Comparative analysis of port performance indicators: independency and interdependency

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Abstract

Port performance measurement (PPM) and comparison research, presenting a multiple criteria decision making (MCDM) issue in nature, has been intensively conducted by researchers from both decision science on modelling and port studies from empirical perspectives. Assigning an appropriate weight to each defined port performance indicator (PPI) is essential for rational decision and precise performance measurement. However, PPIs are often presented in a hierarchy, having the interdependency among them ignored. It causes concerns on the accuracy of PPIs' weight allocation and arguments on the performance measurement results, revealing a significant research gap to be addressed. As far as MCDM modelling is concerned, the importance of criteria has been studied utilising either absolute or relative comparisons, while the calculation of their importance also takes into account both independency and interdependency factors. However, there is lack of empirical studies in the literature to provide supporting evidence to distinguish the different impacts of the two factors. This study aims to compare the analysis of PPIs importance when taking into account their independent relationship using an analytic hierarchy process (AHP) and their interdependent relationship using a decision making trial and evaluation laboratory (DEMATEL) incorporating an analytic network process (ANP), respectively. The same domain experts are invited to evaluate the importance of the defined PPIs based on both approaches. The results demonstrate that a similar variance of relative importance across the PPIs but a clear difference on their importance scores and ranking. As a result, the results make contributions to fulfil the research gap on consideration of interdependency among PPIs in PPM and on the provision of convincing empirical evidence to highlight the impact of interdependency of criteria on MCDM modelling. Another practical significance draw from this study is that use of DEMATEL can aid port stakeholders to make more rational decision as to whether the interdependency among PPIs should be taken into account in PPM and/or port choice.

1. Introduction

Container ports are playing a pivotal role in facilitating global logistics and supply chains. In the era of global supply chains, the port industry has however been facing the challenges, arising on the one hand from the different interests of port stakeholders and on the other hand from the increasingly competitive business environments. Conflicts of interests between the

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stakeholders require one (of them) to interpret the others' assertiveness rightly by delivering mutual benefits to all related parties. Consequently, the analysis of their interests and needs on various dimensions of port activities becomes essential. The process of the analysis is in nature a multiple criteria decision making (MCDM) problem that involves multiple criteria of both quantitative and qualitative features.

The literature with regard to the methods of weighting criteria in the context of MCDM has been carefully reviewed, including the studies such as Gabus and Fontela, 1973; Saaty, 1980; Hwang and Yoon, 1981; Saaty, 1996; Chen, 2000; Yang, 2001; Liou *et al*., 2007; Wang and Chang, 2007; Shieh *et al*., 2008; Chen and Chen, 2010; Najmi and Makui, 2010; Yang *et al*., 2011; Buyukozkan and Cifci, 2012. Using absolute or relative comparisons, the weights can be assigned to each criterion. In the weight assignments, the criteria in a MCDM problem are considered independently or interdependently. The former is formed as a linear hierarchy whilst the latter is demonstrated as a non-linear network. Although many MCDM problems have been studied using both approaches, it is not true that one always presents better results than another (Satty 2001), requiring more evidence obtained from empirical studies. Meantime, it has been widely recognised but not well addressed yet that despite many advanced approaches in MCDM, scholars and practitioners have done little on the comparative analysis of independency and interdependency among criteria to provide empirical evidence to assess the influence of their interdependency. Furthermore, based on the search on Web of Science, in all the relevant papers dealing with "port choice", "port selection", and "port competitiveness", the factors/attributes influencing decision making have been considered independently (Yeo *et al.*, 2014), although the existence of the interdependency among the factors has been widely recognised (Lee *et al.*, 2013). To address this research need and also fulfil the gap on PPIs' independency study in port studies, this study uses an analytic hierarchy process (AHP) to conduct independent weight assignments, while applying a decision making trial and evaluation laboratory (DEMATEL) incorporating an analytic network process (ANP) to catch interdependent features between the criteria. The use of the hybrid of DEMATEL and ANP in this study is because of their capability of dealing with (1) complex decision problems, (2) both quantitative and qualitative PPIs and (3) group decision-making with a relatively small sample size for analysis (Shieh et al., 2010; Buyukozkan and Cifci, 2012; Ha et al., 2017). Furthermore, using DEMATEL to screen significant interdependency among the PPIs can avoid costly and time-consuming data collection when requiring various types of questionnaire surveys, while having ANP to quantify the interdependency based on its sound mathematics and psychology leads to improved judgements reliability. The same group of domain experts are invited to evaluate the importance of PPIs based on both approaches of AHP only and the hybrid of DEMATEL and ANP. The comparative analysis provides the stakeholders especially for ports (i.e. terminal operators, port authorities) with valuable insights to prioritise investment for competitiveness improvement by adjusting their strategies based on the relative importance of criteria.

In the next section, theoretical background of the AHP, DEMATEL and ANP as well as their associated calculation algorithms are introduced. In section 3, the selection of port performance indicators (PPIs) is carefully described. In section 4, the process of analysing the relative importance of the PPIs obtained by AHP and DEMATEL-ANP is presented in Section 5. It is complemented by the detailed comparative analysis with respect to the most important PPIs from the two approaches and provides useful practical guides for the development of investment strategies. Section 6 concludes the paper with its insights and limitations.

2. Methodology

2.1. The use of AHP to PPIs' independency

The AHP introduced by Satty (1980) assumes independence of one cluster from another but it does not allow for feedbacks between clusters in a hierarchy (Saaty, 2001). Accordingly, the hierarchy is a simple structure to decompose a complex problem through identifying unidirectional cause effect explanations with a linear chain (Saaty and Takizawa, 1986). This tool is useful for dealing with MCDM problems and aids decision makers to capture both subjective and objective aspects of a decision (Saaty, 2001). The decision is made based on scores obtained by pairwise comparisons between the criteria, in other words, the higher the score is, the more important the criterion.

In this study, the relative weights of the independent PPIs at the same level can be obtained using pair-wise comparisons. A number of selected experts are approached to respond to a question such as "which PPI should be emphasized more in a port performance management (PPM), and how much more?" A series of pairwise comparisons are developed based on the Saaty's nine-point scale ranging from 1 (equal) to 9 (extreme). Then, the local weights of PPIs can be obtained by following Eqs. (1)-(3) (Satty, 1980). Let e_{ij}^{l} be the relative importance judgement on the pair of PPIs P_i and $P_j (i, j = 1,2, \ldots\ldots n)$ by lth expert. Then, the aggregated weight comparison between P_i and P_j by m experts ($l \in m$) can be obtained by Eq. (1).

$$e_{ij} = \frac{1}{m}\,(e_{ij}^{1} + \cdots + e_{ij}^{l} + \cdots + e_{ij}^{m}) \tag{1}$$

Next, the synthesised ith criterion weight comparison between P_i and P_j by m experts can be calculated using Eq. (2).

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{e_{ij}}{\sum_{i=1}^{n} e_{ij}}\right) \qquad \sum_{i=1}^{n} w_i = 1 \tag{2}$$

Lastly, another critical characteristic of the AHP is the consistency of the pairwise judgements by calculating a Consistency Ratio (CR) in Eq. (3). When the value of CR is greater than 0.1, an inconsistency in the pairwise judgements appears and the experts need to revise their pairwise judgements. Therefore, the judgements should inform an acceptable level with the CR of 0.10 or less. In Eq. (3), CI is consistency index, λ_{max} is the principal eigenvalue of the comparison matrix, RI is average random index and n is the number of PPIs.

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad CR = \frac{CI}{RI(Random\ consistency\ index)} \qquad \lambda_{max} = \frac{\sum_{j=1}^{n}\frac{\sum_{i=1}^{n} w_i e_{ji}}{w_j}}{n} \tag{3}$$

It is noteworthy that the weights obtained are local weights at the same level. In multi-level structures, further computation needs to be conducted to obtain normalised weights of the bottom level PPIs by multiplying the weights of their parent PPIs at the upper level in the hierarchy.

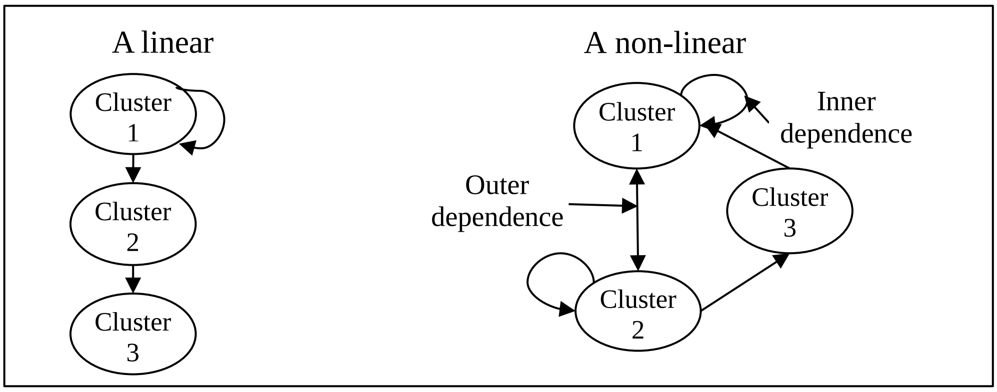
The usage of this tool is enormous across different disciplines, including those in the maritime and port sectors such as shipping company performance assessment (Chou and Liang, 2001), port selection (Lirn et al., 2004), port competitiveness (Song and Yeo, 2004), port's political risk assessment (Tsai and Su, 2005), ship registry selection (Celik et al, 2009). Chou and Liang (2001) employed AHP to construct subjective weights of all criteria and sub-criteria for shipping company performance evaluation. In Song and Yeo (2004), the competitiveness of eight Chinese ports was evaluated using AHP in terms of their competitiveness on four criteria including cargo volume, port facility, port location and service level. Tsai and Su investigated the political risk of 5 major Asian ports with respect to both micro and macro risk factors and the risk level of the ports was obtained by AHP calculations. Celik *et al.* (2009) utilised AHP to model the shipping registry selection and the model was applied in Turkish maritime industry. All the above research considered the criteria to be independent even though some of the criteria are recognised to be closely inter-related, which as a result could delivery error-prone results.

2.2. The use of DEMATEL and ANP to model PPIs' interdependency

Many complex decision problems need to be explained through a network structure because they involve various interplays and interdependences within a cluster and between clusters at the same level or different levels (Saaty, 2001). Given this complexity, decision makers may require an essential understanding of the cause-effect relationship between the criteria (Chen and Chen 2010). A network structure is a special case of a hierarchy which allows for feedbacks between clusters. As shown in Fig. 1, both a linear hierarchy and a non-linear network allow for inner dependence between elements within a cluster, but a non-linear network makes it possible to identify and analyse interdependency both within a cluster and between clusters (Saaty, 2001). The former is called an inner dependence and the latter is called an outer dependence, respectively.

We use a hybrid approach by incorporating DEMATEL in ANP to determine interdependent weights between PPIs in PPM. An integrated method of DEMATEL and ANP has been proven to be a successful tool for measuring dependence and feedbacks among elements in complex decision problems through various applications such as airline safety measurement (Liou *et al*., 2007), service quality (Shieh *et al*., 2010), supply chain performance (Najmi and Makui, 2010), innovation operation (Chen and Chen, 2010) and green suppliers selection (Buyukozkan and Cifci, 2012). However, its feasibility in modelling PPM has not been investigated yet. More importantly, its influence on accuracy of PPM compared to the case in which PPIs are treated independently has not been analysed, often leaving port stakeholders to make irrational investment strategies in a situation where the PPIs are of high interdependency.

In this study, the DEMATEL is first used to identify whether there are significant interdependent relationships among the PPIs while the ANP is then applied to determine the intensity of the relationships among the PPIs from a quantitative perspective. Here if the result from the initial DEMATEL analysis showed insignificant interdependency among the investigated PPIs, then the AHP approach described in Section 2.1 is used.



Note: Cluster N (C_N, N=1,2,3) includes its associated elements (e_{N1}, e_{N2}, e_{Nn_N})

Fig. 1. Structural difference between a hierarchy and a network model

2.2.1. DEMATEL to identify interrelations among the PPIs

The DEMATEL approach was introduced by the Science and Human Affairs Program of the Battelle Memorial Institute in Geneva Research Centre between 1972 and 1976 for investigating and solving the complicated and intertwined social problems (Wu *et al*., 2010). The method is a structural modelling approach, which can divide the criteria into the cause and effect groups. Based on the directed graph, known as *digraph*, it makes it possible to demonstrate the directed relationships and interdependency of the criteria (Liou *et al*., 2007; Buyukozkan and Cifci, 2012). In addition, the digraph enables stakeholders to predict management behaviour and business and financial strategies of a firm, by taking into account interdependent influences among the criteria (Lee and Lin, 2013).

Using the DEMATEL in the context of PPIs, suppose a set of n basic PPIs as $S = \{x_1\, x_2\, ...\, x_i\, ...\, x_{n-1}\, x_n\}$, in which x_i is ith indicator of basic PPIs ($i = 1 \ldots \text{or}\; n$) and S represents the associated upper level PPI of all x_i. The relations among the PPIs can be computed as follows.

Step 1: obtain an initial direct-relation matrix Z.

The initial direct-relation matrix Z is an average $n \times n$ matrix constructed by pair-wise comparisons in terms of directions and strength of influences between PPIs. The pair-wise comparison scale for this study is ranged from 0 to 4 representing '0 (no influence)', '1 (low influence)', '2 (medium influence), '3 (high influence)' and '4 (very high influence)', respectively. As shown in Eq. (4), the initial direct-relation matrix $Z = [z_{ij}]_{n\times n}$, where z_{ij} is denoted as an average direct-relation value of x_{ij} and all principal diagonal z_{ij} $(i = j)$ are equal to zero, $X^k = \left[x_{ij}^k\right]$ is an expert judgement on causal relationship between x_{ij} by the kth expert.

$$Z = [z_{ij}]_{n\times n} = \frac{1}{m}\sum_{k=1}^{m} x_{ij}^k, \qquad i, j = 1...n \tag{4}$$

Step 2: calculate a normalised direct-relation matrix D.

The normalised direct-relation matrix $D = [d_{ij}]_{n\times n}$, where the value of each PPI in matrix D is $0 \leq d_{ij} \leq 1$, can be obtained through following Eq. (5). In order to obtain a coefficient s, the maximum value of the sum of each row and column is used.

$$D = s \cdot Z \quad or \quad [d_{ij}]_{n\times n} = s \cdot [z_{ij}]_{n\times n}, \qquad s > 0$$
$$s = min[\frac{1}{max1 \leq i \leq n \ \sum_{j=1}^{n} z_{ij}}, \frac{1}{max1 \leq i \leq n \ \sum_{i=1}^{n} z_{ij}}] \ i, j = 1, 2, \dots, n \tag{5}$$

Step 3: obtain a total-relation matrix T and its sum of rows and columns.

The total-relation matrix T is obtained by operation of the normalised direct-relation matrix D using Eq. (6), in which I is denoted as the identity matrix. In Eq. (7), R_i and C_j denote the sum of rows and columns in the matrix T respectively, in which t_{ij} indicating the interdependent value of each pair of the investigated PPIs. Furthermore, the horizontal axis value pr_i^+ called "Prominence" indicates how crucial the i^{th} PPI is, whist the vertical axis value pr_i^- called "Relation" makes the PPI classified into the cause and effect group. When the value of pr_i^- is positive, the PPI is classified into the cause group, whereas the value of pr_i^- is negative, the PPI is grouped into the effect group.

$$T = \lim_{m=\infty}(D^1 + D^2 + \cdots + D^m) = \sum_{m=1}^{\infty} D^i = D(I - D)^{-1} \tag{6}$$

$$R_i = \sum_{j=1}^{n} t_{ij}, \quad C_j = \sum_{i=1}^{n} t_{ij} \qquad (\mathrm{i}, j = 1, 2, \dots, n)$$
$$pr_i^+ = R_i + C_i \quad pr_i^- = R_i - C_i \tag{7}$$

Step 4: obtain a threshold value (α) and construct a digraph.

The threshold value is obtained by either subjective judgement by experts (Liou *et al*, 2007) or mathematical equation (Shieh *et al*, 2010). The aim of setting a threshold value (α) is to filter and eliminate the PPIs that have trivial influence on others in the matrix T. In this paper, the threshold value is computed by the average value of t_{ij}, where N indicates the total number of elements ($i \times j$). Only the PPIs whose influence values of t_{ij} are higher than the threshold value can be chosen and converted into a causal relationship diagram (digraph).

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N} \tag{8}$$

2.2.2. ANP to determine PPIs' interdependency weights

After identifying interdependent relationships between the PPIs, the ANP method is used to obtain the final adjusted weights (i.e. global weights). The ANP is a relative method developed on the basis of the AHP to solve the case of dependence and feedbacks among the criteria/alternatives (Saaty, 1996). Unlike the AHP, the ANP allows interaction and feedbacks both between clusters (outer dependence) and within cluster (inner dependence) (Saaty 2001). The former is interaction between the elements in the different clusters whilst the latter is the influence between elements in the same cluster. Another feature of the ANP is to generalise a super-matrix, the partitioned matrix constituted by a set of sub-matrix indicates interdependent relationships between the clusters in decision networks (Saaty 2001). The super-matrix (unweighted super-matrix) of the non-liner network structure in Fig. 1 can be expressed as

$$W = \begin{bmatrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & 0 \end{bmatrix}$$

where W_{12} is a matrix that demonstrates the weights of cluster 1 with respect to cluster 2, W_{21} is the weights of cluster 2 with respect to cluster 1, and both W_{11} and W_{22} are denoted as the inner dependence and feedbacks within the cluster 1 and cluster 2, respectively, and so on. It is noteworthy that the unweighted super matrix (W_{NN}) includes their associated elements' unweighted super-matrix. Thus, the i, j block of the matrix (W_{NN}) is given by

$$W_{ij} = \begin{bmatrix} w_{i1}^{(j1)} & w_{i1}^{(j2)} & \cdots & w_{i1}^{(j_{n_j})} \\ w_{i2}^{(j1)} & w_{i2}^{(j2)} & \cdots & w_{i2}^{(j_{n_j})} \\ \cdots. & \cdots & \cdots & .. \\ w_{in_i}^{(j1)} & w_{in_i}^{(j2)} & \cdots & w_{in_i}^{(j_{n_j})} \end{bmatrix}$$

Then, a weighted super-matrix w_{ANP} can be obtained through multiplying the partitioned matrix $B\ (= W_{ij})$ in unweighted super matrix by their associated cluster weights w_i (Saaty, 2001).

$$w_{ANP} = Bw_i \tag{9}$$

The pair-wise comparisons to obtain the matrix (B) and w_i are conducted based on the digraph of DEMATEL. Surveys are carried out in a form of questions, for example, such as "which PPI influences on PPI 1 more: PPI 2 or PPI 3? and how much more?" A 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 can be formed, which can identify the relative impacts of the principal-PPIs' interdependency. The weights derived from pairwise comparisons are entered as the elements of columns of the matrix B. Then, a weighted supper-matrix can be normalised by setting all columns sum to unity. The sum of the probabilities of all states can be equal to one. Last, the limit supper matrix can be obtained by raising the weighted super-matrix to limiting powers using $W^{\infty} = \lim_{k \to \infty} W^k$ until the column of numbers is the same for every column. The values in column represent the global weights of the associated PPIs.

3. Identification of Port performance indicators

The PPIs for "overall container PPM" are identified in Ha et al. (2017). The potential PPIs which are mostly crucially used for measuring port performance were identified through industrial best practices and the broad areas of literature on port and shipping, logistic and supply chain management (SCM), and strategic management. In addition, we investigated crucial interests in major container ports by researching their missions, visions, goals, and objectives and discussed the found PPIs with port stakeholders. Previous studies suggested that port performance should come across the range of port activities to cope with new evolutionary changes (Marlow and Paixão Casaca, 2003; Bichou, 2006; Brooks 2006; Woo *et al*. 2011; Ri os and de Souse, 2014) and PPIs should allow the ports to measure and communicate their impacts on both its efficiency (De Oliveira and Cariou, 2015) and external society, economy and environment (ESPO, 2010) as well as to be consistent with their goals (Kaplan and Norton, 2004). Sepcifically speaking, the selection of PPIs in this work was conducted through literature review and industrial practices in a pre-selection phase and then the Delphi technique based on semi-structured interviews was applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators (Okoli and Pawlowski, 2004). The aim of the semi-structured interviews in this study is to identify appropriate PPIs for PPM, and to verify whether the PPIs appropriately represent their associated upper-level PPIs. In other words, this survey is to investigate whether the PPIs can signify a number of properties such as their usability, adaptability and relevance to port stakeholders for PPM. The PPIs selection process is described as follows.

- Using purposive and snowball samplings (Saunders et al., 2012), we contacted 25 experts (i.e. terminal operators, shipping lines, logistics service providers, port authority/government and academia) to ask them to participate in the interviews. 9 experts (2 experts in each group except for port authority/government) replied the consent letters, but in order for fair representation from each group we invited 1 expert in government. They[1] include (1) 6 industrial experts who have been working in the shipping and port industries for more than 15 years with PhD (1 expert from a shipping line), MSc (3 experts from a terminal operator, a shipping line and a forwarder) and BA (1 from a terminal operator and a forwarder, respectively) degrees; (2) 2 professors who have more than 15 years teaching and research experience in the port area; (3) 2 experts from government/port authorities (1 department manager and 1 managing director) who have been working for port logistics authorties. The list of potential PPIs and an information sheet that described the definitions of PPIs and calculations for quantitative PPIs were provided to each interviewee at least a week in advance before commencing the interviews. For example, 'ship load rate denotes a rate of handling container volume per vessel capacity over a certain period of time. This PPI is a ratio of the combined two indicators of a container throughput volume and an average vessel capacity and can be calculated as the container throughput volume divided by the average vessel capacity'. The interviews were undertaken for 1 month between March and April in 2014.
- Before asking the related questions, we explained the relevant issues such as overlap among the PPIs. For example, some PPIs (i.e. vessel working time at berth, throughput/number of cranes, labour productivitcy, vessel turnaround, vessel waiting time, truck turnaround, container dwell time) have been used to measure port productivity (i.e. UNCTAD, 1976; De monie, 1987; Tongzon, 1995a; Tongzon, 1995b; Cullinane et al., 2006; Brooks, 2007), while PPIs of the similar nature (i.e. availability and capability of employees, capability of dockworkers, speed of stevedores' cargo loading/unloading,

[1] A panel of ten experts is invited to evaluate the importance of PPIs based on both approaches. The applied methods in this study require various types of questionnaire surveys to evaluate the importance of PPIs in multi-level structures (please refer to Section 4). According to authors' experience on relevant research approaches, the judgements using pairwise comparisons demand high level of evaluators' logical thinking driven from well understandings of research aim, process and each individual PPI and its upper level PPI. The judgements by the panel of experts throughout this research deliver reliable results with the CR of 0.10 or less so that authors can avoid costly and time-consuming data collection.

timely vessel turnaround, timeliness of maritime services) have also used to measure service quality (Marlow and Paixão, 2003; Woo et al., 2011; Brooks and Schellinck, 2013). These duplicate PPIs need to be clarified and classified appropriately to represent their associated upper-level indicators. In addition, we also take into account the collectability of the data because the performance of quantitative PPIs are evaluated using a number of quantitative data that are confidential and sensitive for terminal operators.

- The majority of the experts commented on all dimensions for the validation of the PPI network construction. Through several iterations and feedbacks, some PPIs were modified, removed, divided or combined to one delegate PPI from the duplicated and correlated PPIs. For example, the sub-PPIs of the environment (EVS) were originally defined as 'air pollution', 'land pollution', 'water pollution', 'energy consumption' and 'environment management systems' but the majority of the panel members commented that the implementation schemes for reducing the specified sources of pollution are more important than the pollutions themselves. Furthermore, 'throughput (TEUs)' and 'throughput growth (TEUs/year) are overlap. 'Vessel calls (no. of vessels)', 'capacity of vessel calls (tons)' and 'vessel call size (tons/no. of vessels) growth' are the same specific PPI group. 'Vessel call size growth' is a combined PPI of 'vessel calls (number)' and 'capacity of vessel calls (tons)'. 2 interviewees preferred to use 'throughput (TEUs)', 'vessel calls (number)', 'capacity of vessel calls (tons)' for 'output (OPC)'. For a longitudinal study, however, other 8 experts suggested to use 'throughput growth (TEUs/year) and 'vessel call size growth (tons/no. of vessels)' to investigate the performance changes of port/terminal within different timeframes. Using a series of questions, we managed to probe deeply into the PPIs selection and understand exhaustively the answers provided.
- Based on this, 60 PPIs are defined as representing indicators for container PPM under 16 principal-PPIs and 6 dimensions in Table 1. The 6 dimensions are 1) the extent to which the container port/terminal operates effectively and efficiently in its basic role regarding cargo/vessel handling (core activities, CA); 2) the extent to which the container port/terminal has reliable resources (e.g. HR and technology) in order to support core activities (supporting activities, SA); 3) the extent to which the container port/terminal indicates its financial condition (financial strength, FS); 4) the extent to which the port users are satisfied with port/terminal services delivered and service price (users satisfaction, US); 5) the extent to which the port/terminal achieves its supply chain integration (terminal supply chain integration, TSCI); 6) the extent to which the port/terminal contributes to socio-economic sustainable growth (sustainable growth, SG) (Table 1).

4. Comparisons between PPIs independency and interdependency

4.1. Evaluate PPIs' relative weights using AHP.

The judgements of five among the ten evaluators[2] have been verified with the CR of 0.10

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[2] The 5 experts are 1 terminal operator, 1 liner, 1 forwarder, 1 academia and 1 port authority.

or less by using Eq. (3). Generally, the value of CR is greater than 0.1 and the evaluators need to revise their pairwise judgements. Therefore, five judgements presenting consistent input data, which are sufficient to provide a reasonable AHP outcome (Bottani and Rizzi, 2006; Büyüközkan *et al*., 2012) are used to derive the weights of the criteria.

Using Eqs. (1)-(2), the weights judged by the five evaluators on the six dimensions (i.e. core activities, supporting activities, financial strength, users satisfaction, terminal supply chain integration and sustainable growth) at the second level are obtained as 0.310, 0.128, 0.151, 0.225, 0.116 and 0.07, respectively (Table 1). Core activities are considered to be the most important dimension and followed by user satisfaction, financial strength, supporting activities, terminal supply chain integration and sustainable growth. Similarly, the weights of the third-level and the bottom-level criteria can be obtained. It is noteworthy that the obtained weights are local weights at the same level. Further computation has been conducted to obtain normalised weights of the bottom level criteria by multiplying their local weights with the ones of their associated upper level criteria. For instance, the normalised weight of 'throughput growth' can be obtained as 0.055 (=0.310 (the local weight of core activities) $\times$ 0.257 (the local weight of output) $\times$ 0.696 (the local weight of throughput)).

Table 1. Port performance indicators (PPIs) and their relative weights (independency)

	Local weight	Global weight
Core activities (CA)	0.310	
Output (OPC)	0.257	
Throughput growth (OPC1)	0.696	**0.055**
Vessel call size growth (OPC2)	0.304	0.024
Productivity (PDC)	0.522	
Ship load rate (PDC1)	0.158	0.026
Berth utilization (PDC2)	0.132	0.021
Berth occupancy (PDC3)	0.107	0.017
Crane productivity (PDC4)	0.345	0.056
Yard utilization (PDC5)	0.103	0.017
Labour productivity (PDC6)	0.155	0.025
Lead time (LTC)	0.221	
Vessel turnaround (LTC1)	0.602	0.041
Truck turnaround (LTC2)	0.185	0.013
Container dwell time (LTC3)	0.213	0.015
Supporting activities (SA)	0.128	
Human capital (HCS)	0.419	
Knowledge and skills (HCS1)	0.246	0.013
Capabilities (HCS2)	0.243	0.013
Training and education (HCS3)	0.354	0.019
Commitment and loyalty (HCS4)	0.157	0.008
Organisation capital (OCS)	0.192	
Culture (OCS1)	0.175	0.004
Leadership (OCS2)	0.296	0.007
Alignment (OCS3)	0.198	0.005
Teamwork (OCS4)	0.330	0.008
Information capital (ICS)	0.389	
IT systems (ICS1)	0.364	0.018
Database (ICS2)	0.301	0.015
Networks (ICS3)	0.335	0.017
Financial strength (FS)	0.151	
Profitability (PFF)	0.654	
Revenue growth (PFF1)	0.318	0.031

EBIT(operating profit) margin (PFF2)	0.328	0.032
Net profit margin (PFF3)	0.354	0.035
Liquidity & Solvency (LSF)	0.346	
Current ratio (LSF1)	0.342	0.018
Debt to total asset (LSF2)	0.349	0.018
Debt to equity (LSF3)	0.309	0.016
Users' satisfaction (US)	0.225	
Service fulfilment (SFU)	0.723	
Overall service reliability (SFU1)	0.361	0.059
Responsiveness to special requests (SFU2)	0.147	0.024
Accuracy of documents & information (SFU3)	0.134	0.022
Incidence of cargo damage (SFU4)	0.188	0.031
Incidence of service delay (SFU5)	0.170	0.028
Service costs (SCU)	0.277	
Overall service cost (SCU1)	0.549	0.034
Cargo handling charges (SCU2)	0.315	0.020
Cost of terminal ancillary services (SCU3)	0.137	0.009
Terminal supply chain integration (TSCI)	0.116	
Intermodal transport systems (ITST)	0.528	
Sea-side connectivity (ITST1)	0.466	0.029
Land-side connectivity (ITST2)	0.159	0.010
Reliability for multimodal operations (ITST3)	0.197	0.012
Efficiency of multimodal operations (ITST4)	0.178	0.011
Value-added services (VAST)	0.197	
Facilities to add value to cargoes (VAST1)	0.369	0.008
Service adaptation to customers (VAST2)	0.172	0.004
Capacity to handle different types of cargo (VAST3)	0.262	0.006
Tailored services to customers (VAST4)	0.197	0.005
Information/communication integration (ICIT)	0.275	
Integrated EDI for communication (ICIT1)	0.291	0.009
Integrated IT to share data (ICIT2)	0.261	0.008
Collaborate with Channel members for channel optimisation (ICIT3)	0.232	0.007
Latest port IT systems (ICIT4)	0.216	0.007
Sustainable growth (SG)	0.07	
Safety and Security (SSS)	0.602	
Identifying restricted areas and access control (SSS1)	0.298	0.013
Formal safety and security training practices (SSS2)	0.206	0.009
Adequate monitoring and threat awareness (SSS3)	0.231	0.010
Safety and security officers and facilities (SSS4)	0.265	0.011
Environment (EVS)	0.2	
Carbon footprint (EVS1)	0.158	0.002
Water consumption (EVS2)	0.145	0.002
Energy consumption (EVS3)	0.248	0.003
Waste recycling (EVS4)	0.149	0.002
Environment management programmes (EVS5)	0.300	0.004
Social engagement (SES)	0.198	
Employment (SES1)	0.578	0.008
Regional GDP (SES2)	0.272	0.004
Disclose of information (SES3)	0.150	0.002

4.2. Identify PPIs interdependency and evaluate their weights using DEMATEL and ANP

The same panel of ten experts took part in the survey to determine the interdependency among six dimensions. The initial direct-relation $6 \times 6\ matrix\ Z$ is obtained using Eq. (4) by pairwise comparisons in terms of influences and directions as shown in Table 2. Then, the normalised direct-relation matrix D is calculated by Eq. (5) and the total-relation matrix T

and sum of influence given and received by each category are obtained by Eqs. (6)-(7) (Table 3). A threshold value of 0.82 (=$29.63/36$) is calculated using Eq. (8). According to Table 3, CA, SA and TSCI are assessed as cause factors while FS, US and SG are effect factors. Specifically speaking, CA is affected by SA, FS, US and TSCI and has an inner dependency. SA is affected by CA, FS, US and TSCI. FS is affected by CA, SA and US. US is affected by CA, SA and TSCI. TSCI is affected by CA and SA. Lastly, SG is affected by CA and SA. Based on Table 3, the ten experts are asked to determine the interdependency among the 16 principal-PPIs but eight experts[3] return in this survey. The same process is carried out to obtain a direct influence matrix. The initial direct-relation $16 \times 16\, matrix\, Z$ is obtained by pairwise comparisons in terms of influences and directions as shown in Table 4. It is noteworthy that zero value is given in the matrix when there are no influences involved in the investigated pairs because no pairwise comparisons are conducted. The total-relation matrix T and sum of influence given and received by each principal-PPI are obtained and presented in Table 5. A threshold value of 0.11 (=$28.99/256$) is calculated. Based on threshold value, a diagraph of the 16 principal-PPIs is presented in Fig. 2. After determining interdependent relationships between the principal-PPIs, the ANP method is used to obtain the final adjusted weights (i.e. global weights). Based on Table 5, the ten experts[4] are asked to respond to questions, for example, “which PPI influences more on ‘output’: ‘productivity’ or ‘lead-time’? and how much more?” In terms of this process, a number of comparison matrices are formed, and then an unweighted supper-matrix is obtained and presented in Table 6. By calculating the limiting power of the weighted super-matrix, a limit super-matrix is generated (Table 7). The results in the limit super-matrix is used as weights of sixteen principal-PPIs. The final step is to obtain local weights of 60 PPIs. It is noteworthy that we take into account 60 PPIs independently for the following two reasons: 1) their interdependency is modelled largely through their upper level PPIs and 2) the judgement complexity is too high to exceed the capability of the experts in this study when considering their interdependent relations. The global weights of the 60 PPIs in the bottom level can be obtained by multiplying their local weights with the normalised weights of 16 principal-PPIs (Table 8). Using an integrated method of DEMATEL and ANP, we identified 60 PPIs’ interdependency and their relative importance with success.

Table 2. The initial influence matrix (6 dimensions)

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

Table 3. The total influence matrix, “Prominence” and “Relation”

[3] The 8 experts are 2 from terminal operators, 1from liner, 1 from forwarder, 2 from academia and 2 from port authority and government, respectively.

[4] The judgements of four (1 terminal operator, 1 liner, 1 forwarder, 1 port authority) among the 10 experts have verified with the CR of 0.1 or less, which is sufficient to provide a reasonable ANP outcome (Büyüközkan et al., 2012).

	CA	SA	FS	US	TSCI	SG	pr_i^+	pr_i^-
CA	**0.88**	**1.01**	**0.97**	**1.08**	**0.92**	**0.93**	11.07	0.53
SA	**0.94**	0.77	**0.87**	**0.93**	**0.84**	**0.86**	10.32	0.07
FS	**0.85**	**0.84**	0.65	0.80	0.73	**0.84**	9.50	(0.10)
US	**0.92**	**0.89**	**0.83**	0.74	0.80	0.80	10.08	(0.12)
TSCI	**0.85**	**0.83**	0.78	**0.83**	0.61	0.75	9.22	0.08
SG	**0.83**	0.79	0.70	0.73	0.67	0.59	9.09	(0.46)

Table 4. The initial influence matrix of principal-PPIs

		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
	OPC	0	2.63	2.50	2.38	2.50	2.63	2.75	2.25	2.75	3.13	2.38	2.00	2.38	2.13	1.75	1.88
CA	PDC	3.38	0	3.25	2.75	2.75	2.63	2.63	2.25	2.75	3.00	2.50	2.00	2.25	1.75	2.00	1.75
	LTC	3.00	3.13	0	2.38	2.38	2.75	2.50	2.00	3.38	2.88	2.63	1.88	2.75	2.25	2.00	1.50
	HCS	2.50	3.00	2.75	0	0	0	2.38	2.38	2.75	2.38	2.00	2.50	2.50	2.50	2.13	1.88
SA	OCS	2.63	2.75	2.50	0	0	0	2.63	2.13	3.00	2.25	2.13	2.25	2.50	2.13	2.00	2.00
	ICS	2.88	3.25	3.50	0	0	0	2.38	2.13	2.63	2.38	2.25	2.38	2.75	2.50	1.75	1.50
FS	PFF	1.88	1.88	1.88	2.13	2.13	2.13	0	0	0	0	0	0	0	2.38	2.13	3.13
	LSF	1.88	1.75	1.75	2.25	2.38	2.25	0	0	0	0	0	0	0	2.13	2.75	2.50
US	SFU	3.00	2.88	2.75	2.75	2.88	2.88	2.50	2.50	0	0	0	0	0	0	0	0
	SCU	2.88	2.88	2.63	1.63	1.63	1.63	3.13	3.00	0	0	0	0	0	0	0	0
	ITST	2.88	2.38	2.88	2.13	2.13	2.88	0	0	2.63	2.00	0	0	0	0	0	0
TSCI	VAST	2.38	2.25	2.00	2.00	1.88	2.25	0	0	2.75	2.75	0	0	0	0	0	0
	ICIT	2.63	2.75	3.00	2.75	2.38	3.38	0	0	2.88	2.13	0	0	0	0	0	0
	SSS	2.25	2.50	2.75	0	0	0	0	0	0	0	0	0	0	0	0	0
SG	EVS	1.50	1.75	1.63	0	0	0	0	0	0	0	0	0	0	0	0	0
	SES	1.38	1.38	1.38	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. The total influence matrix of principal-PPIs

		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
	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**
CA	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**
	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**
	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**
SA	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**
	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
FS	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**
	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
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
	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
	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
TSCI	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
	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
	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
SG	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
	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

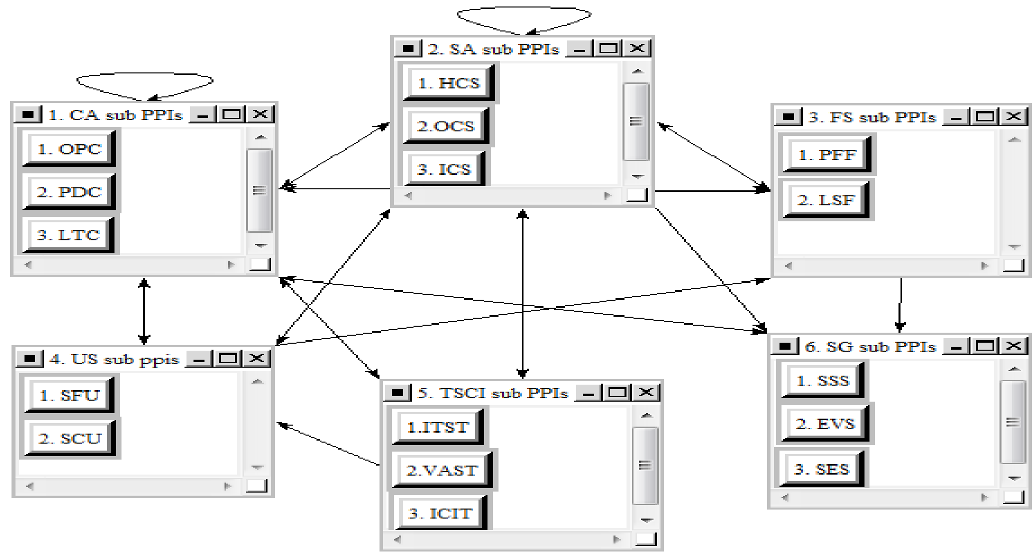

Fig. 2. Interdependency between the 16 principal-PPIs

Table 6. Unweighted supper-matrix

		CA			SA			FS		US		TSCI			SG		
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
CA	OPC	0.31	0.18	0.17	0.37	0.42	0.24	0.53	0.52	0.15	0.45	0.32	0.53	0.29	0	0	0
	PDC	0.46	0.55	0.40	0.39	0.34	0.42	0.29	0.26	0.52	0.32	0.28	0.24	0.29	0	0	0
	LTC	0.23	0.27	0.43	0.24	0.23	0.34	0.18	0.22	0.33	0.23	0.40	0.24	0.41	1	0	0
SA	HCS	0.39	0.41	0.31	0	0	0	0	0	0.37	0.35	0.31	0.34	0.35	0	0	0
	OCS	0.35	0.29	0.26	0	0	0	0	0	0.31	0.37	0.35	0.46	0.31	0	0	0
	ICS	0.26	0.29	0.43	0	0	1	0	1	0.31	0.28	0.33	0.20	0.33	0	0	0
FS	PFF	0.61	0.61	0.50	0.54	0.50	0.50	0	0	0.59	0.63	0	0	0	0	0	0
	LSF	0.39	0.39	0.50	0.46	0.50	0.50	0	0	0.41	0.37	0	0	0	0	0	0
US	SFU	0.72	0.75	0.66	0.71	0.61	0.73	0	0	0	0	0.74	0.39	0.59	0	0	0
	SCU	0.28	0.25	0.34	0.29	0.39	0.27	0	0	0	0	0.26	0.61	0.41	0	0	0
TSCI	ITST	0.50	0.41	0.37	0.33	0.69	0.34	0	0	0	0	0	0	0	0	0	0
	VAST	0.37	0.26	0.21	0.39	0	0.20	0	0	0	0	0	0	0	0	0	0
	ICIT	0.13	0.33	0.42	0.28	0.31	0.45	0	0	0	0	0	0	0	0	0	0
SG	SSS	0.59	0.52	0.62	0.47	0.37	0.74	0	0	0	0	0	0	0	0	0	0
	EVS	0.23	0.25	0.23	0.27	0.31	0.26	0	1	0	0	0	0	0	0	0	0
	SES	0.18	0.22	0.15	0.26	0.31	0	1	0	0	0	0	0	0	0	0	0

Table 7. Limit super-matrix

	CA			SA			FS		US		TSCI			SG		
	OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
Weight	0.12	0.14	0.12	0.06	0.05	0.10	0.08	0.06	0.10	0.05	0.03	0.02	0.02	0.02	0.02	0.02
Ranking	(2)	(1)	(3)	(8)	(9)	(5)	(6)	(7)	(4)	(10)	(11)	(15)	(12)	(13)	(16)	(14)

5. Discussion: comparing results

Appendix 1 shows the global weights of the bottom level PPIs yielded by AHP and ANP. The results demonstrate that a very similar trend but a clear difference in terms of the PPIs' importance score and ranking (Figure 3). Interestingly, the similar results can be found in Yüksel and Dagdeviren (2007) that quantified a SWOT analysis in terms of weights and ranks, but different results from Lee et al. (2013) that applied the two approaches to rank critical success factors of waterfront redevelopment.

Derived from the results of AHP, overall service reliability is the most important PPI, which has a relative importance value of 0.059, followed by crane productivity (0.056), throughput growth (0.055), vessel turnaround (0.041), net profit margin (0.035), overall service cost (0.034), operating profit margin (0.032), revenue growth (0.031), incidence of cargo damage (0.031) and seaside connectivity (0.029), as shown the top 10 highest scores in Table 8. In the contrast, waste recycling (0.002), total water consumption (0.002) and carbon footprint (0.002) under environment (EVS) are the least important PPIs. The same ranking results can be found in ANP interdependent weights: waste recycling (0.001), total water consumption (0.001) and carbon footprint (0.001). The results derived from ANP suggest that throughput growth is the most important PPI, which has a relative importance value of 0.083, followed by vessel turnaround (0.071), crane productivity (0.048), overall service reliability (0.037), vessel call size growth (0.036), IT systems (0.036), networks (0.033), database (0.029), net profit margin (0.035) and operating profit margin (0.032).

The top 10 rank PPIs in the AHP results include three PPIs under core activities (CA), three PPIs under financial strength (FS), three PPIs under users' satisfaction (US) and one PPI under terminal supply chain integration (TSCI). On the contrary, the ANP results involve four PPIs under core activities (CA), three PPIs under supporting activities (SA), two PPIs under financial strength (FS) and one PPI under users' satisfaction (US). In the analysis, the significant importance difference between SA and FS can be observed. A plausible explanation would be that the global weights of the PPIs in AHP are absolutely dependent on their associated upper principal-PPIs and dimensions. Accordingly, the high relative importance of three dimensions (CA, 0.310; FS, 0.151 and US, 0.225) influence more on the global weights of their associated bottom level PPIs than other three dimensions do, despite the fact that no significant weight difference between PPIs in the same cluster. However, the ANP results are mostly dependent on the results of interdependency between the principal-PPIs/dimensions. For instance, SA is an effect dimension that is affected by CA, FS, US and TSCI, at the same time SA is a cause dimension that has an effect on CA, FS, US, TSCI and SG. While FS is affected by CA, SA and US and simultaneously influences on CA, SA and SG. Hence, SA is more influential dimension than FS, representing the higher global weights of the PPIs in SA than the ones in FS in ANP analysis.

The ANP findings denote that on the one hand, the internal activities of port operators such as cargo operations in berth and yard and competency on port equipment, information technology are important criteria for PPM. On the other, the importance of the external effectiveness factor to customer satisfaction cannot be overlooked. The strong internal competency leads to the high customer' satisfactions, which is in line with Brooks and Schellinck's (2013) argument. On top of that, the internal effectiveness factor such as financial performance is relatively crucial in both approaches.

There is no obvious trend variance of relative importance across the bottom-level PPIs, but the difference on importance values obtained by ANP and AHP (Figure 3) is clearly revealed. The ANP results on output (OPC), lead time (LTC), organisational capital (OCS) and information capital (ICS) are higher than those from AHP, while profitability (PFF), service fulfilment (SFU), service costs (SCU) and intermodal transport systems (ITST) yielded by

AHP are higher than those from ANP. Interestingly, very similar results reflect on the importance values of productivity (PDC) and human capital (HCS).

The major objective of this study is to compare the results obtained from the two methods to demonstrate the effect of interdependency among PPIs on their importance. Based on the comparisons, we note that the combined DEMATEL and ANP technique is an approach capable of providing realistic solutions to simulate the interrelationship among PPIs. The importance of criteria (i.e. GW in Table 8) drawn from the DEMATEL and ANP technique show a greater level of differentiation than those from AHP, which may help decision makers easily identify meaningful criteria for solving given problems (Lee et al., 2013). However, we suggest that the results obtained by the two approaches would provide decision makers with useful information for rationalising their investment plans. When the results are harmony, the strategic decision (e.g. investment) can be made with high confidence. When they are different, further investigation on the influence of interdependency can be taken into account to avoid the possible errors caused by a single approach (i.e. AHP). Thus, the comparative analysis between the outcomes can be used by port managers to prioritise their resource allocations in view of improving port competitiveness and stakeholders' satisfaction.

To concrete the ANP results, it requires a sophisticated analysis in advance to identify interdependent relationships among the PPIs. As shown in Table 3, CA, SA and TSCI are assessed as cause factors while FS, US and SG are effect factors. This classification is in line with previous studies. The literature on PPM has used technical or physical container terminal specifications such as berth length, terminal area, number of crane in berth and yard, labour, transport modes' turnaround as input data to measure efficiency and productivity of the container port industry (Tongzon, 1995; Cullinane *et al*., 2002; Cullinane and Wang, 2006, Talley, 2006). Tangible and intangible resources such as human resources, information/ communication technology and organisational values cannot be overlooked as cause factors to investigate firm's performance (Bagozzi *et al*., 1991; Barney, 1991; Alavi *et al*., 2006; Albadvi *et al*., 2007). Furthermore, it is empirically recognised that a higher integration between the players in supply chains leads to a higher competitiveness (Song and Panayides 2008, Panayides and Song 2009, Woo *et al*. 2013). Financial performance is denoted as the monetary units of tangible and intangible values yielded by a company's core business operations and any earning from the company's investment using resources such as land, labour and capital. Customer satisfaction can be measured by the perceived service qualities delivered by service providers. The internal and external effectiveness outcome is the results that are derived by a series of value creation activities. Such evidence further supports our findings that the CA, SA and TSCI belong to cause factors while FS and US are effect factors.

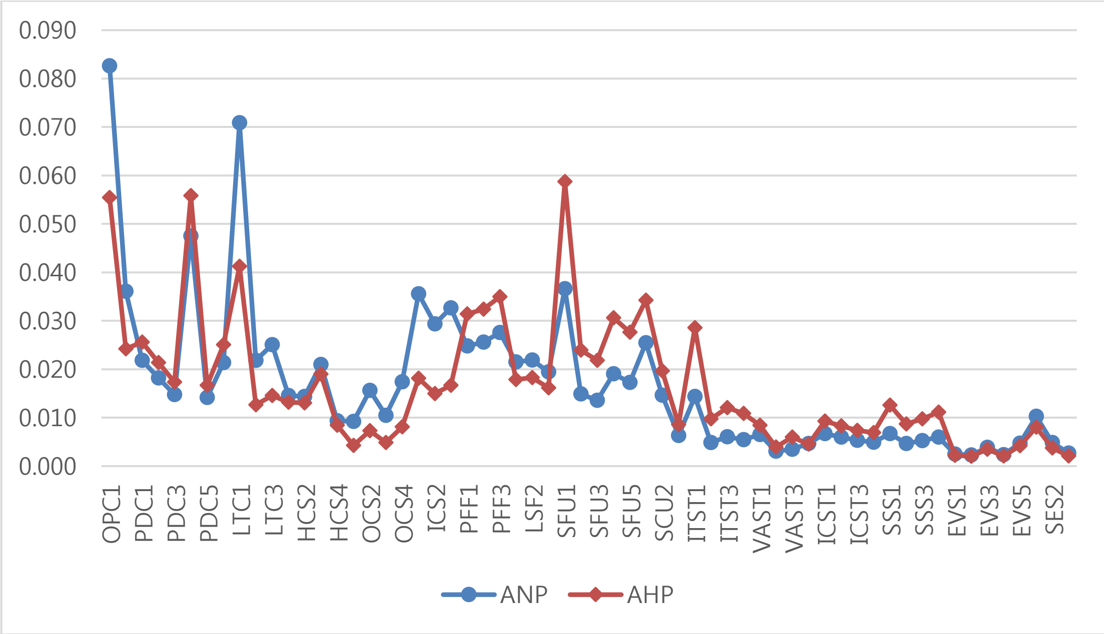

Fig. 3. Relative weight variation yielded by ANP and AHP

Table 8. Top 10 PPIs' ranking and global weight

Ranking	AHP		ANP	
	PPIs	GW	PPIs	GW
1	SFU1	**0.059**	OPC1	**0.083**
2	PDC4	**0.056**	LTC1	**0.071**
3	OPC1	**0.055**	PDC4	**0.048**
4	LTC1	**0.041**	SFU1	**0.037**
5	PFF3	**0.035**	OPC2	**0.036**
6	SCU1	**0.034**	ICS1	**0.036**
7	PFF2	**0.032**	ICS3	**0.033**
8	PFF1	**0.031**	ICS2	**0.029**
9	SFU4	**0.031**	PFF3	**0.028**
10	ITST1	**0.029**	PFF2	**0.026**

6. Conclusions

Modern container port systems denote sophisticated complexity and are cluster of economic activities where a number of port stakeholders provide products and services and create port values together. Given such complex port activities and operations, decision makers require to identify PPIs' importance as a strategic tool to improve port/terminal competiveness. This study applies AHP and ANP to obtain the relative importance of PPIs, and compares their importance values and rankings, respectively. In the context of AHP technique, the importance was obtained under consideration of independency between the PPIs, while, in the ANP analysis, we took into account the PPIs' interdependency. Based on our best knowledge, it presents the first attempt to define the importance differences between the two approaches in port performance study. Its research findings contribute to practice and research in the following ways.

First, the results can be employed as guidelines for practitioners and regulators (i.e. terminal operators, port authority and government) to rationalise their investment strategies. It helps to clarify investment priorities for port competitiveness improvement by adjusting their strategies based on the derived importance of criteria. Due to a series of world economic recessions, container ports are facing emerging challenges in the decision making of their investment portfolios. Under the situation that resources have remained flat or even decreased, decision makers have to manage risk within their investment portfolios while considering that the economic environments present to the shipping and port industries. Secondly, a hybrid methodology using DEMATEL and ANP provides a coherent framework to define interdependent weights between the PPIs. Previous studies on port performance, port selection and port competiveness generally take into account the PPIs as independent attributes, but assuming them as independent and irrelevant to each other is not realistic in many cases to solve MCDM problems in today's complex port activities and operations. Hence, the hybrid approach represents a new conceptual model capable of addressing interdependencies between the PPIs to assist the challenges in PPM. More importantly, the use of DEMATEL to screen PPIs of significant interdependency can reduce the high demand on research data collection in traditional ANP.

Nonetheless, this study has some limitations. First, the relative weights of criteria were obtained using a crisp AHP and ANP instead of fuzzy or interval values to deal with the uncertainty in data. Should linguistic variables for weighting process be considered in the future work, it is important to consider the use of fuzzy numbers or fuzzy AHP and ANP to reflect the uncertainty and imprecision judgements. Secondly, although we tried to generalise the relative importance and ranking of PPIs, this study results were drawn by the experts of knowledge and experience associated with the leading container ports in Asia. Further studies involving a wider selection of experts from different regions/areas (e.g. Europe and America) would strengthen the validity of the findings.

Acknowledgements

The authors would like to thank the EU FP7 Marie Curie IRSES project ‘‘ENRICH” for its financial support.

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Appendix 1. Global weights of the PPIs and their ranking

	PPIs	AHP		ANP	
		GW	Ranking	GW	Ranking
1	OPC1	**0.055**	**3**	**0.083**	**1**
2	OPC2	0.024	14	**0.036**	**5**
3	PDC1	0.026	12	0.022	16
4	PDC2	0.021	17	0.018	22
5	PDC3	0.017	23	0.015	27
6	PDC4	**0.056**	**2**	**0.048**	**3**
7	PDC5	0.017	25	0.014	32
8	PDC6	0.025	13	0.021	18
9	LTC1	**0.041**	**4**	**0.071**	**2**
10	LTC2	0.013	31	0.022	15
11	LTC3	0.015	28	0.025	12
12	HCS1	0.013	29	0.015	29
13	HCS2	0.013	30	0.014	30
14	HCS3	0.019	19	0.021	19
15	HCS4	0.008	42	0.009	36
16	OCS1	0.004	52	0.009	37
17	OCS2	0.007	47	0.016	25
18	OCS3	0.005	50	0.01	34
19	OCS4	0.008	44	0.017	23
20	ICS1	0.018	21	**0.036**	**6**
21	ICS2	0.015	27	**0.029**	**8**
22	ICS3	0.017	24	**0.033**	**7**
23	PFF1	**0.031**	**8**	0.025	13
24	PFF2	**0.032**	**7**	**0.026**	**10**
25	PFF3	**0.035**	**5**	**0.028**	**9**
26	LSF1	0.018	22	0.021	17
27	LSF2	0.018	20	0.022	14
28	LSF3	0.016	26	0.019	20
29	SFU1	**0.059**	**1**	**0.037**	**4**
30	SFU2	0.024	15	0.015	26
31	SFU3	0.022	16	0.014	33
32	SFU4	**0.031**	**9**	0.019	21
33	SFU5	0.028	11	0.017	24
34	SCU1	**0.034**	**6**	0.025	11
35	SCU2	0.020	18	0.015	28
36	SCU3	0.009	40	0.006	41
37	ITST1	**0.029**	**10**	0.014	31
38	ITST2	0.010	36	0.005	49
39	ITST3	0.012	33	0.006	42
40	ITST4	0.011	35	0.005	45
41	VAST1	0.008	41	0.007	40
42	VAST2	0.004	54	0.003	56
43	VAST3	0.006	49	0.003	55

44	VAST4	0.005	51	0.005	53
45	ICIT1	0.009	38	0.007	39
46	ICIT2	0.008	43	0.006	44
47	ICIT3	0.007	46	0.005	46
48	ICIT4	0.007	48	0.005	48
49	SSS1	0.013	32	0.007	38
50	SSS2	0.009	39	0.005	52
51	SSS3	0.010	37	0.005	47
52	SSS4	0.011	34	0.006	43
53	EVS1	0.002	57	0.002	58
54	EVS2	0.002	60	0.002	60
55	EVS3	0.003	56	0.004	54
56	EVS4	0.002	58	0.002	59
57	EVS5	0.004	53	0.005	51
58	SES1	0.008	45	0.01	35
59	SES2	0.004	55	0.005	50
60	SES3	0.002	59	0.003	57