregate level for both port authority and port users (Munim et al., 2019). However, when investigating five environmental frontrunner ports (the ports of Antwerp, Hamburg, Los Angeles, Rotterdam and Vancouver), Poulsen et al. (2018) found that emissions from tenants and mobile port users greatly exceeded the level of port authority operations. As the number of tenants and port users typically increases from service port towards landlord port, one could claim that the governance models for most suitable GPM would be the service port model, as this model would have the lowest number of tenants involved in port operations. Hence, service ports are likely to experience lower tool implementation complexity than both tool and landlord ports, a point also raised by Brooks (2004). Indeed, Poulsen et al. (2018) showed that with greater tool implementation complexity, it is less likely that a port adopts environmental management beyond certain port authority operations. Previous studies of port reform and port governance, on the other hand, have found some evidence that increasing private sector participation and port corporatization lead to increased operational efficiency (Cullinane and Song, 2003; Cullinane, 2010), however subject to geographical context and the particular level of activity of a port (Tongzon, 1995). Indeed, according to the World Bank (2007), sustainability in ports is an area ripe for innovative privatization concepts, as many of the GPM functions can be performed by the private sector.

Against this background, and with the growing environmental concern of port stakeholders, it has become an important question to address — which port governance model is the most viable to GPM? To address this question, relying on social systems engineering (SSE) principles, we developed a multi-criteria decision making (MCDM) framework using the four port governance models depicted in Table 1 as alternatives and five GPM practice indicators as criteria. For greater reliability, we compare two MCDM methods, the Analytic Network Process (ANP) and the Best-Worst Method (BWM), in repeated measures experimental setting.

We collected data from port executives in three countries of the Indian Ocean Rim — Bangladesh and Sri Lanka in the Bay of Bengal and Tanzania in the Arabian Sea. With nearly 40% of the world's containerized cargo and 80% the world's oil shipments passing through this region, the Indian Ocean plays a key role in world trade. It accommodates 30% of the world's coral reefs as well as some of the largest estuaries and marine ecosystems and it is thus vital to ocean sustainability (Economist Intelligence Unit, 2018). At the same time, the majority of littorals in the region are developing countries that depend on marine resources for their livelihood and food supply. This is clearly reflected in the recent focus of the governments in Sri Lanka and Bangladesh, by promoting the so-called Blue Economy in a sustainable, stable and inclusive manner, as well as by the broader notion of the Indian Ocean Rim as the "Ocean of the Future" (Doyle, 2018). Our results from both the ANP and BWM show that increasing the level of privatization in port governance would improve GPM implementation in this important maritime region.

In the next section, we present a review of GPM practices. Section 3 explains the development of the MCDM framework, data collection and step-by-step calculation procedure of priorities in ANP and BWM. Section 4 presents the most important GPM criteria and the priorities for the right port governance model for GPM implementation. Aggregate level priorities are discussed in Section 5. Finally, Section 6 concludes with managerial implications and future research directions.

Table 1
Port governance models.

Governance models/Functions	Service	Tool	Landlord	Private
Infrastructure	Public	Public	Public	Private
Superstructure	Public	Public	Private	Private
Port labor	Public	Private	Private	Private
Other functions	Public	Mostly public	Mostly private	Private

Adopted from World Bank Port Reform Toolkit, Module 3, p. 85.

2. Literature review

Research on green ports is still in its infancy and many aspects still need to be investigated (Davarzani et al., 2016; Bergqvist and Monios, 2018). Previous literature on the topic was mostly dedicated to identifying the environmental indicators for green port development, especially the indicators for monitoring operational, managerial and environmental performance of ports (Chen and Pak, 2017; Puig et al., 2014; Puig et al., 2015). Using the Analytic Hierarchy Process (AHP) method, Chiu et al. (2014) rated five environmental indicators of ports, where environmental quality (measured in terms of water, air, land and noise pollution) ranked the highest followed by energy and resource utilization, habitat quality, waste handling, and social performance. Lam and Notteboom (2014) developed a framework for environmental management strategies for ports based on measuring and monitoring emissions, standard environmental regulations, market access control and pricing.

Recently, studies have examined the role of different GPM strategies on improving environmental impact. Chang and Wang (2012) estimated that a 57.16% reduction in CO_2 emission in ports could be achieved by adopting onshore power supply (OPS). Further, Yang and Chang (2013) found that electric rubber-tired gantry cranes offer a 67.79% reduction in CO_2 emission in addition to energy savings of 86.60%. Green vehicle technology (Kavakeb et al., 2015) and green port dues (Bergqvist and Egels-Zandén, 2012) also contribute significantly to green port development. From previous studies, we identified five broad yet distinctive categories for GPM: port's internal environmental management practices, sustainable port operations, environmental pricing, green technology, and maritime supply chain collaboration. In the following, we briefly outline each of these five GPM practice indicators.

Internal Environmental Management (IEM) practice refers to the existence of an environmental management system in a port, that is, a system for measuring and monitoring emissions, and reporting in the port's annual or sustainability report (Lam and Notteboom, 2014; Puig et al., 2014). Most ports with IEM in Europe are members of the EcoPorts[1] self-regulation initiative, which has been fully integrated into the European Sea Port Organization (ESPO) since 2011. IEM also includes port's communication with local government to improve sustainability, training employees on sustainable practices and allocation of dedicated budgets for sustainable port performance (Chen and Pak, 2017; Puig et al., 2014).

Sustainable Port Operations (SPO) refer to lean operations at the port, for example, minimizing cargo movements, optimizing equipment use, speeding up vessel loading and unloading time (Notteboom and Lam, 2018; Yang and Chang, 2013). Also, sustainable port operating systems, such as autonomous or semi-autonomous terminal management (Kavakeb et al., 2015; Yang and Lin, 2013) and reconfiguring existing terminals (Geerlings and Van Duin, 2011; Yap and Lam, 2013) are considered as sustainable port operations.

Environmental Pricing (EP) can have three dimensions: dynamic, incentive and penalty pricing. Dynamic pricing can refer to adjusting port dues to ships based on emissions on the last voyage (Bergqvist and Egels-Zandén, 2012). An example of incentives pricing is offering reduced port dues to ships scoring high on the Environmental Ship Index, a private standard launched in 2010 by the World Port's Climate Initiative, for reducing air emissions from ships, while an example of penalty pricing could be surcharges and fines to port operators and ships based on low environmental performance (Lam and Notteboom, 2014; Notteboom and Lam, 2018).

Green Technology (GT) can include cold ironing, that is, providing electrical power from shore to a ship when at berth (Chang and Wang, 2012; Poulsen et al., 2018), energy efficient hardware and data centers (Kusi-Sarpong et al., 2016), and cleaner technologies such as electric rubber tired gantry cranes (Lam and Notteboom, 2014; Lu et al., 2016).

Supply Chain Collaboration (SCC) refers to a port authority's collaboration with port operators, other ports in proximity, shippers, shipping lines and other (hinterland) transport providers to achieve environmental goals (Lu et al., 2016; Lun, 2011).

3. Methodology and data

We consider the question of which port governance model is the most viable for GPM as analogous to a complex decision-making problem. Social systems engineering (SSE) principles are particularly useful in solving such problems. According to Wang et al. (2018), "SSE extensively applies principles and concepts of various sciences and knowledge domains to plan, create, design, operate, manage, and improve complex social systems for achieving expected effects and goals that are mutually satisfactory" (p. 25). In the context of this study, the social system includes individuals working at ports and ports themselves as social units. The goal is to implement GPM practices which is measured by multiple criteria. Physical (e.g. port infrastructure, superstructure) and non-physical (e.g. governance models) environments within a certain boundary govern the social system within which individuals and social units interacts.

3.1. MCDM framework and methods choice

To design this study involving a complex social system, we first had to decide which governance models (alternatives) and GPM practices (criteria) to consider for investigation. Based on the above-referenced literature, we have selected four port governance models (see Table 1) and five GPM practices (see Section 2). The decision level here is to select an alternative from the four governance models considering the five criteria of GPM (see Fig. 1). This motivates us to investigate the issue using a MCDM approach. AHP (Saaty, 1990, 1994) and ANP (Saaty, 1996) are the most widely used methods for MCDM. AHP have been widely applied in the maritime literature (Lirn et al., 2004; Song and Yeo, 2004; Tseng and Cullinane, 2018; Yuen et al., 2012), but ANP applications to decision problems in the maritime context have been rather limited so far (Lam and Lai, 2015; Lee et al., 2013; Ren et al., 2018). In contrast, a wide range of applications of ANP can be observed in studies of other sectors (Chung et al., 2005; Lin et al., 2015; Niemira and Saaty, 2004; Wu and Lee, 2007). Conceptually, AHP is limited to hierarchical associations among goals and criteria and requires that the decision criteria are independent from each other. In the development stage of the study, we consulted four maritime experts (two scholars and two port executives) on the associations among the selected GPM practices, and everyone agreed that the selected practices are interdependent. In line with relevant studies (e.g. Chen et al., 2019), the experts also suggest that each of the criteria are positively associated with others indicating that ports that implement one or more of the GPM practices are likely to implement others. Thus, hierarchical associations will fail to capture the true associations, and to allow consideration of the interdependence among criteria we adopt the ANP method.

However, the data requirement, that is, number of pairwise comparisons for complex ANP models, is challenging. Thus, we also used the recently developed BWM (Rezaei, 2015, 2016) for comparison. Several studies has used BWM for MCDM on several topics, including environmental supplier selection (Rezaei et al., 2016), the social sustainability of supply chains (Ahmadi et al., 2017), and R&D performance evaluation (Salimi and Rezaei, 2018). In the sections

[1] https://www.ecoports.com/.

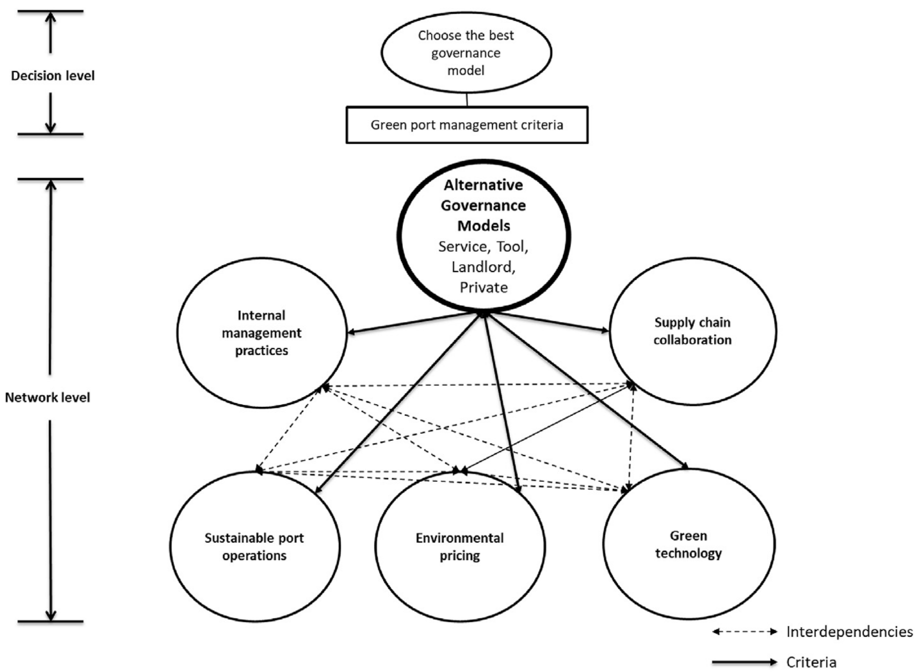


Fig. 1. MCDM framework for port governance model selection for GPM.

Table 2
Sample ports in this study.

Respondent	Selected ports	Relevant experience	Respondent's education
Respondent A	Port of Chittagong	27 years	MSc (WMU)
Respondent B	Port of Colombo	7 years	MSc (WMU)
Respondent C	Port of Dar es-Salaam	9 years	MSc (WMU)

WMU. World Maritime University.

3.3 and 3.4, we present the steps in ANP and BWM modelling, while in section 3.2, we provide an overview of the respondents surveyed.

3.2. *Overview of respondents*

As it is difficult to identify the four port governance models within the context of any particular country, the judgments for pairwise comparisons were conducted with three port executives from three different countries, selected through theoretical sampling. Because we wanted to investigate GPM in the Indian Ocean Rim, we contacted a Professor at the World Maritime University (WMU) in Sweden, as the primary goal of WMU is to train port executives from developing countries. The professor distributed the invitation to participate in this study to his students who were all port executives with five or more years of experience. Three students agreed to participate in the ANP survey in January 2019. In August 2019, we once again contacted the same three port executives and conducted the survey for BWM. When doing the ANP survey in January, the port executives were not aware of our intention to conduct a BWM survey in August. This approach is similar to a repeated measures experimental design, i.e., the alternatives and criteria of the MCDM framework remain the same but data was collected in an interval of six months using two different methods.

The respondents represent the Port of Chittagong in Bangladesh, Sri Lanka's Port of Colombo and Tanzania's Port of Dar es-Salaam. The respondents had a minimum of seven years and a maximum of 27 years of experience from working in the port industry. Table 2 provides an overview of the respondents. All respondents hold a master's degree in either Port Management or Shipping Management & Logistics from the WMU.

Respondent A has worked at the Chittagong Port (CP) for 27 years. CP is by far the largest port in Bangladesh, handling more than 90% of the country's container traffic. It was the 64th largest container port in the world in 2019.[2] When Respondent A joined CP in the early 1990s, the port was a service port. In 2007, CP introduced the tool port model for two of its container terminals. Although there has been some initiative to transform at least one of CP's terminals to a landlord port model, it has not happened yet. While Respondent A is currently Terminal Manager of one of the port's container terminals under the tool port model, he is also knowledgeable of the yet-to-be developed deep seaport of Bangladesh under the landlord port model. Thus, he has extensive knowledge of port operation.

Respondent B is currently working as an Operations Manager at one of the container terminals of the Port of Colombo (ranked 24 container port in the world in 2019)[2] that is operated in the service port model. Apart from the service port model terminal, the Port of Colombo has two other container terminals functioning under the landlord port model in a build-operate-transfer (BOT) concession

[2] https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2019.

for 30 and 35 years, respectively.

Respondent C is currently working at the Tanzania Regulatory Authority for Ports. During the period 2010–2013, he was employed with the Tanzania Port Authority of the Port of Dar es-Salaam. According to Respondent C, most of the ports in Tanzania are currently functioning under the tool port model but aiming to change into the landlord port model.

3.3. Analytic Network Process (ANP)

According to Saaty (1996), the originator of AHP/ANP methods, ANP is an MCDM method that allows to quantify subjective judgments and evaluate interdependencies among the elements of a system. Instead of a hierarchical ordering of the decision problem, ANP structures problems as networks, where the elements or components of the network are compared with each other so that interdependencies among the elements can be analyzed in a pairwise comparison matrix. The final output of the ANP are supermatrices that enable decision-making based on priorities of elements of the system (Saaty, 1996). Fig. 1 presents our ANP framework applied to port governance selection for GPM. The network of components for ANP in this study includes the four alternative port governance models and the five GPM practices. As there are some numerical applications in ANP modelling, stages of ANP in this study can be demonstrated in six step. We used the Super Decisions software (www.superdecisions.com) for modelling purpose, which has already been used by others, e.g. Farias et al. (2019) and Munim et al. (2020).

STEP1. Formulation of the problem

The first step in the ANP model was to identify the alternatives for decision-making and a set of criteria that can vary under each of the alternatives. We then formed the theoretical ANP model considering interdependencies among criteria and alternatives based on the green port literature as depicted in Fig. 1. We consider four port governance models — service port, tool port, landlord port and private port — as alternatives, and five GPM practices — internal environmental management, sustainable port operations, environmental pricing, green technology, supply chain collaboration — as criteria. Before proceeding with the survey, the MCDM framework depicted in Fig. 1 was validated through discussion with the three port executives chosen as respondents (see Section 3.3), and they also confirmed interdependency relationships among the five criteria.

STEP2. Pairwise comparison matrixes of criteria in relation to goals

According to the ANP model in Fig. 1, first we need to conduct pairwise comparisons of five GPM criteria with respect to each of the port governance models. Judgments on all pairwise comparisons were taken from the three port executives. For all pairwise comparisons, they responded on a scale from 1 to 9 (Table 3), originally developed by Saaty (1990). We present a generic illustration of a pairwise comparison matrix in Appendix A. In STEP3-6, we provide an example using data from our first respondent. While performing pairwise judgments, inconsistency of judgment could be an issue. Usually, consistency ratio (CR) of up to 0.20 is considered tolerable (Saaty, 1990), and each of the 42 (3 x 14) matrices in our study meets this requirement.

STEP3. Pairwise comparison matrixes of alternatives in relation to criteria

The first set of matrices is an outcome of the pairwise comparisons among criteria with respect to each of the four port governance models. Table 4 provides an example of a pairwise matrix from our first respondent. In one of the pairwise comparison questions, we asked the respondents the following question: *"With respect to service port governance model, which criterion between environmental pricing and green technology can be implemented better?"* The respondent said that green technology can be two times better implemented than environmental pricing under the service port governance. This response corresponds to values in the cell (4,3) and (3,4) in Table 4. As both cells represent answers to the same questions, one value (e.g., 2) is reciprocal to another (e.g., 1/2). We can calculate the number of required pairwise comparisons from $[n(n-1)/2]$. Here, n is the number of criteria. As we have five GPM criteria to be evaluated with respect to each of the four port governance models, we conduct 40 (4 x 10) pairwise comparisons with respect to four governance models per respondent.

STEP4. Pairwise comparison among alternatives in relation to sustainable port operations

Similar to STEP3, respondents evaluated the four port governance model alternatives for each of the five GPM criteria. Table 5 is an example of one of the pairwise matrices of our first respondent. In one of the pairwise comparison questions, we asked, *"With respect to the sustainable port operation criterion, which alternative port governance models between landlord and private port is more viable?"* The respondent said that the private port governance model is twice more viable than the landlord port model when it comes to better implementation of sustainable port operations. This response corresponds to values in the cell (3,4) and (4,3) in Table 5. Again, as both cells represent answers to the same question, one value (1/2) is reciprocal to another (2). As we have four alternative port governance models with respect to each of the five GPM criteria, we conduct 30 (5 x 6) of such pairwise comparisons per respondent.

STEP5. Pairwise comparison matrixes of all criteria in relation to each other

In STEP5, respondents evaluated the influence of the five GPM criteria with respect to each of them. We give an example of such a pairwise comparison matrix of our first respondent in Table 6. In one of the pairwise comparison questions, we asked, *"Which criterion between environmental pricing and green technology influences the sustainable port operations criterion the most?"* The respondent said that both criteria influence sustainable port operations equally. This response corresponds to values in the cell (2,3) and (3,2) in Table 6. As both cells represent answers to the same question, one value (1) is reciprocal to another (1). Here, we conduct 30 (5 x 6) of such pairwise comparisons per respondent.

STEP6. Final scores of alternatives

We present a three-stage calculation in Tables 7–9 to find priority of the four alternatives or five GPM criteria. We present the calculation stages using the matrix in Table 5 as an example, where Table 7 shows calculation of the column-wise sums in Stage 1, Table 8 shows standardized values by dividing with their respective column-wise sum in Stage 2 and Table 9 shows priorities based on calculation of the row-wise average in Stage 3. The priority values in Table 9 are the same as in the unweighted supermatrix in Appendix B. We get the weighted supermatrix (see Appendix C) after multiplying the values in the unweighted supermatrix by their respective cluster weights (see Appendix D). We then raise the

Table 3
Saaty's fundamental scale.

Value	Definition	Explanation
1	Equal importance/contribution/relation	Two elements contribute equally.
3	Weak importance/contribution/relation	Judgment slightly favors one activity over another.
5	Strong importance/contribution/relation	Judgment strongly favors one activity over another.
7	Very strong importance/contribution/relation	An activity is strongly favored, and its dominance demonstrated in practice.
9	Extremely strong importance/contribution/relation	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values	When compromise is needed.

Adopted from Saaty (1990).

Table 4
Pairwise comparison matrix of GPM practices with respect to service port model.

Service port model	IEM	SPO	EP	GT	SCC
Internal Environmental Management (IEM)	1	1/3	3	3	1/2
Sustainable Port Operations (SPO)	3	1	3	3	2
Environmental Pricing (EP)	1/3	1/3	1	1/2	1/4
Green Technology (GT)	1/3	1/3	2	1	1/3
Supply Chain Collaboration (SCC)	2	1/2	4	3	1

Inconsistency: 0.05.

Table 5
Pairwise comparison matrix of port governance alternatives with respect to sustainable port operations.

Sustainable port operation	Service	Tool	Landlord	Private
Service	1	1/2	2	2
Tool	2	1	3	2
Landlord	1/2	1/3	1	1/2
Private	1/2	1/2	2	1

Inconsistency: 0.03.

Table 6
Pairwise comparison matrix on the influence of GPM practices with respect to sustainable port operations.

Sustainable port operations	IEM	EP	GT	SCC
Internal Environmental Management (IEM)	1	2	2	2
Environmental Pricing (EP)	1/2	1	1	2
Green Technology (GT)	1/2	1	1	2
Supply Chain Collaboration (SCC)	1/2	1/2	1/2	1

Inconsistency: 0.02.

Table 7
Stage 1 → Column-wise sum of port governance alternatives with respect to sustainable port operations.

Sustainable port operations	Service	Tool	Landlord	Private
Service	1.000	0.500	2.000	2.000
Tool	2.000	1.000	3.000	2.000
Landlord	0.500	0.333	1.000	0.500
Private	0.500	0.500	2.000	1.000
Sum	4.000	2.333	8.000	5.500

Table 8
Stage 2 → Standardize values of port governance alternatives with respect to sustainable port operations.

Sustainable port operations	Service	Tool	Landlord	Private
Service	0.250	0.214	0.250	0.364
Tool	0.500	0.429	0.375	0.364
Landlord	0.125	0.143	0.125	0.091
Private	0.125	0.214	0.250	0.182

Table 9
Stage 3 → Priorities of port governance alternatives with respect to sustainable port operations.

Sustainable port operations	Service	Tool	Landlord	Private	Priority[a]
Service	0.250	0.214	0.250	0.364	0.269
Tool	0.500	0.429	0.375	0.364	0.417
Landlord	0.125	0.143	0.125	0.091	0.121
Private	0.125	0.214	0.250	0.182	0.193

[a] Values of the SPO in the unweighted supermatrix.

weighted supermatrix to its powers until all column-wise values stabilize and form the limit matrix (see Appendix E). Finally, we get the priorities of the alternatives and criteria after normalizing (see Appendix F) the values in the limit matrix.

3.4. Best-Worst Method (BWM)

BWM is a recent addition of the MCDM methodology group. In BWM, a decision-maker first compares the best alternative to other alternatives and then other alternatives to the worst alternative. This process generates two comparison vectors. Finally, we estimate optimal weights from the two vectors using a simple linear programming algorithm. Here, we present a six-step process for port governance model selection for better implementation of GPM practices. For further details on BWM, please see Rezaei (2015) and Rezaei (2016).

STEP1. Formulation of the problem

This step is the same as the first step in ANP, that is, we determined the criteria to be evaluated for decision-making about the port governance model alternatives. As one of the goals of our study is to compare ANP and BWM, we again used the four port governance models as alternatives and the five GPM practices as criteria.

STEP2. Find the best and the worst criteria

In the second step we asked the respondents, *"Which of the five criteria is the most important for GPM?"* and *"which of the five criteria is the least important for GPM?"*. Two of the three respondents said that sustainable port operation is the most important criterion and one said that supply chain collaboration is the most important one (see Table 10). The respondents agreed that environmental pricing is the least important of the five criteria (see Table 11).

STEP3. Find the preference of the best criterion over all other criteria

In step 3, we asked the respondent to rank the importance of the best criterion over all other criteria. Similar to ANP, respondents used a 1–9 scale (see Table 3) for the ranking, where 1 stands for

Table 10
Best to others vector.

Respondent	Best	IEM	SPO	EP	GT	SCC
A. Chittagong	SPO	3	1	4	5	1
B. Colombo	SCC	3	1	4	5	5
C. Dar es-Salaam	SPO	5	4	4	4	1

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.

Table 11
Others to worst vector.

Respondent	Worst	IEM	SPO	EP	GT	SCC
A. Chittagong	EP	2	4	1	6	6
B. Colombo	EP	6	4	1	5	5
C. Dar es-Salaam	EP	4	5	1	5	4

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.

equal importance of the two criteria and 9 stands for extreme importance of one criterion over another. As a result, the best-to-others-vector A_B (see Table 10) would be:

$$A_B = (a_{b1}, a_{b2}, \dots, a_{bn}) \tag{1}$$

Here, a_{bj} indicates the preference of the best criterion b over the criterion j. b represents the most important criterion perceived by a respondent. For example, according to the executive of Chittagong port, SPO is the most important criterion (Table 10). $j(1,2,\dots,n)$ represents the number of criteria considered in the study, herein, the five GPM practices.

STEP4. Find the preference of all other criteria over the worst criterion

Similar to STEP3, on a scale from 1 to 9, respondents ranked the importance of all other criteria over the worst criterion. As a result, the others to worst vector A_W (see Table 11) would be:

$$A_W = (a_{1w}, a_{2w}, \dots, a_{nw}) \tag{2}$$

Here, a_{jw} indicates the preference of the criterion j over the worst criterion $w.w$ represents the least important criterion perceived by a respondent. For example, according to the three port executives, EP is the least important criterion (Table 11). $j(1,2,\dots,n)$ represents the five GPM practices.

STEP5. Estimate optimal weights

Following Rezaei (2016), we need to minimize the absolute differences $(|w_b - a_{bj}w_j|, |w_j - a_{wj}w_w|)$ for all j to find the optimal weights of a criteria, which can be found by soling the set of equations in (3) using liner programming.

$$\begin{aligned} &\min \delta^L \\ &s.t. \\ &|w_b - a_{bj}w_j| \le \delta^L, for\ \ all\ \ j \\ &|w_j - a_{jw}w_w| \le \delta^L, for\ \ all\ \ j \\ &\sum_j w_j = 1 \\ &w_j \ge 0, for\ \ all\ \ j \end{aligned} \tag{3}$$

Here, a_{bj} indicates the preference of the best criterion b over the criterion j $(1,2,\dots,n)$ and a_{jw} indicates the preference of the criterion j $(1,2,\dots,n)$ over the worst criterion w. The values of a_{bj} and a_{jw} are obtained from the survey as shown in Tables 10 and 11, respectively. w_b, w_w and w_j represents the optimal weights of the best, worst and other criteria, respectively. By solving the set of equations in (3), we estimate the optimal weights of the criteria $w_j(w_1^*, w_2^*, \dots, w_n^*)$ and the optimal value of δ^L, that is, δ^{L^*}. δ^{L^*} represents the consistency ratio of the comparison procedure in BWM. We use the Solver Linear BWM Excel file (http://bestworstmethod.com/software/) to solve (3). Table 12 presents the optimal weights and consistency ratio of each of the GPM practices.

STEP6. Final scores of alternatives

To find the final scores of the alternatives, first we need GPM practice implementation scores under different port governance model alternatives. Therefore, we asked respondents to rate feasible implementation of each of the five GPM practices under the four alternatives along a 1–9 scale, where 1 refers to 'not implemented at all' and 9 refers to 'most implemented'. As an example, Table 13 shows the responses from the first respondent.

Then, to normalize the values in Table 13, we divide each value by their column-wise maximum value (see Table 14).

We subsequently multiply each of the normalized values in Table 14 by their respective weights. Finally, taking the row-wise averages gives us the final priority scores of each of the governance model alternatives (see Table 15). This process can be expressed by the equation (4):

$$F_i = \sum_{j=1}^{n} w_j x_{ij}^{norm} \tag{4}$$

F_i is the final score of the alternative i and x_{ij}^{norm} is the normalized scores of criterion j under alternative i. Alternative i includes the set of four port governance model alternatives (i.e. service, tool, landlord and private) and criterion $j(1,2,\dots,n)$ represents the five GPM practices.

4. Results

The aggregation of judgment or priorities depends on whether the respondents are supposed to act together as a unit or individually. While our goal is to identify the most viable port governance model for GPM in the Indian Ocean Rim, it is obvious that different ports in the region function under different settings. Thus, aggregation of individual priorities (not judgments) using the geometric mean is recommend by Forman and Peniwati (1998) and Ossadnik et al. (2016). We calculate individual and aggregated priorities using the Super Decisions software for the ANP model and the Solver Linear Excel file for the BWM model. Tables 16 and 17 show the results, respectively.

Table 12
Optimal weights.

Respondent	IEM	SPO	EP	GT	SCC	δ^{L^*}
Chittagong	0.160	0.320	0.040	0.080	0.400	0.160
Colombo	0.217	0.457	0.065	0.130	0.130	0.196
Dar es-Salaam	0.131	0.164	0.070	0.164	0.469	0.188

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration, δ^{L^*}: Consistency ratio.

Table 13
GPM implementation under governance models (Chittagong example).

Governance	IEM	SPO	EP	GT	SCC
Service	6	6	2	6	7
Tool	6	5	1	4	6
Landlord	6	5	4	4	6
Private	6	5	4	5	6

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.

Table 14
Normalized values and criteria weights (Chittagong example).

Governance	IEM	SPO	EP	GT	SCC
Weights	0.160	0.320	0.040	0.080	0.400
Service	1.000	1.000	0.500	1.000	1.000
Tool	1.000	0.833	0.250	0.667	0.857
Landlord	1.000	0.833	1.000	0.667	0.857
Private	1.000	0.833	1.000	0.833	0.857

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.

Table 15
Priority of alternatives (Chittagong example).

Governance	IEM	SPO	EP	GT	SCC	Average
Service	0.160	0.320	0.020	0.080	0.400	0.196
Tool	0.160	0.267	0.010	0.053	0.343	0.167
Landlord	0.160	0.267	0.040	0.053	0.343	0.173
Private	0.160	0.267	0.040	0.067	0.343	0.175

IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.

Based on Table 16, on the individual priority level, Respondent A suggests service port, while Respondent B and C suggest private port governance as the most viable to GPM practice implementation. On the aggregate level, private port governance would be the most viable followed by the tool, landlord and service port models. As of GPM practice, Respondent A gives highest priority to sustainable port operation, Respondent B to internal environmental management system and Respondent C to supply chain collaboration. For GPM practice priority on the aggregate level, the most important criterion is sustainable port operation followed by green technology, internal environmental management, sustainable collaboration and environmental pricing.

The ANP and BWM models produce identical results. The priority ranking of the most viable port governance model by each respondent remains the same in the two analyses. Similarly, on the aggregate level, private port governance would be the most viable followed by landlord, service and tool port governance models. With respect to GPM practices, some differences between the ANP and BWM results are evident. However, environmental pricing is the least important among the five GPM practices both in ANP and BWM.

5. Discussion

The role of privatization in environmental performance is generally believed to be paradoxical (Beladi and Chao, 2006). Fig. 2 presents the ANP, BWM and ANP-BWM aggregate level priorities for the five GPM criteria (a,c,e) and for the four port governance model alternatives (b,d,f). As of priorities of criteria on the ultimate aggregate level (i.e., aggregated score of ANP and BWM by taking their arithmetic mean) depicted in Fig. 2(e), sustainable port operation is the most important criterion followed by supply chain collaboration, internal environmental management, green technology and environmental pricing. On the ultimate aggregate level shown in Fig. 2(f), the most viable port governance model for GPM practice implementation would be private port followed by landlord, service and tool port. One reason for the tool port model being the least preferred could be that division of responsibility in core port operations, among port authority and small private operators, can lead to conflict of interests (Brooks, 2004).

Bangladeshi ports operated under the service port model until 2007. Today, all ports in Bangladesh are either service or tool ports, although soon one of the terminals in the Port of Mongla, the second busiest port in the country, would start operation under the landlord port model (The Daily Star, 2016). However, both in tool and landlord port governance, the currently involved private companies in Bangladesh are local private companies. *"Due to the poor institutional environment in Bangladesh, local private companies would be less viable than the government organizations in caring for society and environment, as it is likely that local private port operators would concentrate on profit maximization"*, said Respondent A during data collection process. This explains the logic behind Respondent A's preference for the service port governance for GPM practices. On the contrary, lack of competition and dependence on government funding under the service port model can lead to inefficiency, lack of innovation and underinvestment (Brooks, 2004).

In Sri Lanka, private companies involved (in the landlord model) are renowned global terminal operators (GTOs), such as South Asia Gateway Terminals (SAGT) (Sri Lanka's first public-private partnership in consortium with APM Terminals, Lanka Marine Services and Mackinnon Mackenzie & Co.) and Colombo

Table 16
Priorities using ANP.

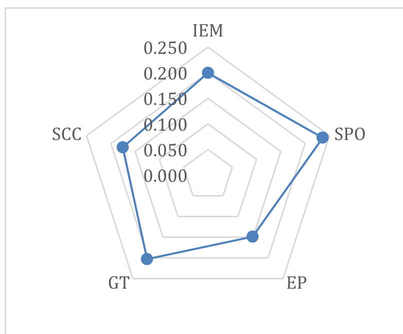
	Respondent A(Chittagong)	Respondent B(Colombo)	Respondent C(Dar es-Salaam)	Geometric mean
Port governance models				
Service port	**0.366**	0.212	0.161	0.217
Tool port	0.321	0.234	0.227	0.235
Landlord port	0.136	0.201	0.209	0.224
Private port	0.177	**0.353**	**0.403**	**0.266**
Green port management practice				
Internal management	0.183	**0.264**	0.115	0.200
Sustainable operation	**0.311**	0.196	0.231	**0.236**
Environmental pricing	0.165	0.124	0.117	0.149
Green technology	0.145	0.262	0.249	0.203
Supply chain collaboration	0.196	0.154	**0.288**	0.175

Bold indicates highest priority.

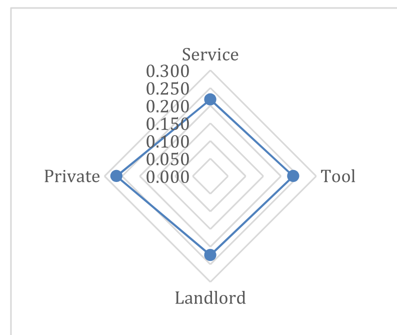
Table 17
Priorities using BWM.

	Respondent A(Chittagong)	Respondent B(Colombo)	Respondent C(Dar es-Salaam)	Geometric mean
Port governance models				
Service port	**0.196**	0.134	0.175	0.166
Tool port	0.167	0.128	0.145	0.146
Landlord port	0.173	0.178	0.198	0.183
Private port	0.175	**0.200**	**0.200**	**0.191**
Green port management practice				
Internal management	0.160	0.217	0.131	0.166
Sustainable operation	0.320	**0.457**	0.164	0.288
Environmental pricing	0.040	0.065	0.070	0.057
Green technology	0.080	0.130	0.164	0.119
Supply chain collaboration	**0.400**	0.130	**0.469**	**0.290**

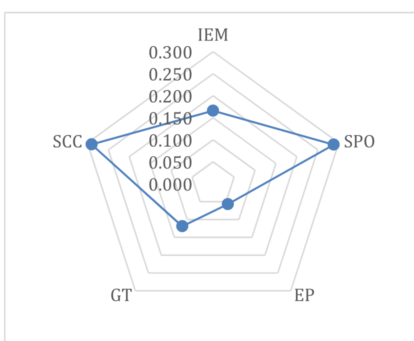
Bold indicates highest priority.



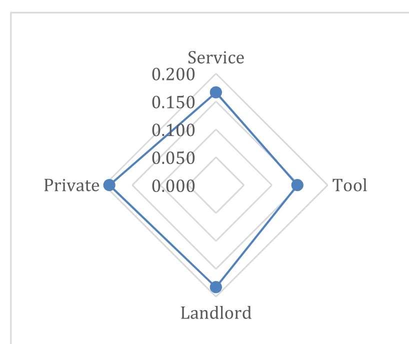
(a) ANP criteria aggregate-Geomean



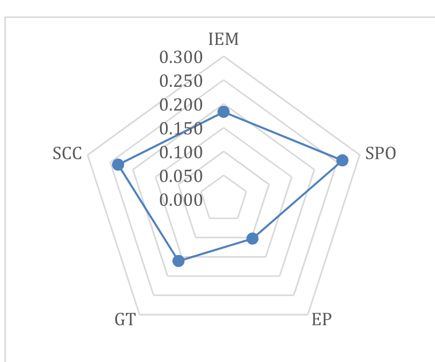
(b) ANP alternatives aggregate-Geomean



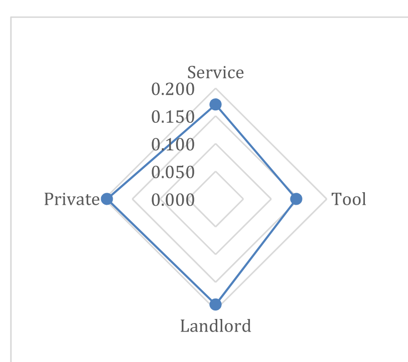
(c) BWM criteria aggregate-Geomean



(d) BWM alternatives aggregate-Geomean



(e) ANP-BWM criteria aggregate-Mean



(f) ANP-BWM alternatives aggregate-Mean

Fig. 2. Aggregate priorities for GPM (*IEM: Internal Environmental Management, SPO: Sustainable Port Operations, EP: Environmental Pricing, GT: Green Technology, SCC: Supply Chain Collaboration.*). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

International Container Terminals Ltd. (CICT) (a joint venture between China Merchants Port Holding and the Sri Lanka Port Authority). These GTOs are much faster in introducing new technologies compared to the government authorities. This was also reflected in a statement by Respondent B, who said that *"we (in the public service terminal) have been planning to implement GPM practices for a long time, but the Chinese GTO in the private terminal (CICT) switched all rubber-tired gantries with electric rubber-tired gantries already, and we (in the public service terminal) are still planning"*. This could be one reason why Respondent B prioritized private port governance for GPM. According to Respondent C, *"although government authorities are willing to serve the society, sometimes they are not capable of implementing GPM practices and there is nobody to push the government authorities. However, the government authorities can push the private port to adopt GPM practices"*. In support of this line of argument, there are examples of private ports, such as, the Port of Felixstowe in the United Kingdom (UK), which perform excellent in terms of GPM practices. On the other hand, as a developed economy the UK has an advanced supportive institutional environment, which is not the case in most developing countries.

Although, it is widely believed that private firms focus mostly on profit generation, Lun (2011) found that GPM positively influence port performance. Thus, private firms operating a port would consider investing in GPM to maximize their profit, indirectly. However, the private port governance model may lead to "monopolistic behavior as well as a loss of public involvement in developing long-term economic policy and strategies" (Brooks, 2004, p. 171). Therefore, we suggest that increasing private participation in port operations, particularly through involvement of well-known GTOs via the landlord port governance would be the best alternative for better GPM practice implementation in the developing countries in the Indian Ocean Rim.

6. Conclusion

This study examined the viability of port governance models in implementing GPM practices. Methodologically, we formulated a MCDM framework considering four port governance models and five GPM practices as network of elements. We compared and aggregated the results from two MCDM methods, ANP and BWM. ANP is one of the widely used MCDM methods, which helps to quantify subjective judgments (Saaty, 1996), and BWM is the most recently developed MCDM method (Rezaei, 2015, 2016). We collected subjective judgments on five GPM practices with respect to four port governance models from port executives in three developing countries in the Indian Ocean Rim, namely, Bangladesh, Sri Lanka, and Tanzania. We analyzed the judgements using the ANP Super Decisions software and the Solver Linear BWM Excel file. We have found that increasing privatization in port governance would improve GPM implementation in these countries.

The study has several implications for port management practice. First, considering the priorities of the five GPM practices (see Fig. 2), port authorities should focus on introducing sustainable port operations such as cargo movements and equipment use optimization, speeding up vessel loading and unloading time, and upgrading to autonomous or semi-autonomous terminal management systems. Collaboration initiatives should be taken among terminals within a port or neighboring ports for better GPM implementation. Second, although the private governance model obtained the highest priority, we recommend port authorities to consider the landlord model, the second-highest priority. This recommendation is based on the host country contextual factors (i.e. social system) of the studied ports and possible drawbacks of the landlord model such private port owner's monopolistic behavior, speculation with the port land and lack of interest in long-term development. Finally, as stated by Respondent C, the landlord model provides the opportunity for the port authority to push the private operator to implement GPM practices which otherwise would take decades for a public port authority to implement due to bureaucracy, particularly in the social system a developing country.

This study certainly has a few limitations. We have collected data from three port executives from three different ports in three different countries. Although this permits theoretical generalizability of the studied phenomenon, generalizability of the findings to a larger population should be avoided. Hence, we plan to conduct a large-scale survey using the proposed MCDM framework. Besides, future research should examine the most viable port governance model in the context of more developed economies in the main maritime trade corridors and consider comparison between ports in different regions. Also, nowadays, most of the medium and large ports use different port governance models for different terminals. Thus, comparing GPM practices under different governance models of terminals within the same port might reveal novel insights. In contrast to traditional belief, we find that higher degree of privatization in port governance can improve GPM implementation. This phenomenon needs further investigation, particularly using qualitative methods. From methodological perspective, instead of linear programming, forming BWM like MCDM methods based on other optimization techniques such as simulated annealing algorithm (Duan et al., 2018) or augmented penalty algorithm (Gharaei et al., 2019) might be useful.

CRediT authorship contribution statement

Ziaul Haque Munim: Conceptualization, Data curation, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Henrik Sornn-Friese:** Conceptualization, Writing - original draft, Writing - review & editing. **Mariia Dushenko:** Writing - original draft, Validation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors thank the three port executives for participating in the study and Assistant Professor Satya Sahoo from the World Maritime University for helping with data collection.

Appendix H. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122156.

Appendix A. *Pairwise comparison matrix*

With respect to e_g	e_1	e_2	…	e_j	…	e_n	Relative importance
e_1	1	a_{12}^g	…	a_{1j}^g	…	a_{1n}^g	w_1^g
e_2	$\frac{1}{a_{12}^g}$	1	…	a_{2j}^g		a_{2n}^g	w_2^g
…	…	…	…	…	…	…	…
e_i	$\frac{1}{a_{1i}^g}$	$\frac{1}{a_{2i}^g}$	…	a_{ij}^g	…	a_{in}^g	w_i^g
…	…	…	…	…	…	…	…
e_n	$\frac{1}{a_{1n}^g}$	$\frac{1}{a_{2n}^g}$	…	$\frac{1}{a_{jn}^g}$	…	1	w_n^g

Adopted from Saaty (1996). Usually judgments of the respondents are composed using the generic question: "Given a control criterion (sub-criterion), e.g. e_g, a component (element) of the network, and given a pair of components (elements), e.g. e_i and e_j where $i < j$, how much more does a given member, e_i, of the pair influence that component (element) with respect to the control criterion (sub-criterion), e_g, than the other member, e_j?" (Saaty, 1996).

Appendix B. Unweighted supermatrix (Chittagong Port Example)

	Service	Tool	Landlord	Private	IEM	SPO	EP	GT	SCC
Service	0.000	0.000	0.000	0.000	0.395	**0.271**	0.385	0.483	0.389
Tool	0.000	0.000	0.000	0.000	0.278	**0.418**	0.385	0.276	0.188
Landlord	0.000	0.000	0.000	0.000	0.163	**0.121**	0.143	0.141	0.124
Private	0.000	0.000	0.000	0.000	0.163	**0.191**	0.087	0.101	0.299
IEM	0.183	0.167	0.236	0.091	0.000	0.395	0.119	0.163	0.159
SPO	0.378	0.395	0.258	0.252	0.416	0.000	0.451	0.490	0.286
EP	0.072	0.071	0.160	0.394	0.237	0.232	0.000	0.116	0.296
GT	0.099	0.108	0.208	0.069	0.150	0.232	0.169	0.000	0.259
SCC	0.269	0.259	0.139	0.195	0.197	0.140	0.261	0.231	0.000

We present calculation of bold values in Tables 7–9

Appendix C. Weighted supermatrix (Chittagong Port Example)

	Service	Tool	Landlord	Private	IEM	SPO	EP	GT	SCC
Service	0.000	0.000	0.000	0.000	0.198	0.135	0.192	0.241	0.194
Tool	0.000	0.000	0.000	0.000	0.139	0.209	0.192	0.138	0.094
Landlord	0.000	0.000	0.000	0.000	0.082	0.060	0.071	0.071	0.062
Private	0.000	0.000	0.000	0.000	0.082	0.095	0.044	0.050	0.150
IEM	0.183	0.167	0.236	0.091	0.000	0.198	0.059	0.082	0.080
SPO	0.378	0.395	0.258	0.252	0.208	0.000	0.226	0.245	0.143
EP	0.072	0.071	0.160	0.394	0.119	0.116	0.000	0.058	0.148
GT	0.099	0.108	0.208	0.069	0.075	0.116	0.084	0.000	0.130
SCC	0.269	0.259	0.139	0.195	0.099	0.070	0.130	0.116	0.000

Appendix D. Cluster matrix (Chittagong Port Example)

	Alternatives	GPM
Alternatives	0.000	0.500
GPM	1.000	0.500

Appendix E. Limit matrix (Chittagong Port Example)

	Service	Tool	Landlord	Private	IEM	SPO	EP	GT	SCC
Service	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Tool	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.107
Landlord	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Private	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
IEM	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
SPO	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207
EP	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
GT	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
SCC	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130

Appendix F. Normalized limit matrix (Chittagong Port Example)

	Service	Tool	Landlord	Private	IEM	SPO	EP	GT	SCC
Service	**0.366**	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366
Tool	**0.321**	0.321	0.321	0.321	0.321	0.321	0.321	0.321	0.321
Landlord	**0.136**	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
Private	**0.177**	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177
IEM	**0.183**	0.183	0.183	0.183	0.183	0.183	0.183	0.183	0.183
SPO	**0.311**	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311
EP	**0.165**	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
GT	**0.145**	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145
SCC	**0.196**	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196

Bold values are the priorities of the Chittagong Port executive in Table 16.

Appendix G. Summary of abbreviations used in this article

Abbreviation	Definition
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BOT	Build-operate-transfer
BWM	Best-Worst Method
CICT	Colombo International Container Terminals Ltd.
CP	Chittagong Port
CR	Consistency ratio
EP	Environmental Pricing
ESPO	European Sea Port Organization
GHG	Greenhouse gas
GPM	Green port management
GT	Green Technology
GTOs	Global terminal operators
IEM	Internal Environmental Management
IMO	International Maritime Organization
MCDM	Multi-criteria decision-making (MCDM)
NOx	Nitrogen oxides
OPS	Onshore power supply
SCC	Supply Chain Collaboration
SDGs	Sustainable development goals
SOx	Sulphur oxides
SPO	Sustainable Port Operations
WMU	World Maritime University

References

Ahmadi, H.B., Kusi-Sarpong, S., Rezaei, J., 2017. Assessing the social sustainability of supply chains using Best Worst Method. Resour. Conserv. Recycl. 126, 99–106.
Anderson, B., den Boer, E., Ng, S., Dunlap, L., Hon, G., Nelissen, D., Agrawal, A., Faber, J., Ray, J., 2015. Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area. Retrieved from International Maritime Organization (IMO), London, UK.
Beladi, H., Chao, C.-C., 2006. Does privatization improve the environment? Econ. Lett. 93 (3), 343–347.
Bergqvist, R., Egels-Zandén, N., 2012. Green port dues—the case of hinterland transport. Res. Transport. Bus. Manage. 5, 85–91.
Bergqvist, R., Monios, J., 2018. Green Ports: Inland and Seaside Sustainable Transportation Strategies, first ed. Elsevier.
Brooks, M.R., 2004. The governance structure of ports. Rev. Netw. Econ. 3 (2).
Chang, C.-C., Wang, C.-M., 2012. Evaluating the effects of green port policy: case study of Kaohsiung harbor in Taiwan. Transport. Res. Transport Environ. 17 (3), 185–189.
Chen, J., Zheng, T., Garg, A., Xu, L., Li, S., Fei, Y., 2019. Alternative Maritime Power application as a green port strategy: barriers in China. J. Clean. Prod. 213, 825–837.
Chen, Z., Pak, M., 2017. A Delphi analysis on green performance evaluation indices for ports in China. Marit. Pol. Manag. 44 (5), 537–550.
Cheon, S., Deakin, E., 2010. Supply chain coordination for port sustainability: lessons for new institutional designs. J. Transport. Res. Board 2166 (1), 10–19.
Chiu, R.-H., Lin, L.-H., Ting, S.-C., 2014. Evaluation of green port factors and performance: a fuzzy AHP analysis. Math. Probl Eng. 2014, 1–12.
Chung, S.-H., Lee, A.H., Pearn, W.-L., 2005. Analytic network process (ANP) approach for product mix planning in semiconductor fabricator. Int. J. Prod. Econ. 96 (1), 15–36.
Cullinane, K.P.B., 2010. Revisiting the productivity and efficiency of ports and terminals: methods and applications. In: Grammenos, C. Th (Ed.), The Handbook of Maritime Economics and Business. LLP, London, pp. 907–946.
Cullinane, K.P.B., Song, D.W., 2003. A stochastic frontier model of the productive efficiency of Korean container terminals. Appl. Econ. 35, 251–267.
Davarzani, H., Fahimnia, B., Bell, M., Sarkis, J., 2016. Greening ports and maritime logistics: a review. Transport. Res. Transport Environ. 48, 473–487.
Doyle, T., 2018. Blue economy and the Indian Ocean Rim. J. Indian Ocean Reg 14 (19), 1–6.

Dushenko, M., Thærie Bjorbæk, C., Steger-Jensen, K., 2019. Application of a sustainability model for assessing the relocation of a container terminal: a case study of kristiansand port. Sustainability 11 (1), 87.
Duan, C., Deng, C., Gharaei, A., Wu, J., Wang, B., 2018. Selective maintenance scheduling under stochastic maintenance quality with multiple maintenance actions. Int. J. Prod. Res. 56 (23), 7160–7178.
Economist Intelligence Unit, 2018. Charting the Course for Ocean Sustainability in the Indian Ocean Rim.
European Commission. (n.d). Transport emissions. Retrieved from https://ec.europa.eu/clima/policies/transport_en.
Farias, L.M.S., Santos, L.C., Gohr, C.F., Rocha, L.O., 2019. An ANP-based approach for lean and green performance assessment. Resour. Conserv. Recycl. 143, 77–89.
Faulin, J., Grasman, S., Juan, A., Hirsch, P., 2018. Sustainable Transportation and Smart Logistics: Decision-Making Models and Solutions. Elsevier.
Fenton, P., 2017. The role of port cities and transnational municipal networks in efforts to reduce greenhouse gas emissions on land and at sea from shipping–an assessment of the World Ports Climate Initiative. Mar. Pol. 75, 271–277.
Forman, E., Peniwati, K., 1998. Aggregating individual judgments and priorities with the analytic hierarchy process. Eur. J. Oper. Res. 108 (1), 165–169.
Gharaei, A., Karimi, M., Shekarabi, S.A.H., 2019. An integrated multi-product, multi-buyer supply chain under penalty, green, and quality control polices and a vendor managed inventory with consignment stock agreement: the outer approximation with equality relaxation and augmented penalty algorithm. Appl. Math. Model. 69, 223–254.
Geerlings, H., Van Duin, R., 2011. A new method for assessing CO2-emissions from container terminals: a promising approach applied in Rotterdam. J. Clean. Prod. 19 (6–7), 657–666.
Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., et al., 2001. Sustainability science. Science 292 (5517), 641–642.
Kavakeb, S., Nguyen, T.T., McGinley, K., Yang, Z., Jenkinson, I., Murray, R., 2015. Green vehicle technology to enhance the performance of a European port: a simulation model with a cost-benefit approach. Transport. Res. C Emerg. Technol. 60, 169–188.
Kuhlman, T., Farrington, J., 2010. What is sustainability? Sustainability 2 (11), 3436–3448.
Kusi-Sarpong, S., Sarkis, J., Wang, X., 2016. Assessing green supply chain practices in the Ghanaian mining industry: a framework and evaluation. Int. J. Prod. Econ. 181, 325–341.
Lam, J.S.L., Lai, K.-h., 2015. Developing environmental sustainability by ANP-QFD approach: the case of shipping operations. J. Clean. Prod. 105, 275–284.
Lam, J.S.L., Notteboom, T., 2014. The greening of ports: a comparison of port management tools used by leading ports in Asia and Europe. Transport Rev. 34 (2), 169–189.
Lee, P.T.-W., Lam, J.S.L., 2015. Container port competition and competitiveness analysis: asian major ports. In: Handbook of Ocean Container Transport Logistics. Springer, pp. 97–136.
Lee, P.T.-W., Wu, J.-Z., Hu, K.-C., Flynn, M., 2013. Applying analytic network process (ANP) to rank critical success factors of waterfront redevelopment. Int. J. Shipp. Transp. Logist. (IJSTL) 5 (4–5), 390–411.
Lin, C., Madu, C.N., Kuei, C.-h., Tsai, H.-L., Wang, K.-n., 2015. Developing an assessment framework for managing sustainability programs: a Analytic Network Process approach. Expert Syst. Appl. 42 (5), 2488–2501.
Lirn, T., Thanopoulou, H., Beynon, M.J., Beresford, A.K.C., 2004. An application of AHP on transhipment port selection: a global perspective. Marit. Econ. Logist. 6 (1), 70–91.
Lu, C.-S., Shang, K.-C., Lin, C.-C., 2016. Examining sustainability performance at ports: port managers' perspectives on developing sustainable supply chains. Marit. Pol. Manag. 43 (8), 909–927.
Lun, Y.V., 2011. Green management practices and firm performance: a case of container terminal operations. Resour. Conserv. Recycl. 55 (6), 559–566.
Monios, J., 2019. Polycentric port governance. Transport Pol. 83, 26–36.
Munim, Z.H., Duru, O., Ng, A.K.Y., 2020. Transhipment port's competitiveness forecasting using analytic network process modelling. Unpublished Work. Submitted for publication.
Munim, Z.H., Saeed, N., Larsen, O.I., 2019. 'Tool port' to 'landlord port': a game theory approach to analyse gains from governance model transformation. Marit. Pol. Manag. 46 (1), 43–60.
Munim, Z.H., Schramm, H.-J., 2018. The impacts of port infrastructure and logistics performance on economic growth: the mediating role of seaborne trade. J. Ship. Trade 3 (1), 1.
Niemira, M.P., Saaty, T.L., 2004. An analytic network process model for financial-crisis forecasting. Int. J. Forecast. 20 (4), 573–587.
Notteboom, T., Lam, J., 2018. The greening of terminal concessions in seaports. Sustainability 10 (9), 3318.
Ossadnik, W., Schinke, S., Kaspar, R.H., 2016. Group aggregation techniques for analytic hierarchy process and analytic network process: a comparative analysis. Group Decis. Negot. 25 (2), 421–457.
Paixao, A.C., Bernard Marlow, P., 2003. Fourth generation ports–a question of agility? Int. J. Phys. Distrib. Logist. Manag. 33 (4), 355–376.
Panayides, P.M., 2006. Maritime logistics and global supply chains: towards a research agenda. Marit. Econ. Logist. 8 (1), 3–18.
Poulsen, R.T., Ponte, S., Sornn-Friese, H., 2018. Environmental upgrading in global value chains: the potential and limitations of ports in the greening of maritime transport. Geoforum 89, 83–95.
Puig, M., Wooldridge, C., Darbra, R.M., 2014. Identification and selection of environmental performance indicators for sustainable port development. Mar. Pollut. Bull. 81 (1), 124–130.
Puig, M., Wooldridge, C., Michail, A., Darbra, R.M., 2015. Current status and trends of the environmental performance in European ports. Environ. Sci. Pol. 48, 57–66.
Ren, J., Lützen, M., Rasmussen, H.B., 2018. Identification of success factors for green shipping with measurement of greenness based on ANP and ISM. In: Multi-Criteria Decision Making in Maritime Studies and Logistics. Springer, pp. 79–103.
Rezaei, J., 2015. Best-worst multi-criteria decision-making method. Omega 53, 49–57.
Rezaei, J., 2016. Best-worst multi-criteria decision-making method: some properties and a linear model. Omega 64, 126–130.
Rezaei, J., Nispeling, T., Sarkis, J., Tavasszy, L., 2016. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. J. Clean. Prod. 135, 577–588.
Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. Eur. J. Oper. Res. 48 (1), 9–26.
Saaty, T.L., 1994. How to make a decision: the analytic hierarchy process. Interfaces 24 (6), 19–43.
Saaty, T.L., 1996. Decision Making with Dependence and Feedback: the Analytic Network Process. RWS Publications, Pittsburgh.
Salimi, N., Rezaei, J., 2018. Evaluating firms' R&D performance using best worst method. Eval. Progr. Plann. 66, 147–155.
Smith, T.W.P., Jalkanen, J.P., Anderson, B.A., Corbett, J.J., Faber, J., Hanayama, S., O'keeffe, E., Parker, S., Johansson, L., Aldous, L., 2014. Third IMO GHG Study 2014. International Maritime Organization (IMO), London. http://www.iadc.org/wp-content/uploads/2014/02/MEPC-67-6-INF3-2014-Final-Report-complete.pdf.
Song, D.-W., Yeo, K.-T., 2004. A competitive analysis of Chinese container ports using the analytic hierarchy process. Marit. Econ. Logist. 6 (1), 34–52.
Sornn-Friese, H., Poulsen, R.T., 2016. Ports as sustainability hubs in global maritime supply chains: a content analysis of the external business communication of the worlds largest ports. In: Paper Presented at the International Association of Maritime Economist.
The Daily Star, 2016. Local firm to build, operate two jetties at Mongla port. Retrieved from. https://www.thedailystar.net/business/local-firm-build-operate-two-jetties-mongla-port-1273420.
Tongzon, J.L., 1995. Determinants of POrt performance and efficiency. Transport. Res. Part A 29 (3), 245–252.
Tseng, P.-H., Cullinane, K., 2018. Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model. Marit. Pol. Manag. 45 (4), 422–438.
Wang, H., Li, S., Wang, Q., 2018. Introduction to Social Systems Engineering. Springer.
World Bank, 2007. Port Reform Toolkit (Retrieved from Washington, DC, USA).
Wu, W.-W., Lee, Y.-T., 2007. Selecting knowledge management strategies by using the analytic network process. Expert Syst. Appl. 32 (3), 841–847.
Yang, Y.-C., Chang, W.-M., 2013. Impacts of electric rubber-tired gantries on green port performance. Res. Transport. Bus. Manage. 8, 67–76.
Yang, Y.-C., Lin, C.-L., 2013. Performance analysis of cargo-handling equipment from a green container terminal perspective. Transport. Res. Transport Environ. 23, 9–11.
Yap, W.Y., Lam, J.S.L., 2013. 80 million-twenty-foot-equivalent-unit container port? Sustainability issues in port and coastal development. Ocean Coast Manag. 71, 13–25.
Yuen, C.-l. A., Zhang, A., Cheung, W., 2012. Port competitiveness from the users' perspective: an analysis of major container ports in China and its neighboring countries. Res. Transport. Econ. 35 (1), 34–40.
Zis, T., Angeloudis, P., Bell, M.G., Psaraftis, H.N., 2016. Payback period for emissions abatement alternatives: role of regulation and fuel prices. Transport. Res. Rec.: J. Transport. Res. Board 2549, 37–44.