Developing Port Sustainability: A Comparative Analysis and Implications

This paper aims to examine the main factors that shape sustainable port development in a comparative analysis and generalize a typology of port – stakeholder decision framework for sustainable port development. First, the main factors of sustainable port development were examined through a comprehensive literature review and a holistic conceptual framework underpinned by sustainable development and stakeholder management theories. Semi-structured in-depth interviews were then conducted with 69 port managers in Singapore and Korea. Lastly, FAHP was performed to analyze the priories of the proposed sustainable port development factors. All proposed factors should be used for evaluating sustainable port development. It was also indicated that Optimized Operation Planning is the most important factor while Internal Social Program and External Environmental Program are the least important factor in Korea and Singapore respectively. A typology of port – stakeholder framework for sustainable development was also generalized to assist port managers in making phased investments decisions. This research contributes to theory building by empirically identifying and validating the sustainable port development factors considering all three aspects of sustainability. It has also generalized a typology of port – stakeholder framework for sustainable development which can be used as a guideline for sustainable development decisions.

Keywords: Sustainable port development; FAHP; Singaporean ports; Korean ports

Introduction

In recent years, ports around the world have been facing challenges to develop sustainably under the spectrum of increasing environmental awareness, pressure of social responsibility along with ever-lasting quest for sustainable economic operations. In this respect, there have been various legislations and initiatives both at domestic and international levels being introduced in order to make ports green and clean, such as those by International Maritime Organisation's (IMO's) International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78, EU (i.e., Ship-Source Pollution – Directive 2000/59/EC), Australia (i.e., Environment Protection Act 1986), Singapore (i.e., Environmental Protection and Management Act (Cap.94A)), Korea (i.e., GREEN - Greenhouse gas Reducing, Energy Efficiency & Nature-friendly Port initiatives) and the latest IMO 2020 Global Sulphur Limit (as an amendment of MARPOL Annex VI) which legally imposes that the sulfur limit in fuel oil used on board ships operating outside designated Emission Control Areas (ECAs) to be 0.5% m/m (mass by mass) (IMO 2019).

The term "sustainability" includes triple bottom line (TBL) aspects of social, environmental and economic responsibilities; however, in the area of sustainable port development the literature has been focusing more on environmental dimensions. In this connection, several studies have been conducted in the literature to measure ports' sustainable performance (i.e., Lirn, Wu, and Chen 2012; Wiegmans and Louw 2011; Chin and Low 2010; Tsinker 2004) mostly from the sustainable environment perspective. However, not much has been known on the important factors that shape sustainable port development from the all-rounded approach. This study therefore aims to identify and validate the key factors that constitute a sustainable port development framework, evaluate the importance of each factor in the context of ports in Singapore and Korea, and suggest a support framework for making related sustainable investment decisions therein. The main motivation to conduct this research on ports in these two countries is multifold. First, ports in Singapore and Korea have over the years secured their leading position in the global port throughput ranking while their development also plays a critical role in the national economy. Secondly, apart from Western European and North American ports, those in Singapore and Korea have been in the forefront of green port development as part of sustainability program among other Asian ports. Specifically, the Singaporean Government initiated the Maritime Singapore Green Initiative in 2011 for initial five years, and in 2019 it has been further extended until 2024 which includes the Green Port Program, among the other three (Maritime and Port Authority of Singapore 2020). Meanwhile, Korea has also enthusiastically been advocating early for green growth initiative through its National Strategy for Green Growth (2009-2050) (OECD 2020), in which ports play a very active role. For example, since 2011, Busan Port Authority (BPA) has been incorporating alternative maritime power and changing yard tractors into ones using changeable batteries or hybrid engines under a plan to reduce greenhouse gas by 30% by 2020 (Seatrade Maritime News 2011). The interesting question is, therefore, in the quest for sustainable development, what other social and economic factors should be considered in the port's development framework apart from environmental ones, as well as their priority.

The remaining of this paper is organized as follows. First, relevant literature on sustainable port development is reviewed which helps shaping a holistic conceptual framework of sustainable port development for this study. This is followed by the discussion on methodology in which the multi-phased mixed methods, combining semi-structured validation interviews and Fuzzy Analytical Hierarchy Process (FAHP), are explained. The discussion of analysis results and findings is presented next. The paper then concludes with a summary of findings, discussion of academic and managerial implication, limitation and future research directions.

Review of literature on sustainable port development

It is well noted that port facilities development and related operations have been playing an important role and exerting both direct and indirect influence on the growth of maritime transport and economies around the world (Paipai 1999). The development of ports is involved with various parties which constitute complex organizations in both economical, social, cultural and administrative aspects (Puig, Wooldridge, and Darbra 2014). Ports are accountable for a broader span of impacts and aim to accommodate public and private interests, short-term views, social and commercial goals (Dooms et al. 2013). Port activities and operations may influence on various environmental aspects (Acciario et al. 2014; Dinwoodie et al. 2012; Gupta, Gupta, and Patil 2005) such as worsening quality of marine water and air in the adjacent area (Grifoll et al. 2011; Kroger et al. 2006). Meanwhile, port operations satisfying the demands of economic and other industrial activities in parallel with sustainable development to comply with legislative requirements while reducing costs and risks is essential (Puig, Wooldridge, and Darbra 2014).

Considering the circumstances above and their increasing significance, the International Association of Ports and Harbors (IAPH) prepared a World Port Sustainability Program (WPSP) in 2018 to efficiently deal with the current environmental and social concerns that ports face and finally intensify sustainability efforts of global ports. In 2019, IAPH, which was set up by the most representative port-related organisations such as the European Sea Ports Organisation (ESPO) and the American Association of Port Authorities (AAPA), announced six ports which are winners of World Ports Sustainability Awards for the first time at the Guangzhou Conference. They are Abu Dhabi ports as a winner of resilient infrastructure, Port of Amsterdam for climate and energy, Port of Busan for community outreach (port development), CIVITAS PORTIS for community outreach (addressing externalities), Kenya Ports Authority and Port of Vancouver for governance and ethics, and Port of Antwerp for safety and security category as listed on the WPSP website in 2019. The best practices of those selected ports can be benchmarked by other ports to reduce a number of negative impacts of the related activities in the ports and hinterland on local communities as well as a worldwide level.

Although the issue of sustainability in port development has received an increasing attention from practitioners and academics recently, only a scarce amount of port operations mode related literature remains limited (Lim et al. 2019). In the extant literature of sustainable port development, only a few authors have engaged in the discussion of sustainable development and covered the whole spectrum of triple bottom lines (Chen and Lam, 2018; Muangpan and Suthiwartanrueput 2019; Roh, Thai, and Wong 2016; Yap and Lam 2013) while most studies only addressed the monitoring of environmental effects (Darbra et al. 2004, 2005; Wooldridge et al. 1999) and ecological issues (Berechman and Tseng 2012; Liao et al. 2010). Furthermore, in the maritime literature, primal interest is in the environmental approach while few others consider economic, environmental, and social aspects (Sislian, Jaegler, and Cariou 2016). In this connection, the identification of the established research streams on maritime logistics and green ports literature was reviewed (Davarzani et al. 2016). It was found that most of the studies in the literature focused on maritime logistics and ports eco-efficiencies i.e., operational emissions modelling, emissions, and energy whilst other aspects of port sustainable development were less researched. Some researchers analyzed green port operations and management (Acciaro et al. 2014) and strategic matters (Haezendonck et al. 2006; Denktas-Sakar and Karatas-Cetin 2012) which identified the ports' value-added environment performance. Among the researches that studied the effect of port management sustainability, only both environmental and economic impacts (Asgari et al. 2015) or environmental impacts solely were considered (Peris-Mora et al. 2005; Villalba and Gemechu 2011).

This trend has also been verified in the most recent study (Lim et al. 2019) in which a systematic literature review of 704 studies on sustainability performance in ports published from 1990 to 2017 was performed. This study is different from the previous studies (e.g., Sislian, Jaegler, and Cariou 2016; Davarzani et al. 2016) by addressing all three aspects of triple bottom lines relating port sustainability. Following a rigorous procedure of filtering relevant articles, they ascertained that although the number of publications over the past few years has been steadily increasing in line with the significant interest in port sustainability performance evaluation, there were only a few studies which concentrate on the social or economic elements of TBL in the port sustainability domain as majority of these studies investigated the issue from an environmental perspective. Most interestingly, no empirical study dealing with all three aspects of TBL was identified. Besides, it was found that many studies were conducted in the United States and Western Europe, while less common in the research context of Asian ports. In addition, very few of these studies reviewed the local group opinions regarding port sustainability, despite the finding that external cooperation was underlined as critical to port sustainability implementation. Addressing such research gaps, the current study therefore aims to establish and validate the model of sustainable port development encompassing all aspects of sustainability.

The triple bottom line and the internal sustainable programs

Devising and implementing environmental management initiatives is a key facet of sustainable development including in the port sector. It is particularly noticeable in port activities, like any business plan of an operation, to be sustainable, compliant with legislation, and efficient environment management is practiced as an important element (Puig et al. 2015). The main goal is to manage the effect of activities, services and products of port on water, air, sediment and soil (Gupta, Gupta, and Patil 2005). In this connection, various initiatives have been initiated and exercised. In responding to the increased pressures of ports' environmental sustainability, environmental training with vial roles and resources has been recognized as a constructive managerial practice (Sarkis, Gonzalez-Torre, and Adenso-Diaz 2010). Allocating budget for environmental promotion campaigns such as green marketing strategies and activities to reduce environmental damage would lead to improved firm competitiveness (Yang et al. 2013). In addition, as emission from diesel-run container trucks are the main source of NO_x, controlling truck operations while in terminals is essential (Hartman and Clott 2012). Meanwhile, regular exercises of ship inspection through Port State Control are also needed for the enhancement of port environmental performance (Saengsupavanich et al. 2009).

Overall, port sustainability is often addressed through green initiatives aiming at emission reduction in the port and terminal area, which have been practiced in various ports nowadays (Gilman 2003; Lirn et al. 2013). However, there are also some negative influences from the implementation of environmental management initiatives as reported in business studies research. In this connection, Walley and Whitehead (1994) argued that it is costly undertaking environmental initiatives, therefore leading to poor economic performance. Gil, Jimenez, and Lorente (2001) also indicated that organizations investing to enhance environmental performance may experience negative economic and financial performance. Nevertheless, in some recent empirical studies, it was affirmed that integrating environmental responsibility has positive influence on economic performance by increasing revenue generated through brand image and stakeholder relations (Rao and Holt 2005; Zhu and Sarkis 2004). Besides, in supply chain research, internal social programs may have positive influence on improving environmental performance by reducing environmental damage (Gimenez, Sierra, and Rodon 2012; Marshall, Cordano, and Silverman 2005).

Due to both air quality and climate change, environmental issues attract significant research interest in port studies. Focusing on the concept of green port operations, Chiu, Lin, and Ting (2014) established a Fuzzy AHP model consisting of the use of social participation, energy, environmental quality, greenery, habitat quality, and waste handling and verified this model through an empirical case study in Taiwan. Meanwhile, based on the case study in four ports in different continents, i.e., Port of Osaka, Sydney Port, Port of Long Beach, and Port of Gothenburg. Styhre et al. (2017) suggested important measures to reduce the greenhouse gas (GHG) emissions level. These are alternative fuels, reduced berth turnaround time, on-shore power supply and reduced speed in fairway channels.

With the increasing environmental pressures from the IMO on port operations regarding, in particular, water and air pollution, there have been many academic efforts devoted to these crucial issues. Wan et al. (2018) addressed green port issues by developing a quantitative measurement model based on the pressures, drivers, pressures, states, pacts and responses (DPSIR) framework which was applied in five major Chinese ports. The framework considered some indexes such as waste (water, gas, and residue), air quality fine rate, noise level of port, rate of recycled waste water and utilization of waste residue, establishment of organization environmental management that includes rewarding and punishment. Besides, Gonzalez-Aregall et al. (2018) expanded the scope of research by including the environmental performance of hinterland areas. Their results demonstrated that only 21% of the sampled ports are found to implement ecological measures with technology improvements, infrastructure development, and monitoring programs as primary tools.

The triple bottom line and the external sustainable programs

Apart from the environmental performance dimension, port sustainable development is also related to the relationship between the port and its community, especially those involved in urban development. This has been emphasized in several studies in the literature. In this respect, it is argued that collaboration with urban authorities must be present so as to reduce any potential conflict with community due to port expansion and development (Daamen and Vries 2013; Wiegmans and Louw 2011). The general public organizations and society firmly oblige ports to play their role responsibly in the society (De Grosbois 2016). Port authorities therefore embed corporate social responsibility

(CSR) practices in their port management systems to satisfy the environmental and social obligations through undertaking statutory duties (Pettit 2008). Drobetz et al. (2014) argued that companies are gaining better reputation and increased revenues when they contribute both ethically and economically to the society, as their sustainability report may potentially influences their economic performance due to the increase of firm's transparency and savings of information costs. Saengsupavanich et al. (2009) emphasized on trust building to develop the positive relationship with the local community through various efforts such as enhancing the environmental performance in the industrial port by promoting and practicing ISO14001 series. Ports are responding to normative requirements and local community pressure by enhancing the corporate responsibility profile that helps improving their ports' image to appear sustainable and environmentally aware (Acciaro 2015). Notteboom (2009) claimed that for sustainable port operation, it is crucial to coordinate closely with logistics companies and approach port resource and infrastructure planning from an economical and societal dimensions.

It is vital for port authorities to collaborate continuously with shipping companies for decreasing environment contamination they create as part of the port's external sustainable programs. The impact of reducing CO_2 emission into the environment has also been widely studied as it is critical in achieving environmental and economic sustainability in container shipping industry (Buhaug et al. 2009). In this regard, many operational strategies are directly related to ship's speed reduction (Qi and Song 2012) since such a reduction of 10% would decrease emissions by at least 10 – 15% (Psarfitis and Kontovas). Puig, Wooldridge, and Darbra (2014) and Lai et al. (2011) also indicated that port authorities should collaborate more with shipping companies to reduce emissions by implementing initiatives such as low sulfur content fuel or vessel speed limit and providing certain percentage of concessions in terms of port dues. Another initiative in reducing emissions from ships is cold ironing in that ships are connected to a landside power supply and encouraged for their generators and engines to be switched off while at berth (Puig et al. 2015; Zis et al. 2014).

Providing incentives for the adoption of environmental-friendly materials, equipment and design as well as auditing, evaluation and assessment practices of external business partners such as shipping lines enhances the positive impact on sustainable performance (Yang et al. 2013). It is however important to note that assessment alone is difficult to achieve an effective result hence constructive engagement and follow-up is crucial (Fabian and Hill 2005). Furthermore, it is not considered sustainable excluding business partners who do not satisfy the environmental standards for business partner evaluation (Reuter et al. 2010).

Ashrafi et al. (2019) found that extensive attention on sustainability strategies and practices has been paid by port executives in Canadian and US seaports and, additionally, this new adoption was also regarded as a means to strengthen the relationships with their stakeholders. However, findings from this study also revealed that sustainability is not entirely integrated when making decisions about operations in most of these ports. Nevertheless, there have been some trials in exploring the social aspect of sustainable ports while most studies examined one of the other elements of TBL in different ways (e.g., Wagner et al., 2002; Schipper et al. 2017). This shortcoming therefore calls for a more balanced approach in examining port sustainability.

As can be seen above, research on sustainable development which taps on all environmental, economic, and social aspects specifically in the port sector is scarce, despite the huge economic, social and environmental implications from port operations and management. In addition, there has not been any comparative study in this area across ports in different countries, which are necessary given the international nature of the maritime industry in which ports are important players. The current study, therefore, aims to address these literature gaps and enhance contemporary knowledge on port sustainable development. The identified main factors for sustainable port development are summarized in Table 1.

[Table 1 near here]

Methodology

Review from the literature indicated that the development of a port in a sustainable manner would need to be founded in the core theory of sustainable development, whose three pillars include economy, society, and environment, or the triple bottom line (Elkington 1997). As ports are an integrated player in supply chains, the management of their social, economic, and environmental sustainable development activities can be scoped within the ports (internal management) as well as between themselves and their stakeholders (external management), and is thus also underpinned by the stakeholder management theory (Freeman 1984; Frooman 1999; Phillips, Freeman, and Wicks 2003). In this connection, a port engages with both primary and secondary stakeholders internally and externally. Primary stakeholders are those engage in a formal relationship with the port (e.g., government bodies, employees, shareholders, customers, and suppliers). Meanwhile, ports have no formal relationship with secondary stakeholders such as NGOs, media, local community, and citizens (Clarkson 1995). It is therefore envisaged that the management of sustainable port development activities is a combined product of managing economic, social and environmental operations that aim to balance the interest of the port and those of its stakeholders. This is illustrated in the proposed holistic conceptual framework of sustainable port development (Figure 1).

[Figure 1 near here]

This study adopts multi-phased mixed methods, combining semi-structured interviews for face validation and Fuzzy Analytical Hierarchy Process (FAHP) for prioritizing sustainable port development factors. First, a semi-structured interview questionnaire was designed based on a comprehensive review of literature (Table 1). Following the previous studies, these was then categorized into external and internal management aspects (Gimenez, Sierra, and Rodon 2012; Gotschol, De Giovanni, and Esposito Vinzi 2014; Yang et al. 2013). 17 ports in Korea and two ports in Singapore listed in the port directory in the countries was used for distributing interview questions. Findings from this phase would provide face validity for the sustainable port development indicators. Once this is completed, FAHP was conducted to reveal their priority. Figure 2 illustrates the flow sequence of methods employed in this research.

[Figure 2 near here]

Phase 1: validation of sustainable port development indicators

Since there is scarce research on important factors which shape sustainable port development, we adopted the 49 sustainable port development indicators (Table 2), which were derived from a comprehensive literature review and empirically validated using in-depth interviews in a recent study (Roh, Thai, and Wong 2016). Nevertheless, since these sustainable port development indicators were validated in the context of a developing country using empirical data collected by a qualitative method, there is the need to validate these indicators in the context of ports in other developed countries employing more rigorous methods so as to enhance their reliability and validity. Therefore, the current research firstly conducted semi-structured interviews to verify sustainable port development indicators from the perspective of port managers in developed countries such as Korea and Singapore where the port sector plays an essentially crucial role in their national economy, and the countries have been very much advocating for sustainable development. Interviewees were asked to indicate whether a port should incorporate the proposed port sustainable development indicators which are reflected in all dimensions and aspects. Their responses were categorized into X – No, O – Yes and △ – Not sure. Open-ended questions were also given to obtain further understandings of Korean and Singaporean ports' sustainable development. Secondary data were subsequently obtained to compare how Korean and Singaporean ports are practicing or implementing the selected indicators.

[Table 2 near here]

Email was used to distribute interview questionnaire to 17 ports in Korea. In total, 67 responses from Korean port managers in three major ports in Korea (Busan North Port – 24 responses, Busan New Port – 8 responses, Incheon – 15 responses, Gwangyang – 20 responses). In Singapore, the same interview questionnaire was administered and two responses from port managers were received. We acknowledge that there is a difference in the number of responses from port managers in Korea and Singapore and this limitation should be addressed in future research.

Phase 2: Fuzzy Analytical Hierarchy Process (FAHP) analysis

The AHP analysis determine the relative importance of each indicators and the priority of major indicators through pairwise comparison matrix. In this phase, a total of 18 Korean port managers from Busan, Gwangyang, Incheon, and Ulsan participated to evaluate the AHP research structure (Figure 3). For Singapore, two port experts from the Maritime and Port Authority of Singapore (MPA) and Jurong Port participated in this phase of the study.

[Figure 3 near here]

The conventional AHP is mainly applied in decision application with nearly crisp-information, which poses some limitations (Yang and Chen 2004). To overcome this obstacle and improve the uncertainty, several studies have integrated fuzzy set theory with AHP. The fuzzy AHP (FAHP) method that handles linguistic variables can capture expert's undetermined imprecise judgement. Trapezoidal fuzzy numbers is used to calculate the weights (Buckley 1985). The FAHP bases on the confidence index α with interval mean approach and fuzzy interval arithmetic with triangular fuzzy numbers to determine the weights for evaluating elements. The FAHP procedure (equation 1-9) is adopted from Hsieh, Lu, and Tzen (2004), Liou, Yen, and Tzeng (2007), and Stević et al. (2018; See Appendix).

[Figure 3 near here]

Results and findings

External and internal management indicators of sustainable port development validated through Phase 1 interviews is shown in Table 3. The subsequent analyses provide more elaboration on these indicators which are grouped according to internal and external management aspects.

[Table 3 near here]

Internal management aspects

It can be seen from Table 3 that only four indicators received a low level of consent as components of the sustainable port development framework. It is noteworthy that they are all in the Internal Environmental Management (A) and Cost Savings (C) groups. The indicators of internal environmental management that had low level of consent are Environmental management system (A4, 70%) and Punishment mechanism to penalize operators that disobey environmental rules (A11, 74%). There was also positive response for a sustainable development port to include Activities to reduce environmental damages (A7, 97%) and Environmental education and training support (A8, 98%). It is also worth noting that having a Regular exercise of Port State Control for ship inspection (A12, 80%) was considered important for sustainable port development but also being cautious of implementing punishment mechanism to penalize operators that disobey environmental rules (A11, 74%).

For Cost Savings, most managers (94%) agreed that the Use of cleaner technology port equipment (C1) should be included as one of the sustainable port development indicators. Meanwhile, the Use of automated port equipment (C2) received a low percentage (74%) of consent while only 50% of the port managers considered that Collaboration with business partners in sharing the cost of environmental-friendly equipment (C3) should be included.

Most of the port managers agreed to include all the proposed indicators in the Internal Management aspect in the sustainable port development framework. Especially, for the groups of Optimized Operation Planning (B1-B8) and Internal Social Programs (D1-D6), all respondents agreed that all the proposed indicators should be considered for a port to be developed sustainably.

External management aspects

For External Environmental Management, port managers indicated low level of consent in general that most of the indicators should be considered in the sustainable port development framework. However, the following indicators received a high level of consent from port managers, including, Having common environmental goals collectively with business partners (E1, 90%), Developing a mutual understanding of environmental risk and responsibilities with business partners (E2, 93%), Working together with business partners to address environmental risk and establish a green supply chain (E3, 94%), Giving support to community social activities (G2, 86%), Improving transparent employee evaluation system (G4, 80%), and Providing transparent information to establish fair transaction culture (H3, 90%). Meanwhile, indicators related to Guiding business partners to comply with environmental management standards (E4), Including environmental criteria in selecting business partners (E5), and Conducting environmental audits for partners (E6) received low levels of consent (62%, 67%, 55% respectively).

Majority of the port managers also concurred that all indicators in the group of Environmental Collaboration with Shipping Companies which contains providing incentives to shipping companies who practice green shipping should be included in the sustainable port development framework. Among them, Providing incentives to shipping companies which use environmental-friendly materials and equipment (F2) received the highest level of consent (77%). Meanwhile, only 61% of port managers agreed that Providing incentives to shipping companies whose ships reduce speed while at the port (F4) should be included in the framework.

Port managers also indicated that all of the indicators in the External Social Programs group should be included in the sustainable port development framework. Among those, 86% and 57% of managers respectively concurred that Giving support to community social activities (G2), and Providing scholarships to students (G3) should be included in the sustainable port development framework.

Meanwhile, all indicators proposed in the External Evaluation Collaboration group should be included in the sustainable port development framework, as agreed by most port managers. Especially, 90% of managers agreed that Providing transparent trade information to establish fair transaction culture (H3) should be part of the framework as well.

FAHP results

The computational results of FAHP analysis from Korean port managers are presented in Table 4. The consistency ratio of the pairwise comparison matrix is 0.018 < 0.1, meaning the pairwise comparison is acceptable and consistent. As can be seen from Table 4, Optimized Operation Planning (B) was considered the most important factor with the weight of 0.1950. The next two most important factors are Environmental Collaboration with Shipping Companies (F) and External Evaluation Collaboration (H) with the weights of 0.1513 and 0.1492 respectively. Meanwhile, Internal Environment Management (A) was considered the least important among factors of sustainable port development with the weight of 0.0709, followed by Internal Social Program (D) with the weight of 0.0733.

[Table 4 near here]

Meanwhile, the computational results of FAHP analysis in the case of Singaporean ports are presented in Table 5. From the Singaporean port experts' perspective, Optimized Operation Planning (B) was also considered the most important factor with the weight of 0.2074, similar to the view of Korean port managers. The next two most important factors are Internal Environmental Management (A) and Cost Savings (C) with the weights of 0.1833 and 0.1347 respectively. On the other hand, External Evaluation Collaboration (H) was considered the least important among factors of sustainable port development with the weight of 0.0665, followed by External Social Program (G) with the weight of 0.0829.

[Table 5 near here]

From the FAHP analyses, Optimized Operation Planning (B) was identified the most important factor which should be included in the sustainable port development framework for both countries (Table 6). This finding echoes with the census found in the validation semi-structured interviews. Specifically, Korean ports collaborate actively with business partners for facility improvements, system development through regular meetings as this collaboration was perceived the most important factor for sustainable port development. They share feedbacks from each other on how to improve their operations planning. Incentives are negotiated by securing a certain level of throughputs. Meanwhile, Singaporean ports regularly reach out to business partners to explore how they can provide better value added services in all aspects including operations planning, which is practiced at dedicated terminals. As Singapore plan for the next generation port, port operators are engaged in various port development projects and assured that their voices are clearly heard. They sit in various planning committees as the biggest stakeholder in the development of the next generation port. Meanwhile, for both countries, IT is applied thoroughly by computer-aided management and operations at the terminal level to execute accurate and rapid information processing and sharing which may result in reduced harbor dues, loading and unloading time, and human errors. Optimization of planning to reduce truck waiting time is also planned as well.

[Table 6 near here]

Environmental collaboration with shipping companies (F) was ranked second most important by Korean port managers while Internal environmental management (A) was perceived the second priority by Singaporean counterparts. Among Korean ports, Busan Port Authority (BPA) and Ulsan Port Authority (UPA) provide incentives to shipping companies. Since 2014, BPA has implemented the Environmental Ship Index (ESI) scheme by assigning scores for four items including NO_x, SO_x, CO_2, and Onshore Power Supply (OPS) installation, on the scale of 1 – 100. Busan Port is the first in Asia to adopt this system by providing ESI incentives, reducing entry and departure charges by 15% for vessels with more than 31 ESI points. In 2014, the number of eco-friendly vessel callings was 423, and a total of KRW 603 million was reduced for entry and departure fees (BPA 2015). Meanwhile, Maritime Singapore Green Initiative was initiated by the Maritime and Port Authority of Singapore (MPA) which aims to promote green and clean shipping and reduce the environmental impact of shipping related activities in Singapore (MPA 2020). It is comprised with three voluntary programs, namely Green Port Programme, Green Ship Programme, and Green Technology Programme. These are designed to provide and recognize incentives to firms achieving over and above the minimum requirement set by International Maritime Organization (IMO) Conventions by adopting green and clean shipping practices.

[Table 6 near here]

It is interesting to note from Table 7 that Internal and External social programs were considered least important by port managers in both countries although their ports implement and practice various social programs in the name of corporate social responsibility (CSR). Korean ports also consistently improve their human resources through transparent recruiting and appraisal systems by developing training and education programs to strengthen their employees' work skills, capabilities and personal responsibility, although the overarching factor (Internal social program) of this criteria was considered least important.

[Table 7 near here]

Port managers in two countries showed significantly different view regarding Internal environmental management (A) and External evaluation collaboration (H). Specifically, the former was perceived second least important by Korean port managers while it was ranked second most important by Singaporean counterparts. Meanwhile, the latter was ranked the third important factor by Korean port managers while it was perceived least important by port managers in Singapore. Hence, these factors deserve further investigation in future research.

Conclusion

In this research, a sustainable port development framework is conceptualized and underpinned by both sustainable development and stakeholder management theories, and includes Internal Management and External Management indicators adopted from Roh, Thai, and Wong (2016). The framework is empirically validated in the context of Korean and Singaporean ports and the priority rankings of sustainable development factors and indicators are also revealed. Unlike previous researches which only considered one or two sustainable dimensions, this study applies a holistic approach which involves all three dimensions of sustainable development (environmental, social, and economic) and takes into account all stakeholders in sustainable port development. Port managers in both countries confirmed that most of the indicators in the proposed conceptual model should be included in developing sustainable port development. Through the FAHP analysis, it was further agreed by both Singaporean and Korean port managers that Optimized Operation Planning is the most important factor for a port to be developed sustainably. Meanwhile, External Evaluation Collaboration and Internal Social Program were perceived to be the least important factors by Korean and Singaporean port managers and experts respectively. The confirmed sustainable port development factors and indicators provide a guideline to port authorities and operators on how their port should be developed for sustainability. Given the factors' prioritized importance, port managers are informed of areas which should be focused on for improvement in order for their ports to be developed sustainably.

This research contributes to both contemporary literature and management practice. First, while the sustainable port development framework in this research is proposed from the literature, it formally conceptualizes how a port can develop sustainably employing an all-rounded approach and leveraging on its complex networks of stakeholders' involvement. Further from the key finding that a sustainable development port would need to design and implement various economic, social and environmental sustainable activities, it is acknowledged that it would be a challenging job for port managers to decide on how to balance these activities taking into account the complex network of their stakeholders. Based on the holistic sustainable port development framework and findings from this research, we therefore put forward the typology of port – stakeholder decision framework for sustainable development as illustrated in Table 7.

Using the framework as a guidance, the decision to design and implement a particular sustainable port development factor that a port manager needs to make is put in the relationship matrix between the port and its primary and secondary stakeholders. If a factor in the 8-factor sustainable port development framework is considered important by both the port and its primary and secondary stakeholders, the port is to proceed with the design and implementation. Vice versa, if a factor is considered not important by both the port and its stakeholders, it has to be suspended. If only the port considers a factor important while the stakeholders do not, the port will need to engage in the process of negotiation and consultation process with both primary and secondary stakeholders. Meanwhile, if the port does not consider a factor important while the primary stakeholders do, the port may need to proceed considering the direct influential relationship that the primary stakeholders have with the port. However, if a factor is not considered important by both the port and its primary stakeholders while secondary stakeholders perceive otherwise, the port managers will need to negotiate and strategically consider whether that factor would have mid- to long-term positive impact on the port to be designed and implemented in short term.

From the managerial perspective, the findings and recommended decision framework of this research offer valuable guidance to port-related practitioners in general and those in Korea and Singapore in particular. First, based on the framework developed in this study, it will be possible to establish a comprehensive and systematic decision support system for the development of sustainable ports. In recent years, investments in social overhead capital/infrastructure including ports that are highly sustainable have been emphasized. To build an economic, social and environmentally sustainable port infrastructure, it is essential to evaluate the sustainable port development factors in the construction and operation process with a standardized tool. This will secure credibility for sustainability assessment and provide an efficient way for data collection in developing sustainable port.

Second, focusing on the key factors that emerged from the results, strategies that can strengthen the capabilities of the world’s major port authorities can be suggested. This will assist in highlighting where improvement of sustainable performance can be made by each port authority in line with the efforts of International Association of Ports and Harbours (IAPH) which launched World Ports Sustainability Program (WPSP) to facilitate sustainable endeavors and collaboration of ports worldwide. In particular, Korea and Singapore targeted in this study are good examples of this sustainable program as both countries were selected as a winner for one of the five categories of IAPH's World Ports Sustainable Awards, "Community Outreach: Port Development" in 2019 and 2020 respectively. The Port of Busan operated by Busan Port Authority has won the award in 2019 in recognition of its contribution to enhancing the social value of the port by operating swimming pools, campsites, and footbaths at the unused sites in the North Port Redevelopment Area while Singapore's Next Generation Tuas Port Project managed by Maritime and Port Authority of Singapore was designated as the best port in 2020 due to the active movement to combine existing terminals and form a mega port in Tuas. Therefore, the decision framework in this research based on those two countries can effectively support port authority managers in the planning and implementation of phased investments in various social, economic, and environmental sustainable development indicators taking into account stakeholders' consultation. Besides, the results of the application of this research's framework are expected to be used in developing mid- and long-term sustainable plans for each port authority by actively finding a role to improve the port environment and contribute to the local community in addition to the traditional tasks, and ultimately this can be used as a marketing instrument.

Third, the results will assist in making good macro decision of each government to maximize the positive effect of environmental and social values as well as the economic aspect in the present development plan of global ports. For instance, in Korea, a feasibility study in port development was conducted solely concentrating on the analysis of economic aspects, but currently, Korean government tries to measure the social impact of ports in order to understand how much social changes occurred and can be attributed to ports' activities. This has become common practice among the port industry worldwide. Thus, the decision framework will be useful for such macro decision making to be made based on the balanced view of ports' role. Last but not least, the effort in developing sustainable ports based on the findings of this study will lay the foundation for improving the residents' quality of life in the vicinity of the port and facilitate cooperation among various stakeholders considering that the port is not an infrastructure that seeks profits by developing and operating ports independently, but co-prospering with the cities behind the port and residents of neighboring regions.

Nevertheless, various limitations exist in the current study. Specifically, responses were low due to limited time frame. However, this research could be a steppingstone for further research in a detailed decision support system to inform port sustainable development policies in the future.

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Appendix. The FAHP Procedure

The FAHP procedure (equation 1-9) is adopted from Hsieh, Lu, and Tzen (2004), Liou, Yen, and Tzeng (2007), and Stević et al. (2018).

Establishing fuzzy number

A fuzzy number Ã on R to be a triangular fuzzy numbers (*TFN*) if its membership function $\mu_{\tilde{a}}(x)$: R → [0, 1] is equal to following Eq. (1):

$$\mu_{\tilde{a}}(x) = \begin{cases} (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

From Eq. (1), l and u mean the lower and upper bounds of the fuzzy number Ã, and m is the model value for Ã (as Fig. 2). The *TFN* can be denoted by Ã = (l, m, u). The operational laws of *TFN* $\tilde{A}_1 = (l_1, m_1, u_1)$ and *TFN* $\tilde{A}_2 = (l_2, m_2, u_2)$ can be expressed in the following Eqs. (2) – (6).

Addition of the fuzzy number ⊕

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2)$$

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \qquad (2)$$

Multiplication of the fuzzy number ⊗

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2)$$

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (3)$$

Subtraction of the fuzzy number Θ

$$\tilde{A}_1 \Theta \tilde{A}_2 = (l_1, m_1, u_1) \Theta (l_2, m_2, u_2)$$

$$\tilde{A}_1 \Theta \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \qquad (4)$$

Multiplication of the fuzzy number ∅

$$\tilde{A}_1 \emptyset \tilde{A}_2 = (l_1, m_1, u_1) \emptyset (l_2, m_2, u_2)$$

$$\tilde{A}_1 \oplus \tilde{A} = (l_1 / l_2, m_1 / m_2, u_1 / u_2) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (5)$$

Reciprocal of the fuzzy number

$$\tilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = (1 / u_1, 1 / m_1, 1 / l_1) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \qquad (6)$$

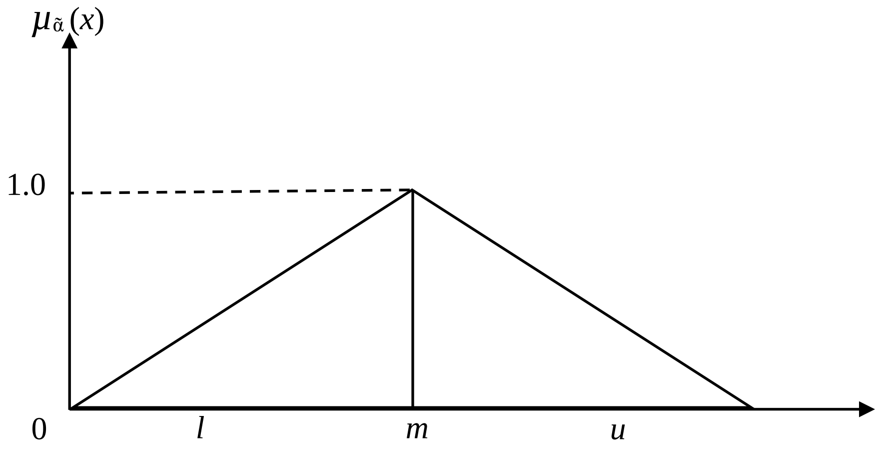

Figure F1. The membership functions of the triangular fuzzy number

Determining the linguistic number

The concept of linguistic variables is very practical in handling with ill-defined or complex situations reasonably described in conventional quantitative expressions (Zadeh 1975). A linguistic variable is a value that can be artificial or natural language in forms of sentences or words. Table 3 shows the equivalent fuzzy numbers and linguistic comparison terms considered in this study adopted from Gumus (2009).

Table T1. Fuzzy Comparison Measures

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Weak advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

FAHP procedure

Step 1: Construct pairwise comparison matrices among all the indicators in the dimensions of the hierarchy system. Assign linguistic terms to the pairwise comparisons by asking which is more important of each two dimensions, as following matrix $\tilde{\mathbf{A}}$ shown in Eq. (7).

$$\begin{bmatrix} 1 & \tilde{\alpha}_{12} & \dots & \tilde{\alpha}_{1n} \\ & & & \\ & & & \end{bmatrix} \begin{bmatrix} 1 & \tilde{\alpha}_{12} & \dots & \tilde{\alpha}_{1n} \\ & & & \\ & & & \end{bmatrix}$$

$$\tilde{\mathbf{A}} = \begin{matrix} \tilde{\alpha}_{21} & 1 & \cdots & \tilde{\alpha}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\alpha}_{n1} & \tilde{\alpha}_{n2} & \cdots & 1 \end{matrix} = \begin{matrix} 1/\tilde{\alpha}_{12} & 1 & \cdots & \tilde{\alpha}_{2n} \\ \vdots & \vdots & & \vdots \\ 1/\tilde{\alpha}_{n1} & \tilde{\alpha}_{n2} & \cdots & 1 \end{matrix} \quad (7)$$

Step 2: Examine the consistency of the fuzzy pairwise comparison matrices. According to the research of Buckley (1985), if $\mathbf{A} = [\alpha_{ij}]$ is a positive reciprocal matrix then $\tilde{\mathbf{A}} = [\tilde{\alpha}_{ij}]$ is a fuzzy positive reciprocal matrix. That is, if the result of the comparisons of $\mathbf{A} = [\alpha_{ij}]$ is consistent, then it can imply that the result of the comparisons of $\tilde{\mathbf{A}} = [\tilde{\alpha}_{ij}]$ is also consistent. Therefore, this research employs this method to validate the questionnaire.

Step 3: Compute the fuzzy geometric mean for each criterion. The geometric technique is used to calculate the geometric mean ($\tilde{r}_i$) of the fuzzy comparison values of criterion *I* to each criterion, as shown in Eq. (8), where $\tilde{\alpha}_{in}$ is a fuzzy value of the pair-wise comparison of criterion *i* to criterion *n* (Buckely 1985).

$$\tilde{r}_i = [\tilde{\alpha}_{i1} \otimes \ldots \otimes \tilde{\alpha}_{in}]^{1/n} \quad (8)$$

Step 4: Compute the fuzzy weights by normalisation. The fuzzy weight of the *i*th criterion ($\overline{\mathbf{w}}_i$), can be derived as Eq. (9), where $\overline{\mathbf{w}}_i$ is denoted as $\overline{\mathbf{w}}_i = (L_{wi}, M_{wi}, U_{wi})$ by a TFN and L_{wi}, M_{wi}, and U_{wi} represent the lower, middle and upper values of the fuzzy weight of the *i*th criterion.

$$\overline{\mathbf{w}}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \quad (9)$$