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Revisiting port performance measurement: A hybrid multi-stakeholder framework for the modelling of port performance indicators

Article

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Abstract

This study develops a new port performance measurement model by taking the perspectives from different port stakeholders. The novelty lies in the modelling of interdependencies among port performance measures, and the combination of weights of interdependent measures with both qualitative and quantitative evaluations of the measures from multiple stakeholders for quantitative port performance measurement. It represents an effective performance measurement tool and offers a diagnostic instrument for performance evaluation and/or monitoring of ports and terminals so as to satisfy different requirements of various port stakeholders in a flexible manner.

1. Introduction

Seaports (hereinafter called 'ports') are key nodes in global logistics networks and contribute to the efficiency of global supply chains. Changes in supply chain management force ports (and terminals) to seek effective integration in supply chains when delivering value to shippers and third-party logistics service providers (Robinson, 2002; Mangan et al., 2008; Song and Panayides, 2008). Ports are thus parts of complex systems operating in an uncertain logistics environment. They are also places where stakeholders provide products and deliver services that create value. The interests of different port stakeholders, i.e., port authorities, port users, service providers and related communities, in economic, social, and environmental issues, are sometimes in conflict (Notteboom and Winkelmans, 2003). Port managers increasingly rely on stakeholder relationship management practices to secure long-term relations with key stakeholders (Dooms and Verbeke, 2007). To this end, port performance measurement (PPM) becomes an important tool in stakeholder relationship management and to achieve a sustainable competitive position.

Over the past decades, PPM has become a well-established segment in port-related academic literature (see Pallis *et al.*, 2011 and Woo *et al*., 2012) but there are still significant research gaps yet to be filled. First, the existing literature tends to focus on limited dimensions of PPM or specific areas of ports. Such a fragmented approach fails to take into account new issues and challenges faced by ports. The extant relevant literature primarily introduces lists of port performance indicators (PPIs) to measure the productive and allocative efficiency of port/terminal operations (i.e., operational efficiency), focusing on terminal quayside operations via the application of, say, data envelopment analysis (DEA) and stochastic frontier models (Tongzon, 1995; Cullinane et al., 2002; Talley, 2006; González and Trujillo, 2009). Compared to port efficiency studies, existing studies on port effectiveness (e.g., Brooks, 2006; Brooks and Schellinck, 2013) are mostly restricted to the dimension of customer satisfaction using qualitative PPIs (i.e., service effectiveness). In this regard, PPM should consider the different natures of PPIs. Using only quantitative PPIs is not sufficient to measure and diagnose performance (Beamon, 1999).

Second, there are few studies available on the development of a systematic approach to address the multi-stakeholder dimension in PPM. PPM demands a stakeholder-driven approach to cover the wide-ranging objectives and desired results of stakeholders. This can be achieved through integrating a multi-stakeholder dimension in a PPM framework which takes into account the corresponding PPIs. These stakeholder-specific PPIs need to be aligned with organisational goals and strategies (Neely et al. 1995; Kaplan and Norton, 2004) and present a clear picture of the organisational performance (Gunasekaran et al, 2001). Moreover, the range of port activities that port stakeholders are concerned with requires a focus on a multi-dimensional set of quantitative and qualitative PPIs. The use of only a single dimension (e.g., financial measures) is not sufficient to cover all related issues in the contemporary business environment (Miller and Vollmann, 1985, Fry and Cox, 1989). The importance of non-financial (i.e., intangible assets) measures and the integral application of multi-dimensional measures (i.e., both financial and non-financial measures) for performance measurement have been continuously acclaimed (Neely et al., 1995). Thus, there is a need for a multi-dimensional PPM approach evaluated by different stakeholders. Evidential reasoning (ER) (Yang and Xu, 2002) is proven to be a powerful method for multi-group multi-criteria decision making (MCDM). The method has been applied in the context of port choice to deal with the associated inherent uncertainty in a MCDM structure (Yeo et al., 2014). Although the study of Yeo et al. (2014) has its merits, it does not address PPIs from multiple dimensions/perspectives, it does not well evaluate PPIs from various stakeholders, and it does not appropriately incorporate the interdependency among PPIs.

The research gaps identified above call for the development of a systematic framework that can answer the questions of 'what to measure' and 'how to measure port performance'. Such a PPM framework does not only meet the needs of port stakeholders, but also enriches the diagnostic tools available to support decision-making in complex port/terminal systems operating in an uncertain environment. The aforementioned ER approach has shown its capability of combining evaluations of different natures (quantitative and qualitative) from stakeholders having different or even conflicting perspectives on a particular PPI. This framework needs to involve multiple dimensions with both quantitative and qualitative PPIs so as to offer diagnostic instruments to decision makers. ER can assist the proposed framework to analyse port measurement results with respect to a single performance indicator, dimension or stakeholder. The decisions are usually made on multiple uncertain attributes, for instance, situations where historical data is not available or seriously inadequate for qualitative performance indicators. Consequently, this study deals with the inherent data uncertainties which are sometimes unavoidable in port/terminal operational contexts. Fuzzy logic (Zadeh, 1978) is proven to be suitable for modelling vagueness or fuzziness caused by subjective judgements (e.g. evaluation of qualitative PPIs in this study).

Furthermore, the framework needs to identify interdependencies among the PPIs. Given the complexity in port activities and operations, decision makers require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improve port performance. Traditionally, analytical network process (ANP) (Saaty, 1996) is used to configure the dependency among factors influencing a decision problem. However, it is observed that the application of ANP typically demands large data inputs for pairwise comparisons. To tackle this, we use a decision making trial and evaluation laboratory (DEMATEL) tool (Gabus and Fontela, 1973) to identify the PPIs of significant dependencies before using ANP to quantify such interdependencies.

The remainder of the paper is structured as follows. In the next section, the proposed port performance measurement (PPM) framework is outlined. The identification and description of the selected PPIs are described in detail in Section 3. In Section 4, a case study on performance of four Korean container ports is conducted using the newly proposed framework and a hybrid approach of fuzzy ER (i.e. FER) with DEMATEL and ANP. Finally, the paper concludes with a discussion of the results, the business and academic implications and recommendations for further research.

2. A conceptual discussion on the port performance measurement (PPM) framework

2.1. Port performance measurement process and methodology

The research question focuses on 'how to develop a PPM framework as a diagnostic instrument to assist decision makers in evaluating port performance?'. The objective of the proposed PPM framework is to identify the most crucial PPIs for each group of port stakeholders and to develop a powerful performance measurement tool. Various aspects such as uncertainty and interdependency among the PPIs are considered in the framework to deliver a more practical application in PPM. As illustrated in Fig. 1, the needs of different stakeholders were investigated in the first phase and their associated PPIs were derived in the second phase. To this end, we identify stakeholders' goals and objectives in major (container) ports, and discuss them with ten port stakeholders[1]. For example, PPIs related to the cost efficiency of cargo handling operations in the port are crucial for port service providers (i.e. terminal operators). However, these PPIs are necessarily a major concern to port users (i.e., shipping lines and land transport operators). Instead, port users might attach greater value to a low service price but with a guaranteed service quality level. Conflicts of interests between stakeholders require them to interpret others' assertiveness rightly. Consequently, an analysis on their interests and needs on various dimensions of port activities becomes essential. The six dimensions defined in this study cover the range of port activities to cope with new evolutionary changes, to measure and communicate their impacts on society, economy and environment and to be consistent with their goals. Then, through a comprehensive review and an analysis of industrial practices, the associated PPIs were first identified and then modified and verified by the ten experts to assess the suitability of the potential indicators and to test the feasibility of the selected indicators as suggested in the studies by Bagozzi *et al*. (1991) and Okoli and Pawlowski (2004). The majority of the experts commented on all dimensions for content validation. For example, the sub-PPIs of environment (EVS) were originally defined as air pollution, land pollution, water pollution, energy consumption, and environment management systems. However, the experts commented that the implementation schemes for reducing the specified sources of pollution are more important than the pollution itself. The defined dimensions and their associated PPIs are discussed in more detail in Section 3.

Previous studies on port performance generally consider the PPIs as independent attributes (Yeo et al., 2014). However, considering PPIs as independent and irrelevant to each other can be error prone to solve MCDM problems in complex port activities and operations (Lee *et al.*, 2013). This was apparent during the PPI verification process by the ten experts and when measuring the performance of four ports in South Korea. To address this issue, we use DEMATEL to identify whether there are interdependent relationships among the PPIs, while ANP is applied to determine the intensity of the relationships among the PPIs. Furthermore, FER is applied for synthesising the evaluations from multiple stakeholders and from different dimensions. The proposed framework for a hybrid PPM system is outlined below, consisting of four steps, while its detailed application in port performance measurement is described in Section 4.

1. Investigate the performance needs and interests of different stakeholders and translate them into corresponding PPIs for each group of stakeholders.
2. Find proper methodologies to deal with various features of the PPIs (i.e., interdependency, uncertainty and MCDM).
3. Assign interdependent weights among PPIs (using DEMATEL and ANP) and evaluate PPIs' performance (degrees of belief (DoB)) with respect to each alternative port.
4. Synthesise the evaluations of PPIs with their weights using a fuzzy rule-based ER algorithm

[1] The group included six industrial experts who have been working in shipping and port industries for more than 15 years with PhD (one expert from a shipping line), MSc (three experts from terminal operators, a shipping line and a forwarder) and BA (one from a terminal operator and a forwarder, respectively) degrees participated in the assessments. two professors who have more than 15 years of research experience as well as they are (ex)member of port committee participated in the survey. Lastly, two experts from governments/port authorities (one department manager and one managing director) who have been working in port logistics departments participated in the survey.

and a utility technique (IDS software).

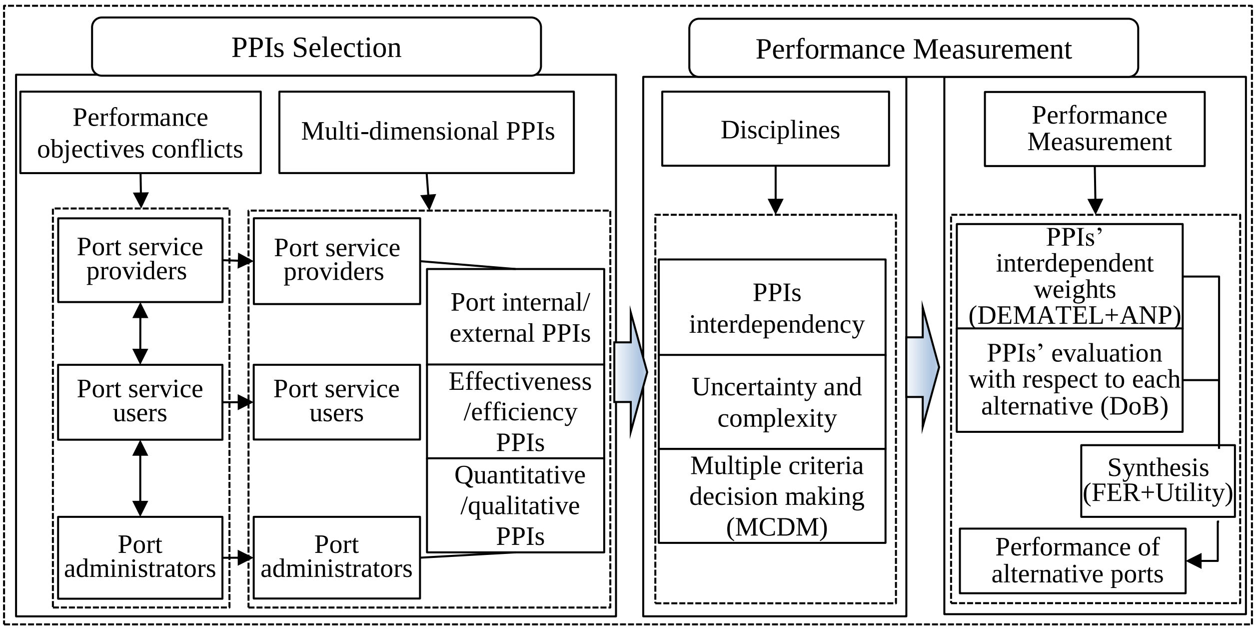


Fig. 1. Port performance measurement (PPM) framework

3. Literature review for the conceptual development of PPIs

Ports are integrated process platforms where different port stakeholders interact in port activities related to cargos, vessels and other transport modes. Ports need an alignment of seaside, intermodal/multimodal and landside logistics to achieve an efficient movement of the physical (i.e. cargos) and non-physical (i.e., information) flows (UNCTAD, 2004). To this end, PPIs in a PPM framework need to reflect these performance aspects. Moreover, PPI evaluation needs to be conducted with inputs from associated stakeholders (Brook, 2006; Brooks and Schellinck, 2013). This may assist decision-makers not only in diagnosing both the efficiency and effectiveness aspects of performance, but also in identifying the strengths and weaknesses of ports. In this study, we analyse 259 relevant papers from 1970 to 2016 on Web of Science (core collection) by combining (using the 'OR' function) the search results of "container terminal measurement" (46 papers), "container terminal selection" (46), "container terminal competitiveness" (61), "container terminal choice" (32), "seaport competitiveness" (51), "seaport choice" (25), "seaport measurement" (39), "seaport selection" (27). By doing so, different PPI classification approaches were identified and screened through the PPI verification process by the ten experts. Base on this approach, six dimensions with their associated 16 principal-PPIs and 60 PPIs are defined as particularly relevant factors for port stakeholders. These dimensions include core activities (CA), supporting activities (SA), financial strength (FS), user satisfaction (US), terminal supply chain integration (TSCI) and sustainable growth (SG) (Table 1). The further justification of the identification and classification of PPIs is provided below.

1) The core activities (CA) relate to the core function of ports, e.g., vessel operations, cargo handling operations and other activities regarding the transfer or transit from terminals to vessels and other transport modes (and vice versa) in a container terminal area. The CA have traditionally, and most frequently, been assessed by scholars and industry practitioners (UNCTAD, 1976; Tongzon, 1995; Cullinane *et al.*, 2002) using different types of taxonomies, such as output, productivity, capacity utilization, and efficiency. Productivity is one of the most important criteria guiding port choice by shipping lines (Murphy *et al.*, 1992). The term productivity refers to how efficiently resources (i.e., labour, equipment and land) are being used.

The outputs generally considered include production, throughput and profit (Bichou, 2006). Output thus refers to the total quantity of work performed in a port over a period of time without considering the resources utilised (De Monie, 1987). The lead-time refers to the speed at which activities are performed. This term gained in importance by the introduction of just-in-time (JIT) production (De Treville *et al*., 2004), where it is defined as the time that elapses between the start of a process and its completion. Schmenner (2004) stresses that companies achieving a higher competitiveness through a combination of speed and variability reduction and productivity improvement would have a higher performance than companies focusing on only one aspect.

2) Supporting activities (SA) refer to the maintenance of internal resources to improve an organization's effectiveness and/or efficiency. Kaplan and Norton (2004) stress that desired strategic outcomes could be achieved by appropriate deployment and effective utilisation of intangible assets in the information era. A value-oriented organization based on collaboration, trust, sharing, learning and openness tends to achieve desirable outcomes such as efficiency, effectiveness, and innovation (Alavi *et al*., 2006). There is a need of reliable human resources (HRs) that cannot be easily imitated by competitors (Marlow and Paixão Casaca, 2003). Employees who have the right skills, talent, and knowledge contribute to enhancing the organization's internal processes and performance (Kaplan and Norton, 2004). A higher worker commitment and loyalty leads to a higher workplace performance (Brown *et al*., 2011). In this case, Albadvi *et al*. (2007) found a statistically significant correlation between ICT and firm performance.
3) The financial strength (FS) dimension concerns financial profitability and stability. Profitability measures a firm's ability to generate profit relative to land, labour and capital inputs. The term liquidity refers to the firm's ability to pay its short liability whilst solvency covers its long-term liabilities. Irrespective of the type of industries, financial performance is very important for managers and investors. This is reflected by the many PPM approaches in literature. UNCTAD (1976) introduced revenue and cost items and classified major port cost items into labour costs, equipment costs and capital costs. Marlow and Paixão Casaca (2003) suggest the measures of cost items in the lean port process. Su *et al*. (2003) used profitability, solvency and return on investment as financial indicators for a comprehensive performance measurement system based on the balanced scorecard (BSC). Brooks (2006) identifies specific revenue and cost items that are widely used by 42 ports located in ten countries. Previous literature mainly investigated whether a service quality delivered by ports meets port users' needs in terms of timing, quantity and quality (Brooks and Schellinck, 2013). Therefore, an indicator to measure port agility, or the speed with which the port service provider responds to special requests of customers is included in this study (Marlow and Paixão Casaca, 2003). It is underpinned by the growing number of studies using the SERVQUAL methodology to measure service quality in the port industry (Pantouvakis *et al*., 2008). Woo *et al*. (2011) use various port service prices as a service quality measure. Service cost is considered as one of the most important criteria which affects port selection by port users and determines port competitiveness when service quality is ascertained (Yeo *et al*., 2014). Consequently, a low port service charge is a key driver for attracting customers (Woo *et al*., 2011).
4) Ports have a key role to play in supply chains. In this context, higher integration and coordination between the players in supply chains lead to a higher competitiveness (Panayides and Song, 2009). Port terminals should provide a reliable and adequate multimodal process such as sea/land side connectivity, multimodal transport integration in order to attract trade flows and increase a port's competitiveness (Woo *et al*., 2013). In addition, they should provide value-added services to better meet the objectives of the associated supply chain systems (Panayides and Song, 2009). Furthermore, the integration of information & communication systems (ICS) cannot be excluded from TSCI; it measures the establishment and use of seamless communication systems and the degree of collaboration with partners (Bichou and Gray, 2004; Notteboom and Rodrigue, 2005). Marlow and Paixão Casaca (2003) demonstrate that integrated IT systems would contribute to total cost reduction in supply chains.
5) Sustainability refers to the intersection of social, environmental and economic contributions that

deliver long-term effectiveness for the natural environment, society and firms (Carter and Rogers, 2008). Despite the wide adoption of ‘sustainability’, its application in the maritime industry is rather recent (Lam, 2015). Due to legislations and the requirement to fulfil corporate social responsibility, ports put considerable efforts on the reduction of environmental impacts and to enhance safety, security, and social and economic responsibility (ESPO, 2010). Hence, ports need to pay more attention to the promotion of long-term sustainable growth with ecological health and social and economic contributions. In the long term, port efficiency and competitiveness can be gained from the implementation of appropriate safety and security schemes (Woo *et al*. 2011), as well as environmental management systems (EMS) (Peris-Mora *et al*. 2005; Darbra *et al*. 2009). Furthermore, the contribution of ports to society and the economy is important in the context of corporate social responsibility (Grewal and Darlow, 2007; De Langen, 2002).

Based on the above, there is a need for a high degree of excellence of modern ports, which can deliver internal and external satisfaction from a multi-stakeholder perspective. The six dimensions for PPM are intertwined in practice. With regard to the ‘employment’ PPI in sustainable growth, for example, an alternative port can be judged with good performance on ‘employment’ when the port has a huge contribution to create an employment opportunity or maximise employment to fulfil corporate social responsibility. However, the situation could simultaneously deteriorate the FS of the firm, leading to a cost increase and an adverse effect on the labour productivity (throughput /number of employee), one of the PPIs in CA.

Table 1
The hierarchy of port performance indicators (PPIs)

Dimensions	Principal-PPIs	PPIs	Literature	Note[1]
Core activities (CA)	Output (OPC)	Throughput growth, vessel call size growth	UNCTAD, 1976; De monie, 1987; Tongzon 1995; Cullinane *et al.*, 2002; Brooks, 2006; Woo *el al.*, 2011	QT; Data input from TO, PA and GOV database
	Productivity (PDC)	Ship load rate, berth utilization, berth occupancy, crane productivity, yard utilization, labour productivity		
	Lead time (LTC)	Vessel turnaround, truck turnaround, container dwell time		
Supporting activities (SA)	Human capital (HCS)	Knowledge and skills, capabilities, training and education, commitment and loyalty	Marlow and Paixão Casaca, 2003; Kaplan and Norton 2004; Albadvi *et al.*, 2007; Brown *et al.*, 2011; Woo *et al.* 2013	QL; Data input by TO
	Organisation capital (OCS)	Culture, leadership, alignment, teamwork		
	Information capital (ICS)	IT systems, database, networks		
Financial strength (FS)	Profitability (PFF)	Revenue growth, operating profit margin, net profit margin	Su *et al.*, 2003; Bitchou and Gray, 2004; Brooks, 2006	QT; Data input from TO and GOV database
	Liquidity & Solvency (LSF)	Current ratio, debt to total asset, debt to equity		
Users’ satisfaction (US)	Service fulfilment (SFU)	Overall service reliability, responsiveness to special requests, accuracy of documents & information, incidence of cargo damage, incidence of service delay	Marlow and Paixão, 2003; Woo *et al.*, 2011; Brooks and Schellinck, 2013	QL, Data input by SL, FF and 3PL
	Service costs (SCU)	Overall service cost, cargo handling charges, cost of terminal ancillary services		
Terminal supply	Intermodal transport systems	Sea-side connectivity, land-side connectivity, reliability for multimodal	Bichou and Gray, 2004; Notteboom	QL, Data input by TO,

chain integration (TSCI)	(ITST)	operations, efficiency of multimodal operations	and Rodrigue, 2005; Panayides and Song, 2009; ESPO, 2010; Woo *et al.*, 2013	SL, FF and 3PL
	Value-added services (VAST)	Facilities to add value to cargoes, service adaptation to customers, capacity to handle different types of cargo, tailored services to customers		
	Information/ communication integration (ICIT)	Integrated EDI for communication, integrated IT to share data, collaborate with channel members for channel optimisation, latest port IT systems		
Sustainable growth (SG)	Safety and security (SSS)	Identifying restricted areas and access control, formal safety and security training practices, adequate monitoring and threat awareness, safety and security officers and facilities	De Largen, 2002; IMO, 2002; Peris-Mora *et al.*, 2005; Darbra *et al.*, 2009; ESPO 2010; Woo *et al.*, 2011	QL, Data input by TO, PA and GOV
	Environment (EVS)	Carbon footprint, water consumption, energy consumption, waste recycling, environment management programmes		
	Social engagement (SES)	Employment, regional GDP, disclose of information		By PA and GOV

[1]Note: QT, quantitative PPI; QL, qualitative PPI; TO, terminal operator; SL, shipping line; FF, freight forwarder; PA, port authority; GOV, government.

4. PPM methodology and its application to four Korean ports

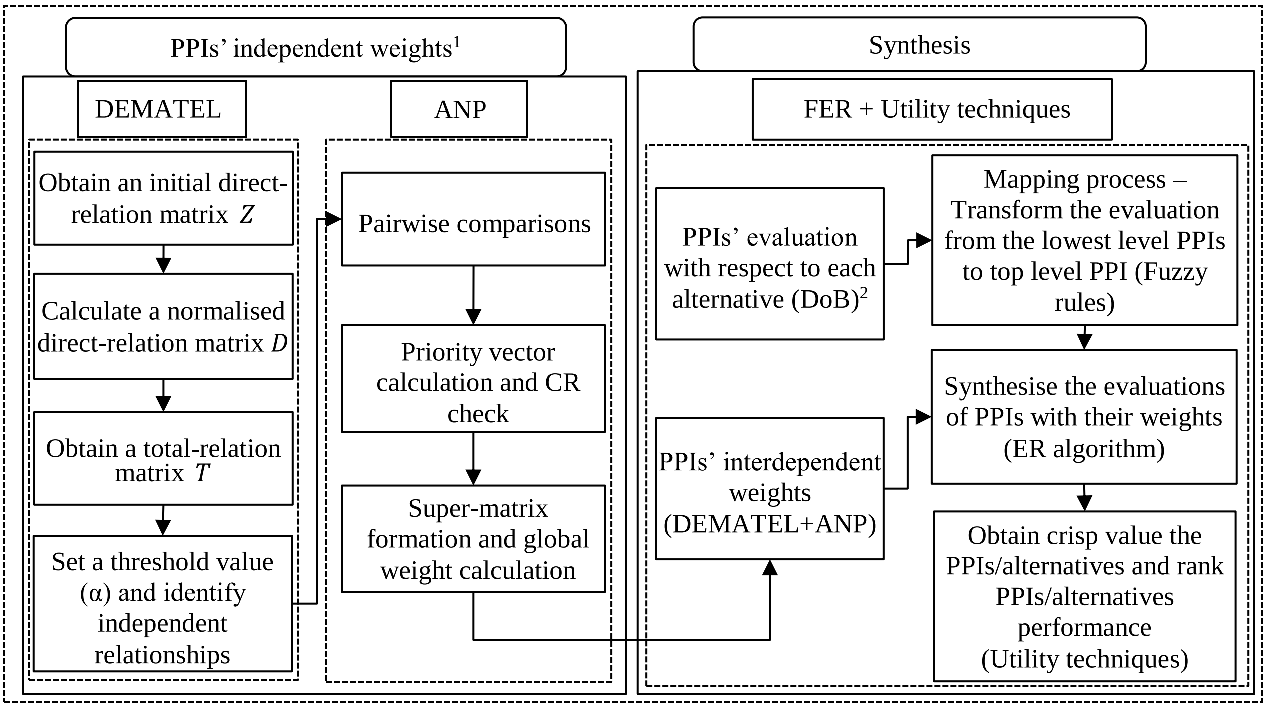
The proposed quantitative modelling for PPM using a hybrid approach of DEMATEL and ANP incorporating FER can be found in Fig. 2. Its main purpose is to demonstrate the application of the proposed method to PPM. For the theoretical background and mathematical algorithms of the relevant techniques, we refer to Shieh *et al.* (2010) for DEMATEL, Saaty (1996) for ANP, and Yang and Xu (2002) for ER, respectively.

In Fig. 2, the combination of DEMATEL and ANP is used to calculate the weights of each interdependent PPI. An integrated method of DEMATEL and ANP is proven to be successful in measuring dependence and feedback among elements in complex decision problems in various applications (Buyukozkan and Cifci, 2012). We use the integrated method in PPM for the following reasons (Shieh *et al.*, 2008; Buyukozkan and Cifci, 2012). First, it is successfully applied in complex decision problems. Second, it deals with both quantitative and qualitative PPIs for weighing and interdependency. Third, it allows for group decision-making. Lastly, it requires a relatively small sample size for analysis.

The evaluations of quantitative and qualitative PPIs in the bottom level and their associated weights need to be conducted in the first phase and then transformed from the bottom level to the top level in the PPI hierarchy to measure port performance. In this process, fuzzy logic is applied to deal with the vagueness caused by subjective evaluation of qualitative PPIs. Furthermore, ER is employed to synthesize the evaluation of all PPIs from the bottom level (PPIs), through principal PPIs, to the top level dimensions. The ER approach, based on the Dempster-Shafer theory of evidence (D-S theory), is a reliable tool in dealing with MCDM under uncertainties. Yang and Xu (2002) develop a new ER algorithm for hybrid MCDM problems with both qualitative and quantitative attributes under uncertainty. The study utilises a belief structure (i.e., degrees of belief (DoB)) in assessing multiple criteria in a bottom level hierarchy and introduces a process of converting the bottom level criteria assessments to their associated top level criterion. In Yeo et al., (2014), the hybrid of fuzzy logic and ER (i.e., fuzzy ER or FER) is revealed as a useful method to handle incomplete and vague data as well as complete and precise data together. This also provides users with a greater flexibility by allowing them to express their judgements both subjectively and quantitatively. As a hierarchical evaluation process, this offers a rational and reproducible methodology to aggregate the assessed data. Moreover, in the MCDM applications, the evaluations of indicators and their importance should be conducted separately and then incorporated into a single value for each alternative to select the best solution from the alternatives. In this regard, FER is a flexible methodology that combines other linear weighting techniques (i.e. analytical hierarchy process (AHP) and DEMATEL). Finally, decision makers can obtain the assessment output through its associated software package, such as the intelligent decision system (IDS; Yang and Xu, 2000).

The hybrid approach opens new avenues for PPM. First, the approach using FER with DEMATEL and ANP, can evaluate the performance of a terminal/port against a specific indicator at any level (e.g. PPIs, principal PPIs or dimensions) and thus can assist to benchmark port performance with particular concerns. Second, it can evaluate the port performance from one group of stakeholders and to compare the difference understandings of various stakeholders, as well as combining the evaluations from different groups of stakeholders for a compromising solution. Third, it can accommodate subjective and incomplete evaluations and deliver a port performance measurement result under high uncertainty. Such capabilities are found to be demanded in both academic research and industrial practice but not well addressed yet from both theoretical analysis and practical implementation. For instance, a domain expert may be able to tell that in terms of a particular indicator, port A is better than port B. However, it is difficult for this expert 1) to precisely quantify the extent to which port A is better than port B, 2) to provide an overall evaluation of port A/B by taking into account all indicators from different dimensions (e.g., internal finance and external effectiveness), 3) to measure the performance when the uncertainty in data is high (e.g., missing data or high interdependency among PPIs).

In the next section, an analysis of four major container ports in South Korea (i.e., Busan North Port, Gwangyang, Incheon, and Busan New Port) is conducted to validate the developed PPM framework and hybrid model. While Busan New Port, Gwangyang and Incheon are the leading container ports in terms of container throughput growth, the development of Busan North Port is not as strong as Busan New Port in recent years. We therefore use the first three ports to investigate the strengths and weaknesses of each port and compare the performance of Busan North Port and Busan New Port to verify the method and model. In general, ports in South Korea are performance-driven as they operate in an international market environment and located in a country with an open and trade-oriented economy. To remain and sustain their competitiveness, these ports need to meet the requirements of (global) shippers, shipping lines, and third-party logistics service providers.



Note: [1]The weight evaluations were conducted by the panel of 10 experts (questionnaire survey) while [2]the evaluations of PPIs' performance were conducted using inputs gained from different stakeholders (questionnaire survey for qualitative PPIs; secondary data for quantitative PPIs).

Fig. 2. A hybrid methodology for port performance measurement

4.1. Collect data to evaluate PPIs' performance

The PPIs that are needed for PPM have been identified in Section 2.2. The PPIs involve various types of numeric and subjective data to reflect the complexity of the port/terminal business environments. The assessments of each PPI's performance with respect to each terminal are conducted from associated stakeholders' perspectives. Previous studies on port performance generally rely on the information gained internally from terminal operators. Brooks (2006) and Brooks and Schellinck (2013) point to the necessity of a third-party performance measurement program (based on inputs gained externally) for benchmarking in the port industry. Such third-party performance measurement programs on operational efficiency and customer satisfaction can be found in the airport industry, but are not yet commonly used in the port industry (Brooks and Schellinck, 2013). In this regard, this study covers inputs gained both internally from terminal operators and externally from other port stakeholders to evaluate performance of the associated PPIs and to represent different port stakeholders' stance. The quantitative data (i.e., CA and FS) were collected directly from terminal operating companies and information systems/databases managed by port authorities and the Korean government. Panel data for 2013 and 2014 were used to measure the growth rate PPIs, e.g., throughput growth, revenue growth, etc., while the other quantitative PPIs, e.g., berth occupancy rate, crane productivity, operating profit margin, etc., were measured using cross sectional data of 2014. The qualitative PPIs were collected using questionnaire results obtained from three groups of terminal operators (TO), users (i.e., shipping lines and freight forwarders, PU) and administrators (i.e., port authority and government, AD) to assess their own associated PPIs and to measure ports' performance. The survey was conducted through an online survey as well as e-mail contacts from October 2014 to March 2015. The detailed responses of the survey and sample questions are listed in Table 2 and Table 3, respectively. To collect subjective data for qualitative PPIs, assessment grades are allocated to the qualitative PPIs. For assessing a qualitative PPI, for example, different sets of linguistic terms such as {very low, low, medium, high, very high} for "commitment and loyalty of terminal employees" are defined by domain experts (Yang, 2001). If a PPI is of quantitative nature, it can be assessed using numerical grades (Yang, 2001) based on various data. A set of quantitative grades, for example, {leq0%, 5%, 10%, 15%, 20%, geq25%} for "throughput growth" are developed based on a list of the world's top 50 container ports (Containerisation International, 2010-2012). Different sets of assessment grades for each PPI are defined based on their features, industrial practices, and reliable references[2].

Each PPI at the bottom level can be assessed using degrees of belief (DoB) represented by judgments (Yang, 2001). The judgments can be presented by DoB which belong to either linguistic terms (for the qualitative PPIs) or numerical values (for the quantitative PPIs). The former was obtained based on the results collected from associated port stakeholders while the latter were calculated through various location measurement techniques (Yeo *et al*, 2014). For example, a set of quantitative grades $H = \{\text{leq } 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), \text{geq } 25\%(H_6)\}$ for "throughput growth" is defined in the previous step. If the assessment of the throughput growth in an investigated port is 12.5%, then it belongs to 50% H_3 and 50% H_4. In a similar way, the bottom level PPI sets of all ports can be obtained.

Table 2
Response details

	Busan North Port			Gwangyang			Incheon			Busan New Port		
	TO	PU	AD	TO	PU	AD	TO	PU	AD	TO	PU	AD
Total distributed	100	200	40	75	200	40	75	200	40	125	200	40
Received by emails	2	38	0	40	26	10	0	15	0	4	38	0
Received by online surveys	30	20	9	0	5	0	41	26	11	26	20	9
Valid responses*	31	43	6	40	29	10	39	28	6	28	43	6
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI	SG	SA, TSCI, SSS, EVS	US, TSCI	SG	SA, TSCI, SSS, EVS	US, TSCI	SG	SA, TSCI, SSS, EVS	US, TSCI	SG

Note:*Valid responses received from PU (port users) and AD (administrators) contain the evaluations of all the associated terminals in the targeted ports, while TO (terminal operators) only evaluate their own terminals. For instance, there are 3 terminals in Busan North Port, 3 in Gwangyang, 3 in Incheon and 5 in Busan New Port. The abbreviations in "judgment on" are the PPIs in Table 1 including SA (supporting activities), TSCI (terminal supply chain integration), SSS (safety and security), EVS (environment), US (user satisfaction), SG (sustainable growth). CA (core activities) and FS (Financial strength) are quantitative PPIs and their data are collected from existing databases.

Table 3
Sample question to each stakeholder group

	Terminal	Very Poor	Poor	Medium	Good	Very Good
Survey for PU Terminal operators' *responsiveness to special requests* is:	T 1					
	T 2					
	…					
	T N					

4.2. The use of DEMATEL and ANP to analyse PPIs' interdependent weights[3]

In this study, we identify six dimensions, 16 principal PPIs and 60 PPIs. If only ANP is used for weighing, the data collection would become too costly and time-consuming. The use of DEMATEL to

[2] The assessment grades, for example, for the PPIs of FS dimensions are defined based on the annual reports of four major global terminal operators (GTOs: PSA, HPH, APM and DPW) between 2008 and 2012 because these TOs are very representative due to their worldwide operations.

[3] The surveys for DEMATEL and ANP analysis were conducted from October 2014 to March 2015.

identify the interdependency among PPIs significantly reduces the required input data in ANP. Furthermore, the literature on ANP does not provide any guidance on identifying a network structure between clusters and/or elements but constructs the relationships in a more subjective way (e.g., Van Horenbeek and Pintelon, 2014; Lam, 2015). This increases a decision subjectivity which may weaken the validity of results. In this case, we use DEMATEL to quantitatively identify interdependent relationships among the PPIs. The method is useful for demonstrating interdependency of PPIs by determining the direction and strength of both direct and indirect relationships (Buyukozkan and Cifci, 2012). The direction and strength of influences between PPIs can be determined by pairwise comparisons. The pairwise comparison scale for this study ranges from 0 to 4 with '0 (no influence)', '1 (low influence)', '2 (medium influence), '3 (high influence)' and '4 (very high influence)', respectively. The ten experts[4] determined the interdependency among the six dimensions (i.e. CA (core activities), SA (supporting activities), FS (financial strength), TSCI (terminal supply chain integration), SG (sustainable growth)). Surveys were conducted in the form of close-ended questions, such as "to what extent (i.e., from 'no influence' to 'very high influence') do the core activities (CA) affect the supporting activities (SA)?" Compared to other methodologies using pairwise comparisons (i.e., AHP and ANP), the questions in a DEMATEL setting are designed to identify bidirectional influences, for example, "to what extent SA affects CA?" An initial direct-relation 6×6 matrix (Z) is obtained by pairwise comparisons in terms of influences and directions (Table 4). Table 5 shows the total influence matrix of the six dimensions in which the threshold value of 0.82 is calculated using DEMATEL. Consequently, any value less than 0.82 refers to an insignificant dependency. Thus, its corresponding indicators will not be investigated further. The results in Table 5 help to minimise the number of pairwise comparisons for the 16-principal PPIs.

Based on Table 5, eight experts[5] determined the interdependency among the 16 principal-PPIs. The same process is conducted to obtain a direct influence matrix for principal-PPIs. A threshold value of 0.11 is obtained. Only the PPIs whose influence values in each cell (Table 6) are higher than the threshold value can be chosen and converted into an ANP network structure. Based on Table 6, the network structure of Fig. 3 can be constructed for ANP pairwise comparisons between the different clusters (i.e., the six dimensions) and/or elements (i.e., the 16 principal PPIs) to derive PPIs' interdependent weights. The three types of dependence seen in Fig. 3 are identified as follows:

- Outer dependence on the six dimensions: (1) all six dimensions with respect to CA; (2) CA, FS, US, TSCI, SG with respect to SA; (3) CA, SA, SG with respect to FS; (4) CA, SA, FS with respect to US; (5) CA, SA, US with respect to TSCI
- Inner dependence: OPC, PDC, LTC in CA and ICS in SA are inner dependent.
- Outer dependence on the 16 principal-PPIs: (1) all 16 principal-PPIs with respect to OPC, PDC and LTC, respectively. (2) 13 principal-PPIs with respect to HCS, etc. See the values in bold in Table 6 for other outer dependences on the 16 principal-PPIs.

Table 4

The initial influence matrix of dimensions (Z)

	CA	SA	FS	US	TSCI	SG
CA	0	2.40	2.70	3.80	2.50	2.10

[4] The same panel of the ten experts in the previous survey participated in the judgments.

[5] Eight experts (two terminal operators, one shipping line, one forwarder, two academics and two government representatives) among the ten experts in the previous survey responded to this survey. The judgments by the other two experts were incomplete, hence we used eight experts' judgements to determine the interdependency among the 16 principal-PPIs, which is sufficient to provide a reasonable DEMATEL outcome (Buyukozkan and Cifci, 2012).

SA	2.30	0	2.30	2.70	2.40	2.20
FS	2.00	2.30	0	1.60	1.70	3.10
US	2.70	2.40	2.20	0	2.20	1.70
TSCI	2.20	2.20	2.10	2.20	0	1.70
SG	2.90	2.40	1.50	1.20	1.40	0
Sum	12.10	11.70	10.80	11.50	10.20	10.80

Note: CA (core activities), SA (supporting activities), FS (financial strength), TSCI (terminal supply chain integration), SG (sustainable growth).

Table 5

The total influence matrix of dimensions (T)

	CA	SA	FS	US	TSCI	SG	R_i	pr_i^-
CA	**0.88**	**1.01**	**0.97**	**1.08**	**0.92**	**0.93**	5.80	0.53
SA	**0.94**	0.77	**0.87**	**0.93**	**0.84**	**0.86**	5.19	0.07
FS	**0.85**	**0.84**	0.65	0.80	0.73	**0.84**	4.70	(0.10)
US	**0.92**	**0.89**	**0.83**	0.74	0.80	0.80	4.98	(0.12)
TSCI	**0.85**	**0.83**	0.78	**0.83**	0.61	0.75	4.65	0.08
SG	**0.83**	0.79	0.70	0.73	0.67	0.59	4.31	(0.46)
C_i	5.27	5.12	4.80	5.10	4.57	4.77	29.63	

Table 6

The total influence matrix of principal-PPIs

		CA			**SA**			**FP**		**US**		**TSCI**			**SG**			R_i	pr_i^-
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES		
CA	OPC	**0.17**	**0.24**	**0.23**	**0.17**	**0.18**	**0.19**	**0.18**	**0.16**	**0.19**	**0.19**	**0.14**	**0.12**	**0.14**	**0.15**	**0.13**	**0.13**	2.70	-0.07
	PDC	**0.26**	**0.18**	**0.26**	**0.19**	**0.19**	**0.20**	**0.19**	**0.16**	**0.20**	**0.20**	**0.15**	**0.13**	**0.15**	**0.14**	**0.14**	**0.13**	2.86	0.09
	LTC	**0.25**	**0.26**	**0.18**	**0.18**	**0.18**	**0.20**	**0.18**	**0.16**	**0.22**	**0.19**	**0.15**	**0.12**	**0.16**	**0.15**	**0.14**	**0.12**	2.83	0.07
SA	HCS	**0.21**	**0.22**	**0.21**	0.10	0.10	0.11	**0.15**	**0.14**	**0.17**	**0.16**	**0.11**	**0.12**	**0.13**	**0.14**	**0.12**	**0.12**	2.32	0.50
	OCS	**0.21**	**0.21**	**0.20**	0.10	0.10	0.11	**0.16**	**0.13**	**0.18**	**0.15**	**0.12**	0.11	**0.13**	**0.13**	**0.12**	**0.12**	2.27	0.45
	ICS	**0.23**	**0.23**	**0.24**	0.11	0.11	**0.12**	**0.16**	**0.14**	**0.18**	**0.16**	**0.13**	**0.12**	**0.14**	**0.14**	**0.12**	0.11	2.43	0.46
FP	PFF	**0.14**	**0.14**	**0.14**	0.11	0.11	0.11	0.06	0.05	0.07	0.06	0.05	0.04	0.05	0.11	0.10	**0.13**	1.45	-0.34
	LSF	**0.14**	**0.13**	**0.13**	0.11	0.11	**0.11**	0.06	0.05	0.07	0.06	0.05	0.04	0.05	0.11	**0.12**	0.11	1.45	-0.13
US	SFU	**0.20**	**0.20**	**0.19**	**0.15**	**0.16**	**0.16**	**0.15**	**0.14**	0.10	0.09	0.07	0.06	0.07	0.08	0.07	0.07	1.95	-0.07
	SCU	**0.18**	**0.18**	**0.17**	0.11	0.11	**0.12**	**0.15**	**0.14**	0.08	0.07	0.05	0.05	0.06	0.07	0.06	0.06	1.68	-0.16
TSCI	ITST	**0.19**	**0.18**	**0.19**	**0.13**	**0.13**	**0.16**	0.09	0.08	**0.16**	**0.13**	0.06	0.06	0.07	0.07	0.06	0.06	1.80	0.56
	VAST	**0.17**	**0.16**	**0.16**	**0.12**	**0.12**	**0.13**	0.08	0.07	**0.15**	**0.14**	0.05	0.05	0.06	0.06	0.05	0.05	1.62	0.49
	ICIT	**0.20**	**0.20**	**0.20**	**0.15**	**0.15**	**0.18**	0.10	0.09	**0.17**	**0.15**	0.07	0.06	0.07	0.07	0.07	0.06	1.98	0.65
SG	SSS	0.11	0.11	**0.12**	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.76	-0.72
	EVS	0.07	0.08	0.07	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.49	-0.88
	SES	0.06	0.06	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.42	-0.91
C_j		2.77	2.77	2.76	1.82	1.82	1.97	1.79	1.58	2.02	1.84	1.24	1.13	1.33	1.48	1.37	1.32	28.99	

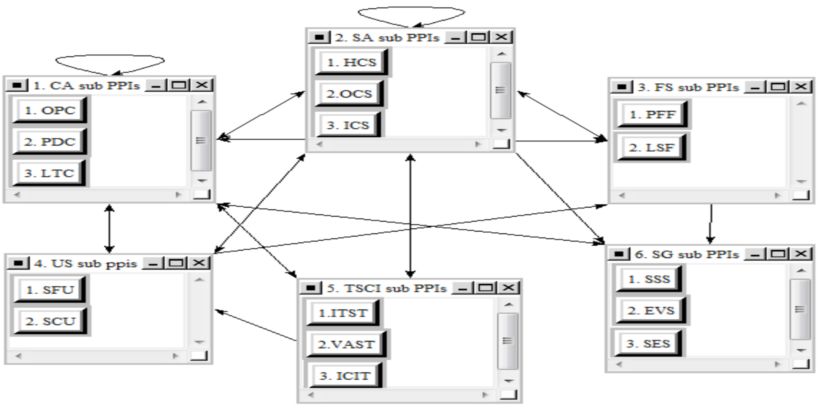


Fig. 3. Interdependency between 16 principal-PPIs (super decisions software)

After determining the interdependent relationships between the PPIs, the ANP method is used to obtain the final adjusted weights. The ten experts[6] were asked to respond to questions, for example, (1) with respect to the 'CA', "which dimension influences 'CA' more: 'SA' or 'FS', and how much more?" (i.e., outer dependence in 6 dimensions); (2) with respect to the OPC, "which principal-PPI influences 'OPC' more: 'OPC' or 'PDC', and how much more?" (i.e., inner dependence with respect to OPC); (3) with respect to the OPC, "which principal-PPI influences 'OPC' more: 'HCS' or 'OCS', and how much more?" (i.e., outer dependence in 16 principal-PPIs). Series of pairwise comparisons are based on Saaty's nine-point scale ranging from 1 (equal) to 9 (extreme). By repeating this process, a number of comparison matrices were formed, which helped identifying the relative impacts of the principal-PPIs' interdependency. Using ANP, the global weights of sixteen principal-PPIs are calculated. Productivity is the most important principal-PPI with a value of 0.14, followed by output (0.12), lead-time (0.12), service fulfilment (0.1), information capital (0.1) and profitability (0.08). A plausible explanation would be that in the context of the container port industry, container throughput, berth-yard operation, turnaround time and labour productivity and competency of information technology are important criteria for PPM. However, cost (0.05) and price competitiveness is crucial but not as important as the above six indicators for port performance measurement. This finding is partially in line with the general argument in port selection/competitiveness research that a shipping line is likely to choose a port due to the port's cargo generation, port efficiency, service quality and hinterland connectivity (Yeo *et al*., 2008; Tongzon, 2009; Wu and Goh, 2010; Wiegmans *et al*., 2008). Ports should not only take into account internal competency of core and supporting activities, but also be aware of the tangible and intangible integration with stakeholders so as to sustain themselves in the highly competitive global business environment.

The final step is to obtain local weights of 60 PPIs. The local weights of 60 PPIs were obtained by AHP. Further computation is conducted to obtain global weights of the bottom level PPIs by multiplying their local weights with the ones of their associated upper level criteria. For instance, the global weight of 'throughput growth (OPC1)' can be obtained as 0.083 (=0.12 (the global of output (OPC)) $\times$ 0.696 (the local weight of throughput (OPC1)). The results derived from ANP suggest that throughput growth (OPC 1) is the most important PPI which has a relative importance value of 0.083, followed by vessel turnaround (LTC 1, 0.071), crane productivity (PDC 4, 0.048), overall service reliability (SFU 1, 0.037), vessel call size growth (OPC 2, 0.036), and IT systems (ICS 1, 0.036). On the contrary, waste recycling (EVS 2, 0.002), water consumption (EVS 4, 0.002), and carbon footprint (EVS 1, 0.002) under environment (EVS) are the least important PPIs. The global weights obtained are used as inputs for the FER method for evaluating the performance of the investigated ports.

4.3. Synthesise DoBs and weights of PPIs and case study results.

Given the performance data (from Section 4.1) and the weights (from Section 4.2) of all the 60 PPIs of the four ports, their performance can be evaluated by using ER. The synthesis of four ports against all PPIs together with their weights in this study was conducted using IDS and by incorporating the ER algorithm. The window-based tool, IDS, facilitates the process of making decisions from collecting information to building up a model, defining alternatives and criteria and different assessments (Yeo *et al*., 2014). This software provides assessment information including evidence and comments, systematic help at every stage of the assessment process including guidelines for grading criteria and a tailored report with strengths and weaknesses.

The results derived from IDS are shown in Tables 7-9 and Fig. 4 with respect to different ranking criteria. The performance of individual 60 PPIs with respect to the alternative ports is shown in Table

[6] Four experts (one terminal operator, one shipping line, one forwarder, one academic) of the ten experts obtained a CR of 0.10 or less, which is sufficient to provide a reasonable ANP outcome (Buyukozkan and Cifci, 2012).

7. They provide direct information on the performance of each port activity driven by each stakeholder, which makes it possible for port managers to interpret the performance results easily. For example, both the container throughput growth and vessel call size growth are negative in Busan North Port. However, the ship load rate, a ratio of the combined two PPIs of container throughput volume (TEU) and average vessel call size (GT), performs well with a score of 0.8471. Even though the number of vessel calls to Busan North Port saw a relatively small decrease from 7,702 in 2013 to 7,386 in 2014 (-4.1%), the total gross tonnage (GT) of the vessels decreased radically from 136,448k GT to 113,405k GT (-16.9%). This indicates that smaller sized vessels came into Busan North Port in 2014 compared to the vessel size in 2013. Accordingly, container throughput decreased dramatically (-12.5%) but the decline was not as dramatic as the drop-in vessel capacity calling the port (-16.9%). This leads to the remarkable performance result of the ship load rate in 2014 (81.69 TEU/GT). Moreover, the higher number of calls of smaller vessels leads to a higher berth occupancy rate (the ratio of time that a vessel is occupying a berth, 1.0000) because the vessel berthing practices, in general, are conducted in terms of berth (identity) number regardless of berth capacity. However, the high number of smaller vessels lowers the berth utilisation performance (TEU/berth length, 0.704). Busan North Port performs moderately against other PPIs but shows a very poor performance on all profit PPIs. It is due to the poorest performance on the container throughput PPI that generates revenues for terminal operators. It may be noted that terminal operators in Busan North Port need to put more efforts to create a coopetition strategy as per Song (2002) to tackle intensified port competition.

Beyond the individual PPI performance, port managers can analyse performance at a higher level (i.e., the 16 principal PPIs and six dimensions). The performance scores of the four ports in terms of the sixteen principal-PPIs are presented in Fig. 4, in terms of the six dimensions in Table 8 and the overall performance results of each alternative port is obtained and shown in Table 9. It is noteworthy that the performance scores at a higher level are derived from the transformed values through the mapping process from the lowest level PPIs to their associated principal-PPIs, six dimensions and overall performance. Therefore, the results in Table 7 (i.e. 60 PPIs' performance) lead to performance scores for the 16 principal-PPIs (Fig. 4), the six dimensions (Table 8), and the overall performance results of each alternative port (Table 9).

The results shown in Fig. 4 indicate that Busan North Port is the least competitive port with the lowest performance especially in terms of output and profitability. Busan New Port outperforms the other ports in terms of output, lead-time, profitability, intermodal transport systems, value-added services, information and communication integration, safety and security, environment, and social engagement but is less competitive at the level of two principal PPIs, i.e., liquidity & solvency and service costs.

Table 7
Performance score of each port against the 60 PPIs

PPIs	Busan North	Gwangyang	Incheon	Busan New
Throughput growth (OPC1)	0.0000	0.1630	0.3203	0.7317
Vessel call size growth (OPC2)	0.0000	0.6160	0.2436	0.3824
Ship load rate (PDC1)	0.8471	0.0000	0.0496	0.1817
Berth utilization (PDC2)	0.7040	0.1177	0.6042	0.9272
Berth occupancy (PDC3)	1.0000	0.0000	0.1055	0.0000
Crane productivity (PDC4)	0.4353	0.5359	0.5359	0.6797
Yard utilization (PDC5)	0.1055	0.0105	0.0000	0.6381
Labour productivity (PDC6)	0.5967	0.5000	0.5000	0.5823
Vessel turnaround (LTC1)	1.0000	1.0000	1.0000	1.0000
Truck turnaround (LTC2)	0.9114	0.8516	0.7656	1.0000
Container dwell time (LTC3)	0.9367	0.8301	0.9051	0.9525
Knowledge and skills (HCS1)	0.8270	0.7402	0.8609	0.8701
Capabilities (HCS2)	0.6531	0.6236	0.7736	0.6973
Training and education (HCS3)	0.5345	0.5397	0.7302	0.6136

Commitment and loyalty (HCS4)	0.6686	0.6205	0.7796	0.7365
Culture (OCS1)	0.6613	0.6186	0.7494	0.7517
Leadership (OCS2)	0.7294	0.6944	0.7615	0.7746
Alignment (OCS3)	0.7081	0.6978	0.7368	0.6959
Teamwork (OCS4)	0.7081	0.6415	0.7420	0.7289
IT systems (ICS1)	0.7828	0.6162	0.7615	0.7280
Database (ICS2)	0.6807	0.5957	0.7470	0.6620
Networks (ICS3)	0.6857	0.6849	0.7118	0.6531
Revenue growth (PFF1)	0.0000	0.7194	1.0000	1.0000
EBIT(operating profit) margin (PFF2)	0.0000	0.0000	0.4856	0.7201
Net profit margin (PFF3)	0.0000	0.0705	0.4209	0.3929
Current ratio (LSF1)	0.8047	1.0000	0.8047	0.8047
Debt to total asset (LSF2)	0.1953	0.1953	1.0000	0.1953
Debt to equity (LSF3)	1.0000	0.5000	1.0000	0.0000
Overall service reliability (SFU1)	0.6891	0.7457	0.6634	0.7084
Responsiveness to special requests (SFU2)	0.6247	0.7510	0.6355	0.6307
Accuracy of documents & information (SFU3)	0.6831	0.7134	0.6439	0.7518
Incidence of cargo damage (SFU4)	0.7152	0.7294	0.6136	0.7560
Incidence of service delay (SFU5)	0.5634	0.7299	0.6113	0.6720
Overall service cost (SCU1)	0.6060	0.6002	0.5876	0.5760
Cargo handling charges (SCU2)	0.5842	0.6476	0.6179	0.5395
Cost of terminal ancillary services (SCU3)	0.5702	0.6279	0.5687	0.5079
Sea-side connectivity (ITST1)	0.6526	0.6784	0.6960	0.7128
Land-side connectivity (ITST2)	0.6915	0.6426	0.6405	0.7049
Reliability for multimodal operations (ITST3)	0.7002	0.7078	0.6896	0.7299
Efficiency of multimodal operations (ITST4)	0.6741	0.6605	0.6473	0.7178
Facilities to add value to cargoes (VAST1)	0.6300	0.6015	0.5513	0.6470
Service adaptation to customers (VAST2)	0.6181	0.6820	0.5676	0.7310
Capacity to handle different types of cargo (VAST3)	0.6321	0.6981	0.6210	0.6863
Tailored services to customers (VAST4)	0.6031	0.7078	0.6365	0.6849
Integrated EDI for communication (ICIT1)	0.6963	0.7228	0.6870	0.7628
Integrated IT to share data (ICIT2)	0.6963	0.6744	0.6620	0.7389
Collaborate with Channel members for channel optimisation (ICIT3)	0.6721	0.6513	0.7196	0.7218
Latest port IT systems (ICIT4)	0.6189	0.6576	0.6641	0.7181
Identifying restricted areas and access control (SSS1)	0.8841	0.8860	0.9344	0.9502
Formal safety and security training practices (SSS2)	0.8478	0.8791	0.7552	0.9178
Adequate monitoring and threat awareness (SSS3)	0.8486	0.8602	0.8494	0.9326
Safety and security officers and facilities (SSS4)	0.8915	0.9139	0.8941	0.9679
Carbon footprint (EVS1)	0.4269	0.3943	0.3785	0.6492
Water consumption (EVS2)	0.7086	0.4266	0.5124	0.8446
Energy consumption (EVS3)	0.8023	0.4661	0.5847	0.9207
Waste recycling (EVS4)	0.7228	0.5332	0.6471	0.7512
Environment management programmes (EVS5)	0.5479	0.4779	0.4590	0.6308
Employment (SES1)	0.6552	0.4250	0.4329	0.7184
Regional GDP (SES2)	0.6915	0.5355	0.4803	0.8504
Disclose of information (SES3)	0.5473	0.6021	0.6655	0.4961

This is because the operations in Busan New Port started rather recently (i.e., 2005 to 2011), hence there was a short time span for the heavy initial capital spending for port superstructure, state-of-the-art systems, and equipment in the calculation. The required capital is generally raised from financial institutions and investors through project finances. As regards the service costs, the adjacent Busan North Port lowered its service price to secure its market share from the moment Busan New Port started operations (based on interviews with terminal operators in Busan Port). The 'lower price' strategy is the more preferential strategy when port operators adjust themselves to a changing business environment characterised by intense port competition. On the other hand, customer satisfaction on service fulfilment (SFU) is relatively higher than that on service costs (SCU) in all ports. Incheon possesses strengths in human capital, organisation capital, information capital, and liquidity & solvency, accordingly in supporting activities and financial strength. Another striking feature is that some of the ports show a very similar trend but a clear difference in performance score and ranking. For example, a relatively poor performance on output, productivity, environment, social engagement, and profitability can be observed in combination with strong performance in terms of lead-time and safety and security. These results can provide a validation of the proposed methodology as the case ports are pursuing similar objectives[7] under a similar logistics environment (i.e., similar organisational structure, port governance, policy and economic condition).

Table 8 shows the performance scores of the six dimensions. Busan New Port shows the highest performance on core activities (CA), terminal supply chain integration (TSCI) and sustainable growth (SG). A possible explanation for the above results would be that Busan New Port has been developed based on the Korean port master development plan (KMPH, 1989) aiming to achieve hub-port status in the Far-East Asia region. Thanks to the abundant capital inputs by both public (i.e., government and PA) and private (i.e., TOC) bodies for port infrastructure and superstructure development, Busan New Port has superior cargo handling systems and equipment at its disposal to improve terminal efficiency, better seaside and landside connections with new inter-port roads and rails to attract salient port users, and larger port hinterland development to stimulate cargo generation. Interestingly, supporting activities (SA), the internal satisfaction measures evaluated by staff members in TOCs, of Busan New Port and Busan North Port show very similar performance scores, whilst the performance on sustainable growth (SG) evaluated by port authorities and the Korean government is relatively higher than the other two ports. However, Gwangyang outperforms the others on user satisfaction (US). Gwangyang has a container throughput (2,338k TEUs in 2014) far below its design capacity (3,880k TEUs). Hence, this port has been developing friendly policies to attract mega carriers and alliances. This includes low service prices with extended A/R (account receivable) payment terms.

The results in Table 9 suggest that Busan New Port shows the best results, followed by Incheon. The difference is significant especially between the adjacent ports of Busan New Port and Busan North Port. The crisp performance score, for example, in Busan North Port (0.61) is transformed from the set of degrees of belief (DoB): {Very Poor 0.23; Poor 0.1; Medium 0.03; Good 0.22; Very Good 0.42}. Due to the DoB belonging to 'very poor (0.23)' Busan North Port is evaluated as the poorest performer in terms of overall performance score. Still, the DoB (0.42) belonging to 'very good' is greater than that of Gwangyang (0.40). Thus, the performance variance of Busan North Port with respect to each PPI is higher than other ports, with a 'very poor' evaluation on indicators such as throughput growth (OPC1), vessel call size growth (OPC2), revenue growth (PFF1) and operating profit margin (PFF2). In terms of pr_i^- in Table 6, the poor performing PPIs are all classified in effect factors (i.e. negative pr_i^- value). A possible advisable strategy for port managers in Busan North Port is to focus on the cause determinants such as container cargo handling equipment, skilled port labour, intermodal link, etc., thereby allocating these resources in an optimal way.

From the analytical results, the strengths and weaknesses of the four ports can be analysed. Accordingly, decision makers in the ports can identify the particular areas for improvement to enhance their competitiveness. These results offer important insights for decision makers to enhance their port performance. Furthermore, it can be used as a longitudinal study to investigate the improvement of ports within different timeframes.

[7] With reference to the taxonomy developed by Baird (1995, 1997), the governance of the case ports in Korea is located somewhere between the private and the private/public model, which is in pursuing the maximisation of the port profits or market shares.

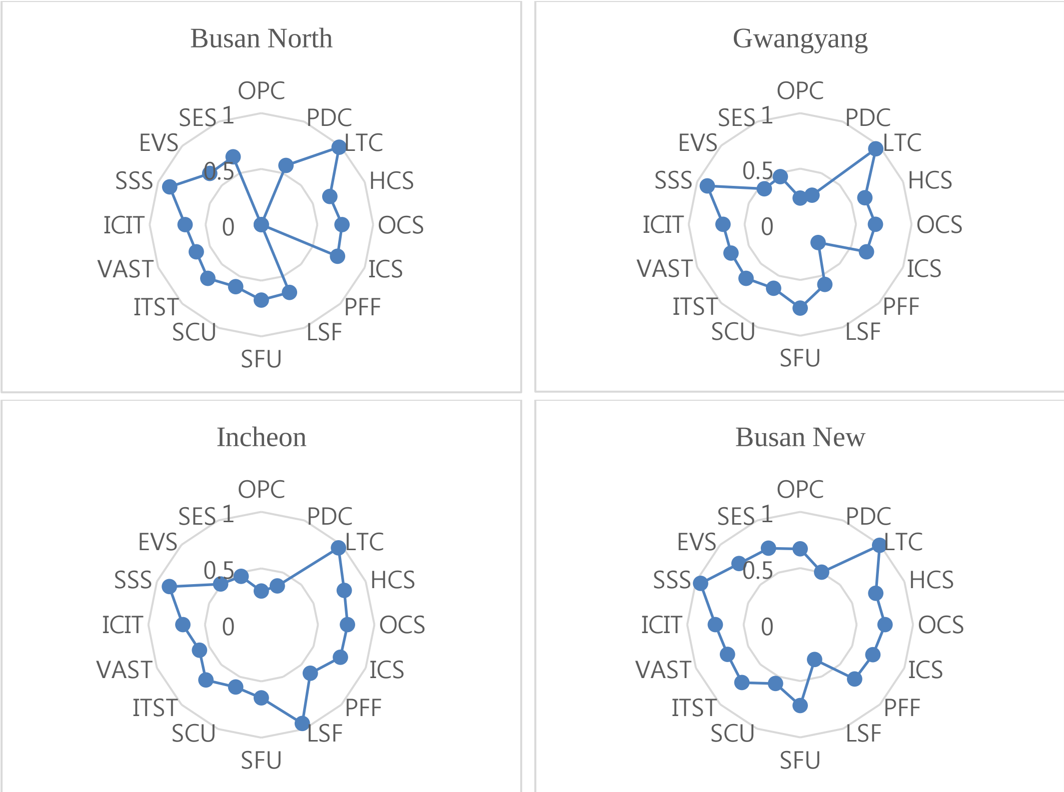


Fig. 4 Performance score on 16 principal-PPIs

Table 8

Performance score on 6 dimensions

6 dimensions	Busan North	Gwangyang	Incheon	Busan New	Ranking
Core activities	0.5313	0.4716	0.5274	0.7146	BN>B>I>G
Supporting activities	0.7305	0.6601	0.7848	0.7306	I>BN>B>G
Financial strength	0.2432	0.3488	0.7707	0.5527	I>BN>G>B
User satisfaction	0.6667	0.7347	0.6458	0.6973	G>BN>B>I
Terminal supply chain integration	0.6822	0.6987	0.6858	0.7442	BN>G>I>B
Sustainable growth	0.7744	0.6633	0.6705	0.8580	BN>B>I>G

Table 9

Performance score of each port

Ports	Performance	Ranking index	Ranking
Busan North	VP 0.23; P 0.1; M 0.03; G 0.22; VG 0.42	0.61	4
Gwangyang	VP 0.21; P 0.14; M 0.03; G 0.21; VG 0.40; UK 0.01	0.61	3
Incheon	VP 0.11; P 0.14; M 0.04; G 0.22; VG 0.48; UK 0.01	0.70	2
Busan New	VP 0.10; P 0.11; M 0.04; G 0.25; VG 0.51	0.74	1

Note: 1) VP, very poor; P, poor; M, medium; G, good; VG, very good; UK, unknown.
2) UK has arisen due to unavailable quantitative data.

5. Discussion and research implications

As port management becomes market-oriented and actor-centred (i.e., multi-stakeholder environment), port research and investigation needs to focus on the firm level (i.e., actor-, terminal, firm-centred) rather than just on the port level (Woo et al., 2012). A comprehensive analysis of port performance helps port managers to make better decisions on port operations. This study provides port managers with a standard toolkit and dashboard on port related PPIs. It can increase transparency on port performance with respect to different dimensions and hence port managers can increase their port attractiveness by taking into account important concerns from a specific key stakeholder. It offers diagnostic instruments to port managers, aiming to meet the different needs of port stakeholders. Furthermore, it enables port managers to better understand and value the opinions of different stakeholders and offers diagnostic instruments for stakeholder relations management.

Focusing on the empirical application, it should be noted that the role of each port is crucial to the South Korean economy in terms of their geographical locations to cover cargoes generated from their adjacent areas[8]. In this respect, this study investigates the performance of the container terminals in four major container ports and then aggregated them into their corresponding port to measure port performance. Therefore, port authorities or managers can, for the first time, use the model to benchmark the performance of different terminals in the same port and to evaluate the overall performance of the port by taking into account all terminals involved. The comparative analysis between importance and performance can be used to identify areas where port managers should prioritise their resource allocations in view of improving port competitiveness and stakeholders' satisfaction. Priority should be given to PPIs with high importance but low performance rate (i.e. under-performed).

This is a pioneering study investigating performance of each terminal/port using detailed information of both quantitative and qualitative nature to yield a performance analysis at port level. Most existing PPI systems rely on quantitative indicators largely because such data is readily available and the indicators can easily be measured. As qualitative PPIs are often too ambiguous to interpret them in a meaningful way, they are not used frequently in performance measurement. The hybrid approach can successfully deal with both quantitative and qualitative PPIs within a single framework and hence provides port managers with a powerful tool to realise a more comprehensive evaluation of port performance. Furthermore, this study utilises quantitative data (e.g., financial related data) that are confidential and sensitive for terminal operators. The introduction of belief degrees to predefined grades can help to address the confidentiality requirements of the operators who provided the data. As a result, the terminal/port financial performance can also be evaluated and compared to provide useful insights for port managers to improve their operational efficiency.

Complex inter-relations exist among the dimensions and/or the principal PPIs. This work has successfully addressed multi-stakeholder perspectives and the interdependency among PPIs in a quantitative way. The introduced methodological framework enables port managers to identify the indicators which have a high influence on other PPIs so as to help them to focus their investments to a group of interdependent (instead of individual) indicators. For instance, in the empirical study in Section 4, the results in Table 9 and Fig. 4 suggest that all ports considered have relatively poor performance on the sub-PPIs of output, productivity, environment, social engagement, and profitability. Except for productivity the others are classified as effect factors (i.e. negative pr_i^- value in Table 6). This indicates that port managers should adjust their strategies by taking into account the underlying relevant PPIs.

6. Conclusion

This study presents a hybrid PPM model that measures PPIs and the interdependency among PPIs in a quantitative manner by taking the perspectives from different port stakeholders. The proposed framework represents an effective performance measurement tool in complex port/terminal systems, which is validated through the case study of four major container ports in South Korea. Previous studies

[8] Busan Port is located in the South-Eastern corner of South Korea. Gwangyang is located in the South-West while Incheon is located in the North-Western corner of South Korea, respectively.

on port performance, port selection and port competitiveness generally treat PPIs as independent factors and mainly focus on seaside operations only. Moreover, they typically lack a structured approach to performance measurement in a multi-stakeholder environment. To address this gap, this paper develops a new framework based on the combination of DEMATEL and ANP together with FER to capture the interdependency among PPIs and to incorporate multiple objectives of key stakeholders. We identify the overall PPIs with respect to different stakeholders as well as evaluate the weights of the interdependency PPIs and synthesise the evaluations of quantitative and qualitative PPIs with their weights through an IDS decision support tool. The hybrid method is applied to port performance research and demonstrated through case studies on four major South Korean container ports. To the best of our knowledge, this study represents a pioneering work addressing PPM from a multi-stakeholder dimension and from both quantitative and qualitative PPI perspectives. Also, it is the first research work to incorporate the interrelationships among the PPIs into the analysis and to present the performance of ports in a precise manner.

Nevertheless, there is a need for further research to identify the relationships among PPIs using a larger number of samples. Further empirical studies to benchmark port performance in different regions/areas and for different timeframes will help to identify the best practices for each PPI. Moreover, future research should incorporate other stakeholders, such as environmentalists and local inhabitants, into the decisions on port performance and improvement. It should also present the PPM results of the target port from each of the different stakeholder groups in view of comparing the different understanding of the stakeholders on port performance with respect to the common PPIs. The results can offer invaluable insights to the evaluation of impacts of each stakeholder group on port performance.

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