MEASUREMENT, MODELLING AND ANALYSIS OF CONTAINER PORT PERFORMANCE

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Abstract

This thesis aims to develop a new framework of container port/terminal performance measurement, modelling and analysis. There is a need for a new performance measurement framework not only to meet the need of port stakeholders, but also to develop diagnostic tools capable of supporting decision-making in complex port/terminal operations in an uncertain environment. This study follows the related questions of ‘what to measure’, ‘how to measure’ and ‘how to control and improve’ container port performance.

In this regard, this study proposes the development of a systematic approach to address the multi-stakeholder dimension in port performance measurement. This was achieved by integrating a multi-stakeholder dimension in a port performance measurement framework which takes into account the corresponding port performance indicators (PPIs). To this end, this study identified six dimensions of crucial interests in major (container) ports investigating stakeholders’ goals and objectives, and discussed them with port stakeholders. 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 literature review and an analysis of industrial practices the associated PPIs were selected. The semi-structured interviews were applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators. The multi-stakeholder dimension involves both quantitative and qualitative PPIs in order to reflect complexity of port/terminal business environments.

This study develops two hybrid port performance measurement models: PPIs independency model and PPIs interdependency model. In the first port performance measurement model, a hybrid approach of the Analytic Hierarchy Process (AHP) and Fuzzy Logic based Evidential Reasoning (FER) for solving multiple criteria decision making (MCDM) problems is applied to address the challenges in port performance measurement. AHP is applied for a part of the FER to evaluate the relative importance of the selected PPIs. FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs as well as aggregation of the evaluations of PPIs and their importance. An analysis of 12 container terminals in South Korea is conducted to validate the proposed method.

The second approach, a new conceptual PPI interdependency model, is developed using a hybrid approach of a Fuzzy Logic based Evidential Reasoning (FER), a Decision Making Trial and Evaluation Laboratory (DEMATEL) and an Analytic Network Process (ANP). These methods are combined to deal with the inherent data uncertainties and the interdependencies among the port performance indicators (PPIs). Its novelty lies in its capability of dealing with interdependency among the performance measures as well as accommodating both qualitative and quantitative evaluations on the measures simultaneously. An analysis of 4 major container ports in South Korea is conducted to demonstrate the feasibility of the proposed method.

The empirical investigations are conducted by taking the perspectives from different port stakeholders. For instance, the quantitative data (i.e. cargo and vessel operations and financial data) are collected directly from terminal operating companies and information systems/databases managed by port authorities, government and credit rating agencies. The qualitative PPIs are collected using questionnaires from three groups of terminal operators, users (i.e. shipping lines, shippers, logistics service providers and freight forwarders) and administrators (i.e. port authority and government) to assess their own associated PPIs to measure each container port/terminal performance. The empirical results indicate that the hybrid approach attempting to use quantitative modelling for dealing with the uncertainties and interdependency problems can be successfully fulfilled. The framework and its supporting method suggest an effective performance measurement tool and offer a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner.

Finally, this thesis proposes a decision making framework for prioritising and selecting port performance improvement strategies. It can be achieved by the concepts of benchmarking-best practices using the analytic hierarchy process (AHP) incorporating a fuzzy order preference by similarity to ideal solution (FTOPSIS) method. Based on the results obtained from the two performance approaches, the leading performer (i.e. Busan New Port) and the poor performer (i.e. Busan North Port) are analysed as real cases to demonstrate the feasibility of the proposed methodology. The results yielded by the framework present the ranking of strategy options in terms of their preference to different terminal operating companies (TOCs), which enables decision makers to find optimal solutions to improving performance under their own dynamic business environments.

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Abbreviations

AD	Administrators
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BOT	Built-Operate-Transfer
BSC	Balanced Scorecard
CA	Core Activities
CFA	Confirmatory Factor Analysis
CI	Consistency Index
CR	Consistency Ratio
CSI	Container Security Initiative
CSR	Corporate Social Responsibility
C-TPAT	Custom Trade Partnership Against Terrorism
CY	Container Yard
DEA	Data Envelopment analysis
DEMATEL	Decision Making Trial and Evaluation Laboratory
DoB	Degrees of Belief
DPW	Dubai Ports World
D-S	Dempster-Shafer theory
DWT	Deadweight Tonnage
EBIT	Earnings Before Interests and Tax
EBITDA	Earnings Before Interests, Tax, Depreciation and Amortisation
EDI	Electronic Data Interchange
EMS	Environmental Management Systems
EPIs	Environmental Performance Indicators
ESPO	European Sea Ports Organisation
EVS	Environment
FER	Fuzzy Logic based Evidential Reasoning
FNIS	Fuzzy Negative-Ideal Solution
FPIS	Fuzzy Positive-Ideal Solution
FS	Financial Strength
FTOPSIS	Fuzzy Technique for Order Preference by Similarity to Ideal Solution
GBP	Gross Berth Productivity

GRT	Gross Registered Tonnage
GTOs	Global Terminal Operators
HCS	Human Resources Capital
HPH	Hutchison Port Holdings
ICIT	Information and Communication Integration
ICS	Information Capital
ICTs	Information and Communication Technologies
IDS	Intelligent Decision System
ILO	International Labour Organisation
IMO	International Maritime Organization
I-P	Importance - Performance
ISO	International Organization for Standardization
ISPS	International Ship and Port Facility Security
ITST	Intermodal Transport systems
JIT	Just - In- Time
KIFFA	Korea International Freight Forwarders Association
KILA	Korea Integrated Logistics Association
KPIs	Key Performance Indicators
KRIs	Key Result Indicators
LSF	Liquidity and Solvency
LTC	Lead - Time
M&A	Mergers and Acquisitions
MADM	Multiple attributes Decision Making
MCA	Multi-Criteria Analysis
MCDM	Multiple criteria Decision Making
MSC	Mediterranean Shipping Company
NBP	Net Berth Productivity
NRT	Net Registered Tonnage
OCS	Organizational Capital
OPC	Output
OSC	Operation Safe Commerce
PA	Port Authority
PCA	Principal Component Analysis

PDC	Productivity
PDCA	Plan-Do-Check-Act (Adjust)
PFF	Profitability
PIs	Performance Indicators
PPIs	Port Performance Indicators
PPP	Public-Private Partnerships
PPRISM	Port Performance Indicators: Selection and Measurement
PSA	Port of Singapore Authority
PU	Port User
RI	Random Consistency Index
RIs	Results Indicators
RMG	Rail - Mounted gantry
RTG	Rubber - Tired gantry
SA	Supporting Activities
SCIPT	Supply Chain Integration Practices
SCM	Supply Chain Management
SCU	Service Costs
SEM	Structural Equation Model
SES	Social Engagement
SFA	Stochastic Frontier Analysis
SFU	Service Fulfilment
SG	Sustainable Growth
SMART	Strategic Measurement and Reporting Technique
SSS	Safety and Security
TEU	Twenty Foot Equivalent Unit
TESCI	Terminal Supply Chain Integration
TFNs	Triangular Fuzzy Numbers
TFP	Total Factor Productivity
TGS	Terminal Ground Slots
TOCs	Terminal Operating companies
UNCTAD	United Nations Conference on Trade and Development
US	Users Satisfaction
VAST	Value - Added Services

CHAPTER 1 INTRODUCTION

This chapter presents an overview of this thesis. The first section provides the background of this study, followed by the research objectives and questions. The third and fourth sections outline the research framework and the structure of this thesis, respectively.

1.1 RESEARCH BACKGROUND

Container ports have become the backbone in defining the efficiencies of global logistics and supply chains (Ng and Liu, 2014). Thanks to its advantages with cost saving and capacity utilisation, shipping via container ports has always been considered as a primary mean in international transportation. In 2007, seaborne trade through ports accounted for approximately 90% and 70% of global trade in terms of volume and value, respectively (Nam and Song, 2011). Recently, container ports have experienced a number of challenges and restructures to survive in an uncertain logistics environment. Consequently, modern container ports are part of complex systems operating in an uncertain logistics environment. They are also places where a number of port stakeholders provide products and services and create value together. 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 authorities increasingly rely on stakeholder management practices to secure long-term relations with key stakeholders (Dooms and Verbeke, 2007). Performance measurement has become an important tool in stakeholder management, while at the same time the challenging multi-stakeholder environment complicates port performance measurement.

The study of performance measurement in ports and terminals has been attracting scholars and industrial practitioners in the past three decades. The study of port and terminal performance can be seen as a well-established segment in the port-related academic literature in terms of the number of publications (see Pallis *et al*. (2011) and Woo *et al*. (2012)). While over time they have developed in a broader and more advanced way, there are still research gaps yet to be filled.

The studies on port performance measurement traditionally focus on the efficiency and productivity of port/terminal operations (Suykens, 1983, Kim and Sachish, 1986, De Monie, 1987, Talley, 1988, Chadwin *et al.*, 1990, Roll and Hayuth, 1993, Talley, 1994, Tongzon and

Ganesalingam, 1994, Tongzon, 1995a, Tongzon, 1995b, Sachish, 1996, Tongzon, 2001, Cullinane *et al*., 2002, Barros and Athanassiou, 2004, Cullinane *et al.*, 2004, Wang and Cullinane, 2006, Cruz *et al.*, 2013). In such studies, various research scopes and approaches are used for productivity comparisons or engineering and economic optimums for benchmarking purpose. Benchmarking, taking reference from the successful practices and outcomes of other ports, is a key strategic activity that allows a port to recognise its own strengths and weaknesses on the one hand, and to monitor the conditions and status of its competitive ports on the other hand (Brooks, 2006). However, ports are often treated as isolated nodes that provide basic ship-shore operations with an emphasis on cost and technical efficiency rather than as a crucial part of international supply chains. Accordingly, these studies fail to make a link between quayside operations and landside systems (Bichou, 2006).

Compared to port efficiency and productivity studies, research focusing on port effectiveness was lacking until the mid-2000s (Brooks, 2006). In this regard, Schellinck and Brooks (2014) defined "efficiency is *doing things right* while effectiveness is *doing the right things*". In this context, the notion of 'the right things' refers to the delivery of the desired results to port stakeholders who have different performance objectives. The effectiveness for port users, for example, denotes their satisfactions relative to services delivered by ports. Hence, port effectiveness should be measured by taking into account different port stakeholders' perspectives (Brooks, 2006). Furthermore, the effectiveness-oriented port operators and authorities tend to provide more customer-focused services and they deem service quality as an important measure (Brooks and Pallis, 2008). Existing studies, however, are mostly restricted to the dimension of customer satisfaction on services.

Over time, the concept of ports has been redefined in terms of their functions, geographical scopes and activities (Notteboom and Winkelmans, 2001, Paixão and Bernard Marlow, 2003, Beresford *et al.*, 2004). Hence, ports have continuously been adapted to the evolving changing environment to sustain themselves in highly competitive environments (Woo *et al.*, 2011a). Numerous studies introduced conceptual frameworks and dealt with the port evolutionary changes such as supply chain integration, lean/agile perspectives, customer-oriented practices, and value-added activities (Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, De Langen *et al.*, 2007, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al.*, 2013). While these researchers have emphasised the impact of current issues on port performance, few studies have been empirically and intensively conducted to identify correlations between current issues and port performance.

Little research has been done on addressing the multi-stakeholder dimension in port performance measurement and the interdependency of PPIs in a quantitative way. For example, the EC-funded PORTOPIA project (www.portopia.eu) is a large scale project focusing on the identification of relevant port-level based PPIs in five categories, i.e. environmental performance, supply chain performance and connectivity, throughput and market structure, socio-economic impacts and governance. The PORTPIA project aims for the creation of a standard toolkit and dashboard to increase transparency on the performance of European ports. However, the interdependency between PPIs and the relevance of indicators to specific stakeholder groups have not been sufficiently dealt with.

Furthermore, the existing literature tends to focus on limited dimensions or specific areas of ports and terminals. Such fragmented approaches may fail to take into account new issues and challenges faced by ports, indicating that more studies are needed to overcome the shortcomings.

The above analysis indicates that there is a need for a new performance measurement framework not only to meet the needs of port stakeholders facing emerging challenges, but also to enrich the diagnostic tools available to support decision-making in complex port/terminal systems operating in an uncertain environment. This framework involves multiple dimensions with both quantitative and qualitative port performance indicators (PPIs) in order to offer diagnostic instruments to decision makers. The decisions are usually made on multiple uncertain attributes. Consequently, this study deals with the inherent uncertainties in data. Furthermore, it needs to identify interdependency among the PPIs. Given complex port activities and operations, decision makers may require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improving port/terminal performance. The framework suggests an effective performance measurement tool and offers a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner.

1.2 GENERAL RESEARCH QUESTIONS

Given the research background aforementioned, this study aims to develop a new port performance measurement framework for container ports/terminals and a decision support tool to enhance quantitative port performance analysis by taking the perspectives from different port stakeholders.

The designed analytical logic follows the related questions of ‘what to measure’, ‘how to measure’ and ‘how to control and improve’ container port performance. In this regard, the general research questions that this study is interested in investigating and finding the answer to are:

What are the most crucial dimensions and port performance indicators (PPIs) for port performance measurement? How can the crucial dimensions and PPIs be selected? What is main considerations on the PPIs selection? How can the identified dimensions and PPIs be integrated in port performance measurement systems?

Answering the questions above requires developing a systematic approach to address the multi-stakeholder dimension in port performance measurement. This can be achieved by integrating a multi-stakeholder dimension in a port performance measurement framework which takes into account the corresponding PPIs. These stakeholder-specific PPIs need to be aligned with organisational goals and strategies and present a clear picture of the organisational performance. 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. Using only one dimension (e.g. financial measures) in a performance measurement setting is no longer sufficient to cover all related issues for the new business environment. As a consequence, the framework needs to involve multiple dimensions with both quantitative and qualitative PPIs in order to offer diagnostic instruments to decision makers. Chapters 2 and 4 will be dedicated to answer these questions.

How much the multi-stakeholder dimension approach can reflect the complex systems of container ports/terminals operating in an uncertain logistics environment? How can the identified dimensions and PPIs be prioritised and ranked? How efficiently does port/terminal deal with quantitative data and qualitative data together in a unified manner? What kind of disciplines needs to be considered to deliver more practical applications in port performance measurement?

To answer the above questions, a port performance measurement framework is needed not just to meet the needs of port stakeholders, but also to enrich the diagnostic tools available to support decision-making in complex port/terminal systems operating in an uncertain environment. The decisions are usually made on multiple uncertain attributes. Consequently, this study needs to deal with the inherent data uncertainties which are sometimes unavoidable in port/terminal operational contexts. Furthermore, it needs to identify interdependencies among the PPIs. Given complex port activities and operations, decision makers may require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improve port performance. From the discussion, port performance measurement can be viewed as a typical multi-criteria decision making (MCDM) problem under uncertainty as it involves multiple criteria of both quantitative and qualitative features to solve multi-dimensional and complicated problems. This study uses a MCDM approach as a data analysis technique (i.e. a performance measurement tool). In the MCDM applications, the evaluations of PPIs and their importance should be conducted separately and then synthesised. With regard to this, applying a mixed methodology (i.e. hybrid approach) is essential. A mixed approach that uses different methods, techniques and data sources in the same study can offset weaknesses in each. Therefore, this study adopts a mixed approach; more than one method to collect data, such as interviews, questionnaires, and documents, more than one data sources and more than one method to analyse the data. Chapters 5 and 6 will be dedicated to develop appropriate port performance measurement models.

What are the performance improvement strategies and how can the poor performing ports be improved and controlled?

The proposed port performance measurement models enable us to identify the strengths and weaknesses of the container ports/terminals and offered insights to find optimal strategies to improve their performance. The poor PPI score needs to be improved with reference to the associated PPI performance in a leading performer. This will be achieved by the concepts of benchmarking best practices. A relevant peer group of ports in Asia will be investigated to identify the potential performance strategies to improve the weak PPIs in poor performer. Chapter 7 is dedicated to introduce a new decision making framework for selecting port performance improvement strategies

1.3 RESEARCH FRAMEWORK

The primary objective of this thesis is to develop the measurement, modelling and analysis framework of container ports/terminal performance in order to provide an effective performance measurement tool, and offer a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner. In order to achieve the objective, the potential port performance indicators which are most crucially needed to be used for measuring port performance are identified through industrial best practices and the broader areas of literature on port and shipping, logistic and supply chain management (SCM), and strategic management. In addition, it needs to investigate the crucial interests in major container ports investigating their missions, visions, goals, and objectives and discuss them with port stakeholders. And then the semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators. Through the content validation, both quantitative and qualitative PPIs in the lowest level can be selected, which is particularly significant as representing indicators for container port performance measurement under different types of principal-PPIs from dimensions. The PPIs at the bottom level are associated with various types of numerical and subjective data to reflect complexity of port/terminal business environments. Next, this study develops a couple of the hybrid port performance models using sophisticated tools that are already proven to be successful applications under uncertain and complex environments. In the first port performance measurement model, a hybrid approach of the Analytic Hierarchy Process (AHP) (Saaty, 1980) and Fuzzy Logic based Evidential Reasoning (FER) (Yang and Xu, 2002) for solving MCDM problems is applied to address the challenges in port performance measurement. The AHP is a suitable application when comparing the importance or rating of a criterion against that of other criteria at the same level in the hierarchy decision tree (Saaty, 1980). The second port performance measurement model uses a hybrid approach of a Fuzzy Logic based Evidential Reasoning (FER), a Decision Making Trial and Evaluation Laboratory (DEMATEL) (Gabus and Fontela, 1973) and an Analytic Network Process (ANP) (Saaty, 1996). The DEMATEL is first used to identify whether there are interdependent relationships among the PPIs, while the ANP is applied to determine the intensity of the relationships among the PPIs. Furthermore, the FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs.

The models are validated through empirical investigations. For the empirical studies, the quantitative data (i.e. CA and FS) are collected directly from terminal operating companies and information systems/databases managed by port authorities, governments and credit rating agencies. The qualitative PPIs are collected using questionnaires from three groups of terminal operators (TO), users (i.e. shipping lines, shippers, logistics service providers and freight forwarders, PU) and administrators (i.e. port authority and government, AD) to assess their own associated PPIs to measure each container port/terminal performance. The surveys are conducted through an online survey tool as well as distributed by emails.

Finally, the performance improvement model is established to suggest the performance improvement strategies for poor performing ports. In this framework, the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) is used in order to support the critical decision making on the selection of the most suitable performance improvement strategies based on multiple criteria. The fuzzy set theory is a powerful tool in dealing with vagueness of human thoughts and expressions in making decisions (Zadeh, 1965). It permits vague information, knowledge and concepts to be used in an exact mathematical manner. Normally, in a fuzzy environment, the assessment grades (i.e. linguistic terms) for criteria are expressed by fuzzy numbers (i.e. triangular or trapezoidal fuzzy numbers) rather than crisp numbers. Furthermore, the fuzzy set theory can be easily combined with other methods for the selection issue. A TOPSIS method is well suited to modelling with multiple conflicting objectives and sub objectives to determine the ranking order of alternatives (Hwang and Yoon, 1981). The framework is designed based on the performance results obtained from the performance measurement models in previous chapters. The research framework of this thesis is shown in Figure 1.1.

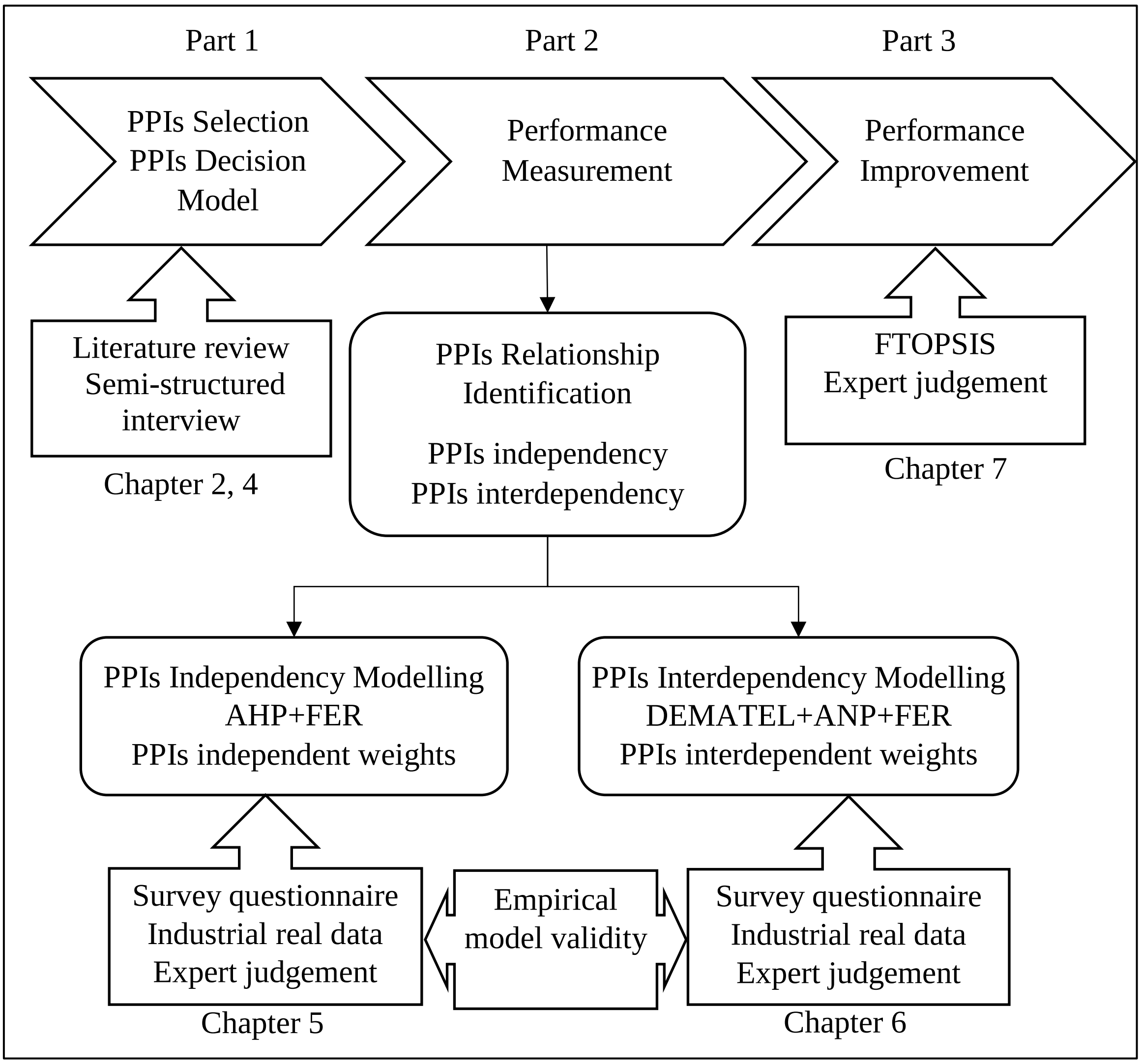

Figure 1.1 Research framework in this study

1.4 STRUCTURE OF THIS THESIS

The thesis consists of eight chapters to achieve the major research objectives.

Chapter 1 outlines research background, research objectives and questions, research framework and the structure of this thesis, respectively.

Chapter 2 conducts the literature review with reference to the changing port business environment, performance measurement and port performance measurement to establish the direction of the research framework with regard to port performance indicators (PPIs) selection, port performance measurement and performance improvement strategies.

Chapter 3 describes how the research will be conducted in order to fill the research gap identified from previous studies. Thus, this chapter mainly deals with the main issues of the research framework, such as research strategy and design, research methods, data collection and analysis techniques.

Chapter 4 discusses the selection of port performance indicators (PPIs) taking reference from broader areas in port and shipping, logistic and supply chain management (SCM), and strategic management and industrial best practices. Next, the semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators. To guide the conceptual development on PPI selection, six dimensions with 16 principal PPIs and 60 PPIs are identified as particularly relevant factors for port performance measurement to incorporate multiple objectives of key stakeholders.

Chapter 5 develops a new conceptual PPI measurement model using a hybrid approach of a fuzzy logic based evidential reasoning (FER) and an analytic hierarchy process (AHP). In this framework, the PPIs are considered as independent attributes. An analysis of 12 container terminals in Korea is conducted to validate the proposed framework. The empirical results yielded by the hybrid approach present the ranking of the terminals in terms of their overall performance with respect to multiple PPIs as well as a single PPI selected through a single performance value. This feature enables us to identify the strengths and weaknesses of the ports and offers insights to the terminal operating companies to find optimal strategies to improve their performance.

Chapter 6 develops a new port performance measurement model using a hybrid approach based on a fuzzy logic based evidential reasoning (FER) method, a decision making trial and evaluation laboratory (DEMATEL) and an analytic network process (ANP) technique. The novelty lies in its capability of dealing with interdependency among the performance measures as well as accommodating both qualitative and quantitative evaluations on the measures simultaneously. An analysis of four major container ports in South Korea is conducted to demonstrate and validate the proposed method. The empirical results indicate that the hybrid approach attempting to use quantitative modelling for dealing with the uncertainties and interdependency problems can be successfully implemented. The hybrid model represents an effective performance measurement tool and offers a diagnostic instrument to ports/terminals for performance evaluation and/or monitoring so as to satisfy different requirements of various groups of port stakeholders in a flexible manner.

Chapter 7 develops a decision making approach for modelling PPI improvement strategies. This can be achieved by the concepts of benchmarking best practices with a novel utility method such as a fuzzy order preference by similarity to ideal solution (FTOPSIS) method in MCDM problems. Based on the performance results in Chapter 6, the best practices of the Busan New Port (leading performer) is used as a benchmark to improve the weak PPIs in Busan North Port (poor performer) as a case study for modelling PPIs improvement strategies. In order for this, the performance improvement strategies for Busan North Port are identified through interviews with port/terminal operating companies in major Asian ports and a literature review. Then, the priority of investment on the strategies to improve Busan North Port's competitiveness and customers' satisfaction is determined by FTOPSIS.

Chapter 8 summarises overall results and findings of this study and provides academic and practical implications for port/terminal managers, policy makers and academics. Finally, this study is finished with a discussion of research limitations and recommendations for further research.

CHAPTER 2 LITERATURE REVIEW

This chapter conducts the literature review with reference to the changing port business environment, performance measurement and port performance measurement to establish the direction of the research framework with regard to port performance indicators (PPIs) selection, port performance measurement and performance improvement strategies.

2.1 CONTAINER PORT BUSINESS ENVIRONMENT

Due to changing port business environment, ports have continuously adopted new strategies for improving service quality to meet complicated and diverse demands of customers (Marlow and Paixão Casaca, 2003, Panayides and Song, 2009, Woo *et al*., 2011a). In parallel with traditional studies of port performance measurement on port efficiency and productivity (Talley, 1994, Sachish, 1996, Tongzon, 1995a, Tongzon, 1995b, Tongzon, 2001, Cullinane *et al*., 2002, Barros and Athanassiou, 2004, Cullinane and Wang, 2006a, Cullinane *et al*., 2006, Talley, 2006), the arguments for extending port performance need to take into account new issues and challenges faced by ports (Woo *et al*., 2011a). This approach is in line with arguments that PPIs need to be inclusive of all aspects of port operations (Bichou, 2006, Brooks, 2006). To this end, this section outlines the contemporary issues across the range of port and maritime industry to capture crucial dimensions for measuring port performance.

2.1.1 Port evolutionary changes

Traditionally, ports were considered as a simple transhipment place where cargos are loaded/unloaded between ships and landside modes. Over time, the concept of ports has evolved in terms of their functions, geographical scopes and activities (Notteboom and Winkelmans, 2001, Paixão Casaca and Marlow, 2003). Monios & Wilmsmeier (2012) explained the trends of port development within a port regionalisation concept, beginning with the port's core business of container throughput (i.e. infrastructure, superstructure and spatial development) and developing towards either physical or operational/strategic hinterland development to support the core business. Ports have continuously been adapted to the evolving changing environments to sustain themselves in highly competitive environments (Woo *et al*., 2011a). In addition, numerous studies introduced the new port roles and conceptual frameworks to deal with port evolutionary changes such as supply chain integration and port centric-logistics, lean/agile perspectives, customer-oriented practices, port sustainability, and value-added activities (Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, Mangan *et al*., 2008, Panayides and Song, 2009, Woo *et al*., 2011a, Woo *et al*., 2013). The port evolutionary changes from various perspectives can be found in existing literature and previous studies.

UNCTAD (1992) recognised radical port changes in the global patterns of port activities. In terms of three key criteria (i.e. port development policy, strategy and attitude; port activities scope and extension; the integration of port activities and organisation), ports were classified into three generations (i.e. first-, second- and third-generation ports). First-generation ports (i.e. before 1960s) operate in isolation, where they provide simple cargo transfer or transit between sea and land transports. Second-generation ports (i.e. after 1960s) are recognised as transport, industrial and commercial service centres, providing value-added service and extended ports' hinterland. Third-generation ports (i.e. after 1980s) are the places where the dynamic nodes in the complex international production/distribution network and the integrated transport centres/logistics platforms for international trade interconnect. However, the classification of ports in terms of the evolution of ports would not be sufficient to cope with uncertain port environment today (Paixão Casaca and Marlow, 2003). Paixão Casaca and Marlow (2003) introduced fourth generation ports by empolying a new logistics approach, agility, to cope with the uncertainty. "Agility is a strategy responsible for strengthening the links between the internal and the external business environments, as it is a knowledge-based strategy that helps any business to move quickly in the new economy (Paixão Casaca and Marlow, 2003, pp.7)." Beresford *et al*. (2004) introduced a WORKPORT model to explain the port changes on a timeline basis. The WORKPORT model adopted the main categories of the UNCTAD model as well as port operational and development issues such as working cultures, health and safety and environment to identify the transition process of European ports since the 1960s. According to the model, the ownership of ports has increasingly involved the private sector (i.e. private ports in the UK since the 1980s and increased container terminal ownership by global terminal operators since the 1990s). General cargos have been almost completely unitised in the 2000s (i.e. containerisation) and the size of ships has increased. Cargo-handling processes have become increasingly automated and mechanised, inversely the numbers of workers have decreased. Cargo support process and information systems have proliferated (i.e. EDI, mail, telephone, fax, radio, telex, internet, intranet and standardisation of information). Port related activities have diversified (i.e. globalisation of port communities). The safety and environment concerns forced ports to invest in less commercial return assets, leading to decreasing accident rates, absenteeism and emerging quality-assured environment management systems. The World Bank (2007) recognised the major drivers on port dynamic changes in 21st century: global competition, innovative systems and new technologies, realignment and consolidations, distribution patterns and structure of maritime geography and environmental, safety and security regulations. The external forces have made ports to restructure their operations to survive in a new era of increased competition (Paixão Casaca and Marlow, 2003). Woo *et al*. (2011a) identified port evolutions in changing logistics environments from the perspectives of consumers and providers of logistics services: efficient operation, price competition, service quality improvement, customer oriented practices, connectivity to other transport modes, value-added services, port cooperation and networking, security and safety. According to their contention, as manufacturing companies adopt new strategies such as SCM, global sourcing and outsourcing of certain functions, transportation companies are required to provide more diversified services in a wider geographical scale (Rabinovich *et al*., 1999, Heaver, 2002). This leads shipping companies to become dedicated to the new strategies such as horizontal and vertical integration and network redesign, resulting in the emergence of powerful clients and intensifying competition (Nooteboom and Winkelmans, 2001, Notteboom, 2004). Accordingly, these changes directly influence the port industry.

Ports have also played an important role in global logistics and supply chains. The role of ports in the supply chain has been defined and emphasised as an integrated transport centre and logistics platform for international trade (Beresford *et al*., 2004). A port supply chain may be defined as an integrated process platform where a number of different port stakeholders (i.e. terminal operating companies (TOCs), port authorities, shipping lines, 3rd party logistics providers (3PLs), freight forwarders, trucking companies and railway companies) cooperate closely in port operational activities of cargos/vessels/other transport modes operations. This chain is characterised by a bilateral convergence and divergence of the physical and non-physical flows of cargos, transportation modes and information. Within ports' role in the supply chain, port performance measurement is perceived as a crucial function to achieve sustainable growth of ports (Mentzer and Konrad, 1991, Bichou and Gray, 2004).

2.1.2 Containerisation and emergence of mega-vessels

Containerisation is one of the remarkable innovations in the transport industry and realises a significant transportation efficiency and effectiveness with a lower cost and higher quality than ever before. This enables a global based single market through a greater velocity in freight distribution, which, consequently, increases the velocity of supply chains (Notteboom and Rodrigue, 2008). Containers have been moved since the mid-1950s when the Sea Land owned converted tanker, Ideal X, carrying 58 containers made its initial voyage between New York and Houston (World Bank, 2007). Since then container volumes around the world have observed tremendous growth and the capacity of containerships has greatly increased (Paixão Casaca and Marlow, 2003, Notteboom, 2004). More than 60 percent of the world's general cargo is being carried by containers and the percentage shipped between highly industrialised countries approaches more than 90 percent (World Bank, 2007).

Containerisation has directly impacted on the port industry, enforcing huge investments on port infrastructures, superstructures and equipment, including purchasing container cranes and yard equipment, developing larger terminal sites and storage facilities and optimising berth-yard-gate operations (and vice-versa). This reduces ships' time in port and raises terminal operational productivity. In addition, thanks to ports' new adaptations, shipping lines serve an expanded geographical span with a wider choice of ports (Fleming and Hayuth, 1994). Containerisation also increases the average size of containerships and changes ship types. In the early phase of container shipping in the 1950s and 1960s, containers were carried by the converted containerships fitted with on-board cranes from tanker ships and dry cargo ships with capacity of less than 1,000 TEU in voyages between the U.S ports (World Bank, 2007). The first container ship was built in 1969, the new generation of containerships with a larger capacity (1,000-1,500 TEU) and a faster speed (20-27 knots) was designed to use quay cranes to achieve a higher cargo handling productivity and more containers on board (World Bank, 2007). In 2016, the 60th anniversary of container shipping, more than 18,000 TEU capacity containerships are serving mostly between Asia-Europe trade routes (i.e. MSC Oscar and its sister vessels: 19,300 TEU, CSCL Globe: 19,100 TEU, Maersk's Triple E Class vessels: 18,270 TEU). There has been unavoidably a huge capital investment in port facilities and vessel constructions since the containerisation revolution, but the benefits such as a significant reduction in transport costs and improvement in transport efficiency through economies of scale have been shared throughout the supply chains (Cullinane and Khanna, 2000, Slack, 2001).

2.1.3 Globalisation

Container ports have played an important role in global logistics and supply chains. Since the world economies have become integrated as a result of globalisation of production and consumption, world trade has dramatically increased (Notteboom and Rodrigue, 2008). In addition, the globalisation has been strengthened by the manufacturing companies' strategies of global sourcing of raw material and finished products, which accordingly leads to an increased geographical span of business activities both between suppliers and manufacturers and between manufacturers and consumers (Heaver, 2002). These trends have significantly impacted on global logistics and supply chains that are functionally integrated in all stages of production, trade and service activities (Woo *et al*., 2011a). Consequently, logistics companies' service activities have become expanded and diversified to meet customer requirements in a wider geographical span, while at the same time the changes have led to intense global competition.

In the maritime industry, shipping lines have restructured themselves to adjust to the changes in order to yield economies of scale. Two distinct ways of consolidation have been taken: mergers and acquisitions (M&A) and strategic alliances. There have been major deals of M&A in the past 20 years: P&O-Nedlloy (1996), CMA-CGM (1996), Hanjin-DSR Senator (1997), NOL-APL (1997), Evergreen-Lloyd Triestino (1998), Hamburg Süd-Alianca (1998), Maersk-Safmarine (1999), Hamburg Süd-Transroll Nav.S.A. (1999), Maersk-Sea-Land (1999), CSAV-Norasia (2000), Hamburg Süd-Ellerman (2002), Hamburg Süd-Kien Hung Shipping Co. (2003), Maersk-Royal P&O Nedlloy (2005), CMA—Bollore Delmas (2005), Hapag-Lioyd-CP Ships (2005), Hamburg Süd-Costa Container Lines (2007), Hapag-Lloyd and CSAV (2014), Hamburg Süd-CCNI (2014) and CMA CGM-OPDR (2015) (Firmin, 2015). M&A is one of the aggressive consolidation strategies to seek to secure assets' synergies and commercial and logistical networks but has a number of risks such as ownership structure, value misconception and cultural challenges.

Strategic alliance is economically the best available consolidation option for increasing quality of logistic services through slot exchange agreements (Cariou, 2008). In the alliances, all members share vessels (cooperation strategy) but their sales, marketing and pricing stay independent (competition strategy). Hence, the optimum size of vessel can be utilised in each trade lane, leading to reduced voyage costs and expanded service flexibility to customers (i.e.

service frequency and space availability). The history of a modern form of alliance dates back to the mid-1990s (Heaver *et al*., 2000, Slack *et al*., 2002, Cariou, 2008, Panayides and Wiedmer, 2011). There were four alliances: global alliance, grand alliance, M-S alliance and Hanjin/Trican. In 2010, there were three alliances, but this has changed drastically in 2014 (Merk *et al*., 2015) (see Figure 2.1). The major shipping lines have regrouped themselves with the other alliance members in previous alliances (i.e. the grand alliance + the new world alliance) and formed four new alliances including 2M, O3, G6 and CKYHE, which represents four fifths of the total world fleet (Merk *et al*., 2015). This new era of strategic alliances in the container shipping industry is expected to have a massive impact on the container port industry with their considerable bargaining power.

In these two consolidation ways, one over anther has been preferred in terms of market conditions and financial capacities or market positioning of shipping lines (Cariou, 2008). For example, no major M&A deals between 2007 and 2013 can be explained due to global economic recessions and, consequently, a slump in the maritime market. On the contrary, the recent new form of alliances represents the difficulties in making a profit due to global economic recession and over-capacity of the total container fleet.

A typical example of globalisation in the port industry can be found from public-private partnerships (PPP). The private participation in the port industry has increased after introducing various concession schemes such as lease contract and BOT (Built-Operate-Transfer). In general, they have more flexible decision structures and customer driven management practices than those in public organisations, consequently compromising the business excellence on port performance, operational effectiveness and efficiency. In this regard, the top five global terminal operators (i.e. PSA (Port of Singapore Authority), HPH (Hutchison Port Holdings), APM terminals, DP (Dubai Ports) World and COSCO) accounted for more than 28 percent of the total world container market share in 2005 (World Bank, 2007). The PPP scheme is an efficient tool for major shipping lines to integrate their logistics activities vertically (i.e. APM, COSCO and Hanjin terminals) due to advantages in cost savings through control over door-to-door port services. Further, these maritime companies have transformed themselves into total logistics service providers by engaging in all logistics activities over the entire logistics chains (Notteboom and Winkelmans, 2001). This phenomenon, evidently, has brought intense competition throughout the whole supply chain and has shifted a market bargaining power from ports to shipping lines through incremental influences on cargo handling operations (Heaver *et al*., 2000).

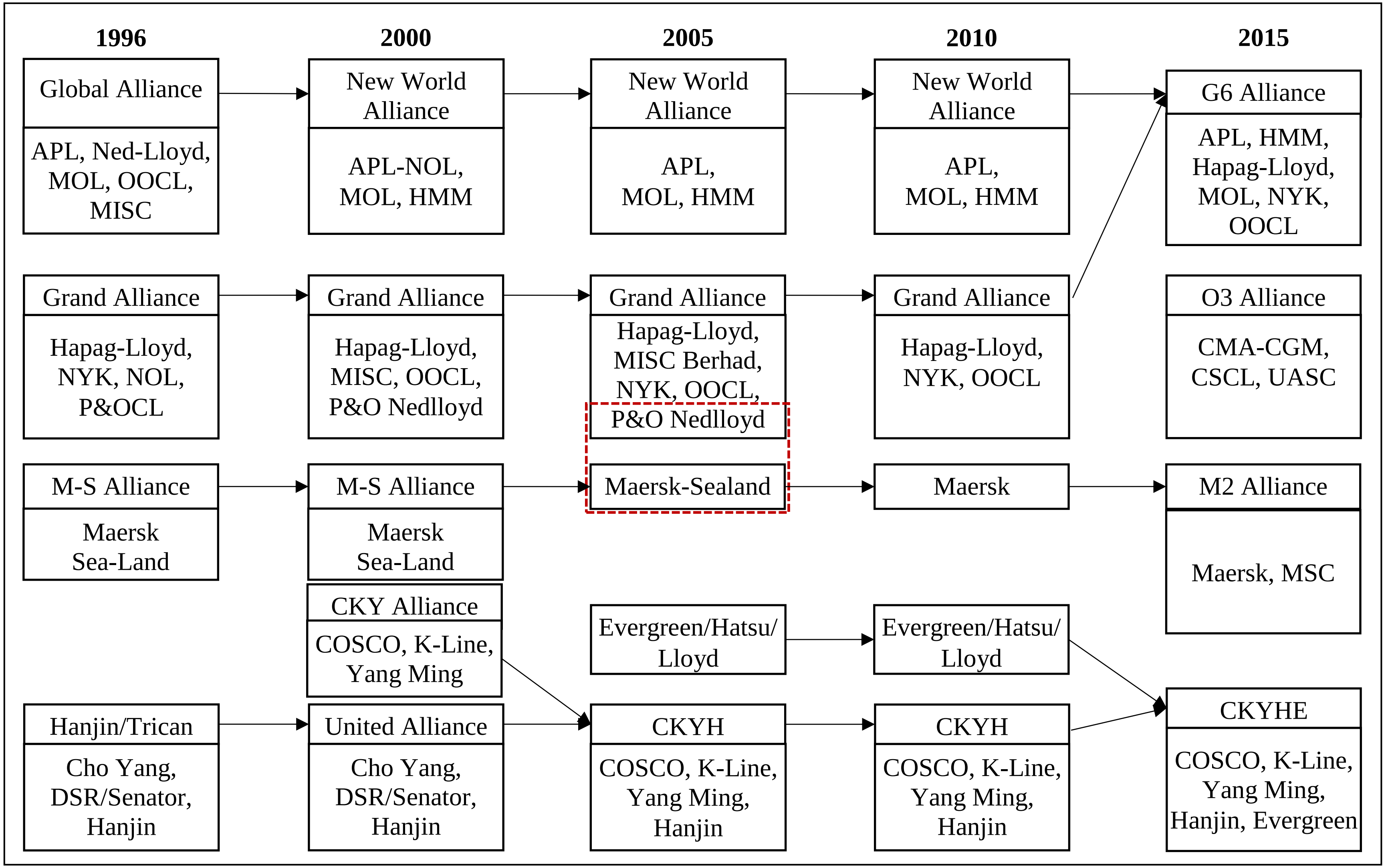

Figure 2.1 Development of strategic alliances

Source: Created by Author based on Heaver *et al*. (2000), Slack *et al*. (2002), Cariou (2008), Panayides and Wiedmer (2011) and Merk *et al*. (2015).

2.1.4 Port competition and coopetition

Port competition is an inevitable trend of industry rivalry. There is no doubt that the internal and external port business environments such as the emergence of mega-vessels, inter-modality, strategic alliances and M&A of shipping liners and various co-operative agreements in maritime and port industries have had an effect on the level of port competition and reshaped port hierarchy (Heaver *et al*., 2000, Song, 2002). The types of port competition can be explained in terms of both port/terminal's service ranges and players. Monios *et al*. (2016) explained a growing competition in port-related distribution activities between seaport and inland locations has been driven not only by market forces but also by institutional settings and the governance relations between the actors involved. Van de Voorde and Winkelmans (2002) explained three types of port competition: intra-port competition at operator level, inter-port competition at operator level and inter-port competition at port authority level. The World Bank (2007) classified port competition into three categories: inter-port competition, intra-port competition and Intra-terminal competition. The categories of port competition suggested are very similar but the difference between them is still identified (see Table 2.1). However, the major interests of port competition in industry are mostly on inter-port and intra-port competition cases, accordingly, they have attracted scholars and practitioners (Heaver *et al*., 2000, Notteboom, 2002, De Langen and Pallis, 2006, Yap and Lam, 2006). In the context of the inter-port competition, there are great overlaps between hinterlands of major ports, leading to a great amount of competition among them, for instance, among ports in Far East Asia (Yap and Lam, 2006), Antwerp-Hamburg range (Veldman and Bückmann, 2003), the US, UK and North-Western Europe (Fleming and Baird, 1999). Notteboom (2002) argued that the structural change such as consolidation of the port demand side, port privatisation and maturity of port business has indicated a new era of intra-port competition. These structural changes have provoked port attractiveness and the prerequisite have led to port competitiveness (Heaver *et al*., 2000, Ng, 2006). The benefits of intra-port competition have been addressed from different perspectives: to yield economies of scope through diversifying service organisation structures (Chlomoudis and Pallis, 1998), to prevent monopolistic rent and profits (Goss, 1999, Notteboom, 2002) and to explore the relationships both between intra-port competition and market power weakness of port service providers and between intra-port competition and port specialisation, flexible adaptation and innovation (De Langen and Pallis, 2006).

With regard to intra-port competition in Busan Port (Busan North Port and Busan New Port), it has seen intense intra-port competition since 5 container terminals in Busan New Port started up operations from 2005 to 2011 respectively. The strengthened intra-port competition in Busan Port has now resulted in an almost 50 percent reduction of the cargo handling price compared to the year before 2005 (based on interview with terminal operators in Busan Port). The situation is not in line with De Langen and Pallis (2006) and indicates a market power shift from ports to shipping lines. In addition, this extreme competitive rivalry has a high risk on recovering the terminal operators' investments which leads to poor financial conditions that could aggravate customer satisfaction on services.

The term 'port coopetition', a mixture term of port competition and cooperation, is a win-win strategy for ports/terminals that provide logistics services within the same or a similar market (Song, 2002). Song (2002) provided the first acknowledged argument for port co-opetition: it is a useful strategic option for terminal operators to increase their market power. In practice, this strategy is predominant especially for transhipment containers: container shifts from one terminal to another terminal and container shuttle service between Busan New Port and Busan North Port.

Table 2.1 Types of port competition

	Types of port competition
World Bank (2007)	- Inter-port competition: competition between ports or their terminals for the same trades - Intra-port competition: competition between terminal operators within the same port for the same markets - Intra-terminal competition: competition between companies to provide the same services within the same terminal
Van de Voorde and Winkelmans (2002)	- Intra-port competition at operator level: competition between operators within a given port with regard to a specific traffic category - Inter-port competition at operator level: competition between operators from different ports mainly within the same range and serving more or less the same hinterland - Inter-port competition at port authority level: competition between port authorities – utility mission of seaports with local/national port range

2.1.5 Backbone role of port

The backbone role of seaports refers to vessel operation, cargo operation and other activities regarding cargo transfer or transit from ports to vessels and other transport modes (or vice-versa). Modern container ports essentially require a higher operational productivity with a higher service quality due to increased vessel sizes, growing throughput volumes and more stringent customer needs. The performance of the backbone role has been assessed in terms of productivity (efficiency + utilisation), output, and lead-time (see section 2.3.1). The term productivity refers to how efficiently resources (i.e. labour, equipment and land) are being used. Output refers to the total quantity of work performed in a container port over a period of time without considering the resources utilised (De Monie, 1987). In the container port industry, container throughput volume is widely used as an indicator of port performance partly due to the data availability. Lead-time refers to the speed at which activities are performed. Schmenner (2004) stressed that companies achieving a higher competitiveness through a combination of speed and variability reduction and productivity improvement would have a higher performance than those only focusing on one aspect.

2.1.6 Port in global supply chains

Ports have a key role to play in supply chains. A number of studies acknowledged the significant roles of the port/terminal in the context of supply chains (Carbone and Martino, 2003, Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013).

In the context of the third generation port (UNCTAD, 1992) and the WORKPORT model (Beresford *et al*., 2004), the role of ports in supply chains has been defined and emphasised as an integrated transport centre and a logistics platform for international trade. Charler and Ridolfi (1994) identified the role of ports as an intersection place where four modes such as ocean ships, short-sea/river ships, road and rail transportation cross to one of the most important logistics nodes in supply chains to provide value added services. Panayides and Song (2009) emphasised seaport terminal supply chain integration (TESCI) on setting up systems and processes, but also on the functional activities. Marlow and Paixão Casaca (2003) argued that ports need to transform their role in such a way that they are able to create value rather than cost. Ports have conducted a number of value-adding roles in terms of functional and geographical aspects. Functional value-adding activities are such as transport consolidation, product mixing, or cross-docking services alongside their basic operations of cargo handling and storage. Geographical value-adding activities involve development of maritime industrial areas, trade and distribution maritime centres, industrial clusters and distriparks, free zones and trading hubs and networks. Furthermore, ports should become transport solution providers in supply chains (Marlow and Paixão Casaca, 2003) and should be integrated with other logistics players in supply chains (Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013). The recognition that the higher the integration between the players in the supply chain the higher the competitive performance (or competitiveness) of the whole supply chain is illustrated or empirically proven by many studies (Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013).

As mentioned above, a port supply chain is an integrated operational and managerial platform where the physical and non-physical flows of the port functions and institutions intersect within port as well as across the extended supply chain networks (UNCTAD, 2004). To achieve the port supply chain integration, ports have to be aligned their all roles to seaside, intermodal/multimodal and landside logistics to achieve an efficient movement of the physical and non-physical flows, strengthening coordination between landside and seaside links. Figure 2.2 illustrates the conceptual port supply chain integration for the bilateral convergence and divergence of the physical and non-physical movements from port to seaside and landside links (and vice-versa). Physical flows encompass ship/vehicle and cargo movements, whereas non-physical flows denote capital, payment and information flows in the port supply chain. These flows interact one another and well-collaboration between them determine the extent to which port products or services conform to the requirements or objectives of the key stakeholders.

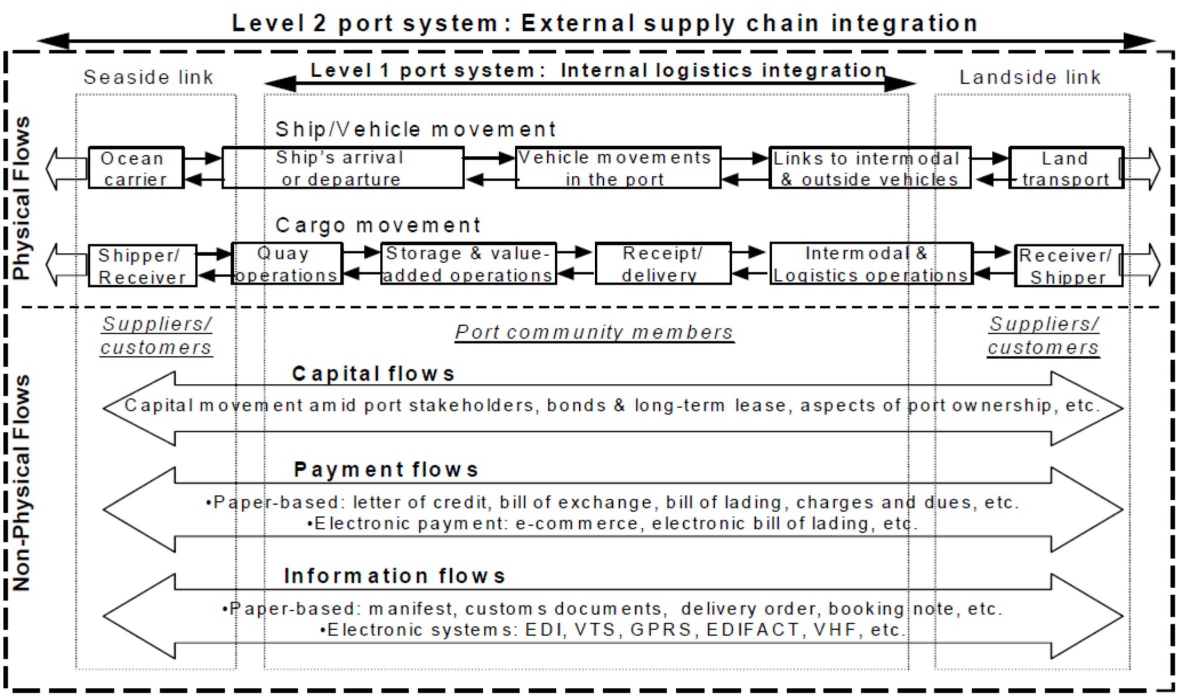

Figure 2.2 Integration of port internal and external systems
Source: UNCTAD, 2004

2.1.7 Customer-oriented practices

Ports are places where a number of port stakeholders provide products and services and create value together. The customer-oriented practices may refer to the delivery of desired results to port stakeholders who have different performance objectives. 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 authorities increasingly rely on stakeholder management practices to secure long-term relations with key stakeholders (Dooms and Verbeke, 2007). In this regard, port operators and authorities tend to provide more customer-focused services and they deem service quality as an important measure (Brooks and Pallis, 2008). Therefore, performance measurement has become an important tool in stakeholder management to investigate whether a service quality delivered by ports meets port users' needs in terms of timing, quantity and quality.

The studies on customers' satisfaction relating to services delivered by ports have actively been addressed since the mid-2000s (Marlow and Paixão Casaca, 2003, Brooks, 2006). In the context of the lean and agile ports, the speed with which the port service provider responds to and flexibly meets customers' special requests is one of the most crucial indicators (Brooks and Schellinck, 2013). In addition, a growing number of studies using the SERVQUAL on service quality in the port industry has underpinned the importance of customer-oriented practices (Ugboma *et al*., 2004, Pantouvakis *et al*., 2008).

2.1.8 Port sustainability

Port sustainability is referred to as the port's responsibilities for various port stakeholders' social and economic wellbeing. Ports have delivered huge contributions to regional and national economy and society. At the same time, however, port stakeholders such as environment agencies have strongly kept an opposite position against port development projects. In the light of this stance, ports need to pay more attention to promote long-term sustainable growth with ecological health and community integrity. Therefore, ports' roles in the 21st century era are required to enhance environment, safety and security and social and economic responsibility.

To enhance the safety and security of port and shipping industries, the issues have been brought up with national and international concerns since the 9/11 terrorist attacks, enacting a number of international conventions and legislations (i.e. the Maritime Transportation Security Act 2002 in the US and International Ship and Port Facility Security (ISPS) Code, etc.). In the long term, an appropriate safety and security scheme is a powerful role for improving port efficiency and competitiveness (Beresford *et al*., 2004, Woo *et al*., 2011a).

Recently, port stakeholders have paid significant attention to port environmental issues for minimization of environmental pollution during its operation and development. Furthermore, a number of studies emphasised the importance of the environmental management systems (EMS) in port operations (Darbra *et al*., 2005, Peris-Mora *et al*., 2005, Darbra *et al*., 2009).

Besides, port contribution to society and economy is important to fulfil corporate social responsibility (CSR). Grewal and Darlow (2007) suggest the key concerns and issues for CSR engagement include financial and time costs, risks involved with disclosure, how to engage in CSR, standardisation and value of the process. They found that CSR benefits the development of trust and a responsible reputation, important cost savings, and the importance of CSR to sustainable success within the context of Australian seaports. Studies regarding port impacts on society and economy in general are measured by employment (direct and indirect) and gross value add (direct and indirect) on port hinterlands and foreland areas (De Langen, 2002, ESPO, 2010).

2.2 PERFORMANCE MEASUREMENT

This section outlines the issues associated with performance measurement systems and measures how they have been evolved over time. This will be helpful to design such a "good" port performance measurement framework for this study.

2.2.1 Performance measurement systems

Performance measurement plays a vital role in all organizations. The function of performance measurement is to investigate how well the given activities of an organization have effectively and efficiently achieved their goals (Mentzer and Konrad, 1991) and to give guidance on how the organization can make improvements (Woo *et al*., 2011a). In other words, the performance measurement is to observe and investigate what we did in the past and what we are doing at present and how we drive the situations for the future improvement. Neely *et al*. (1995) defined "performance measurement as the process of quantifying the efficiency and effectiveness of action", "a performance measure (indicator) as a metric used to quantify the efficiency and/or effectiveness of action"; and "performance measurement systems as the set of metrics used to quantify both the efficiency and effectiveness of actions." Bourne *et al*. (2003) referred the performance measurement to "the use of a multi-dimensional set of performance measures for the planning and management of a business."

Traditionally, cost accounting (or financial) principles were a main tool to measure and evaluate organizations' performance. The problems with regard to the traditional approach have been widely documented with criticism especially for encouraging short-term decision making (Banks and Wheelwright, 1979, Hayes and Garvin, 1982, Kaplan, 1984). On top of that, using only financial measures in performance measurement is no longer sufficient to cover all related issues for the new business environment; presenting this approach is highly outdated and inadequate (Kaplan, 1984, Miller and Vollmann, 1985, Fry and Cox, 1989). As a consequence, the importance of non-financial (i.e. intangible assets) measures and the integral applications of both financial and non-financial measures for performance measurement have been continuously acclaimed (Johnson and Kaplan, 1987, Daniel and Keegan, 1989, Neely *et al*., 1995). According to Kaplan (2008), Lewis (1955) is a pioneer who introduced financial (i.e. profitability) and nonfinancial (i.e. market share, productivity, product leadership, public responsibility, personnel development, employee attitudes and balance between short and long term objectives) measures to evaluate business units' performance of General Electric, which the measures are the roots of the Balanced Scorecard (BSC). There are some outstanding balanced performance systems such as the Performance Criteria Systems (Globerson, 1985), Supportive Performance Measures Matrix (Daniel and Keegan, 1989), SMART (Strategic Measurement and Reporting Technique) Pyramid (Cross and Lynch, 1991), Results-Determinant Matrix (Fitzgerald *et al*., 1991), BSC (Kaplan and Norton, 1992) and Performance Prism (Neely and Adams, 2000). The BSC, among the performance systems, has been popularly adopted by private, public and non-profit companies around the world. Kaplan and Norton (1992) published "The Balanced Scorecard: Measures that Drive Performance" which shown a balanced set of indicators. In the BSC, financial metrics are employed as the final outcome measures, but these are supplemented with metrics from three additional perspectives-customer, internal process, and learning and growth are included in order to create long-term shareholder value. The system provides a concise overview of the organization's performance, linking all the matrix from the bottom to the top level which enables us to identify cause-and-effect relationships between the different measures.

Another key consideration in balanced performance systems is designing an appropriate performance measurement system. According to Neely *et al*. (1995), a framework for a performance measurement system can be examined at three different levels: the individual performance measures, the set of performance measures-the performance measurement system and the relationship between the performance measurement system and the organisation's given internal/external environment. In order to satisfy the requirements, the design process of the performance measurement systems needs to be integrated into the business level strategies and objectives. Neely *et al*. (2000) introduced 12 phases of the performance measurement system design as (1) what measures are required? (2) Cost-benefit analysis (3) Purpose for measurement (4) Comprehensiveness check (5) Detailed design (function) (6) Integration (function) (7) Environmental considerations (function) (8) Inter-functional testing (9) Environmental considerations (inter-functional) (10) Destructive testing (inter-functional) (11) Institutionalisation (12) Ongoing maintenance. The proposed guideline crucially takes into account who should be involved, what procedure should be adopted, suitableness and usefulness.

Therefore, well-conceived performance systems need to be able to support questions such as what to measure, how and when to measure, who to measure and how to utilise the results. The system can provide information for contributing to a firm's feedback and feedforward control system (Hon, 2005).

2.2.2 Performance measures

Performance indicators are very useful measures that quantify and simplify the critical success factors of a firm (Kaplan and Norton, 1992). Neely *et al*. (1997) argued that performance measures are a somewhat mechanistic view to represent a behavioural impact. De Langen *et al*. (2007) suggested the main functions of performance indicators (PIs) are as follows:

- *PIs provide management for organization.*
- *PIs serve to compare (the organization and other units, such as countries).*
- *PIs are used to communicate with relevant stake holders.*

It is a powerful tool for decision makers or other related stakeholders to measure and control the performance from a large amount of incomplete quantitative and qualitative data. According to Hon (2005), the performance measures in terms of their scope and dimension have differently evolved in different eras. For instance, in the 1960s, most measures were based on cost and labour contexts to enhance manufacturing performance and business competitiveness. The total productivity measures and quality management (i.e. ISO 9000) were more attractively used in the 1980s, while the multi-dimensional approach including financial and non-financial measures was introduced (i.e. BSC) in the 1990s.

As mentioned before, one of the crucial problems in traditional performance measurement systems is its narrow stance. The design and selection of proper performance indicators are crucial for every business or organization towards the measurement and ultimately improvement of its performance. Inadequately designed performance measures can result in dysfunctional behaviour (Neely *et al*., 1997). In order to tackle the problem, Kaplan and Norton (1992) suggested a balanced set of indicators that include the four perspectives of financial, customer, internal business process, and learning and growth. This somewhat mechanistic viewpoint is that the performance measures need to cover multi-dimensional organization's functions and actions, incorporating them into their strategies and goals. A framework to seek to find such a "good" performance measure constitutes the following 11 elements: (1) title (2) purpose (3) relates to (4) target (5) formula (6) frequency (7) who measures (8) source of data (9) who acts on the data (10) what do they do (11) notes and comments (Neely *et al*., 1997).

There are various types of measures in terms of their usages and characteristics. Parmenter (2015) classified four types of performance indicators (i.e. key result indicators (KRIs), result indicators (RIs), key performance indicators (KPIs) and performance indicators (PIs)). KRIs inform about how something has been done in a perspective or critical success factor. They provide the right direction but do not provide what to do to improve the results. KPIs inform what to do to increase the current and future success of the organization but also provide necessary actions which should take place and be monitored constantly. RIs and PIs lie between the KRIs and KPIs. PIs inform what to do while RIs inform that something has been done.

In view of the studies above, the performance measurement can be referred within a similar idea to "the set of metrics used to quantify both the efficiency and effectiveness of actions (Neely *et al*., 1995, p 80)" and "the use of a multi-dimensional set of performance measures for the planning and management of a business (Bourne *et al*., 2003, p. 3)". The measures have to present a clear picture of the organisational performance (Gunasekaran *et al*., 2001) and they have to be clearly classified between strategic, tactic and operational level as well as be aligned from the strategic goals, through the tactical to the operational objectives (Gunasekaran *et al.*, 2001, Benhard *et al.*, 2006, Van Horenbeek and Pintelon, 2014).

2.3 PORT PERFORMANCE MEASUREMENT

The study of performance measurement in ports and terminals has been attracting scholars and industrial practitioners in the past three decades. The study of port and terminal performance can be seen as a well-established segment in port-related academic literature in terms of the number of publications (see Pallis *et al*. (2011) and Woo *et al*. (2012)). In this section, previous studies with regard to port performance measurement will be rigorously reviewed and examined how port performance studies have been conducted over time.

2.3.1 Port efficiency and productivity measurement

Studies on port performance measurement have traditionally focused on efficiency and productivity of the port (terminal) operations. In such studies, various research scopes and approaches are used for productivity comparisons or engineering and economic optimums. However, ports are treated as isolated nodes that provide a basic ship-shore operation with an emphasis on cost and technical efficiency rather than as a crucial part of international supply chains. Accordingly, these studies fail to make a link between quayside operations and landside systems (Bichou, 2006).

UNCTAD (1976) suggested productivity and effectiveness indicators have been used by many researchers as a means of measuring port performance. Furthermore, the suggested port performance indicators are said to be divided in two broad categories, which are financial and operational. Financial aspects measure a quantitative contribution on a port's economic activity, whereas operational aspects evaluate the effectiveness of port operations such as service time, arrival time and tons per ship-hour at berth. From the initial study by UNCTAD, many researchers used the indicators for these port performance measurement.

Studies with regard to port performance measurement have been conducted for making comparisons at a single-port level (Talley, 1994, Sachish, 1996, Tongzon, 1995a) and at multi-ports level (Tongzon, 1995b, Talley, 2006). Port performance at the single-port level is generally evaluated by comparing ports' real throughputs with their optimum throughputs over time (Talley, 1988). In this scope, an engineering optimum approach is typically used to define the maximum throughputs that a port can handle under its capacity (Chadwin *et al*., 1990). However, when ports are in a competitive environment, the economic optimum approach on cargo handling and cargo competing volume, i.e. port charges, cargo handling charges, vessel turnaround time, can be applied since cost related variables are crucial determinants for port users in a port selection (Talley, 2006).

Suykens (1983) discussed the cargo-handling productivity in the Port of Antwerp and crucial indicators influencing the port productivity. The indicators that he highlighted are particularly focused on labour, physical lay-out of the port/terminal and type and extent of equipment.

Kim and Sachish (1986), who first applied total factor productivity (TFP) to the port industry (Port of Ashdod in Israel), investigated the contribution of technical change that is measured as the percentage of containerisation to TFP. They found the main contribution to TFP growth is due to containerization, economies of scale and output growth.

Tongzon and Ganesalingam (1994) investigated ASEAN port performance and efficiency and identified two broad categories of port efficiency indicators: operational efficiency and customer-oriented indicators. The former includes containers per net crane hour, twenty foot equivalent units (TEUs) per crane and TEUs per berth meter. The latter includes reliability and ship's waiting time.

Tongzon (1995a) attempted to identify determinants that influence the port's performance and efficiency. An empirical research was conducted to establish proper performance models and to define vital factors with regard to terminal operation aspects. The identified indicators are divided in two broad categories: cargo size (or throughput) and terminal efficiency. He suggested the cargo size is generally affected by the following factors: location, frequency of ship calls, port charges, economic activity and terminal efficiency. While the terminal efficiency is determined depending on container mix, work practices (delays in commencing and during stevedoring), crane efficiency, and vessel size and cargo exchange (economies of scale).

Tongzon (1995b) introduced a systematic approach to identifying similar ports based on principal component analysis since any port comparison can be appropriately validated through making comparison between similar size ports. In this study, he identified three groupings of port size in terms of their natures and roles, management policies, infrastructures and operations in order to develop a performance benchmarking programme. He used the following 6 quantitative criteria for analysis: total throughput, number of commercial ship visits, vessel size and cargo exchange, nature and role of the port, port functions and infrastructure.

Sachish (1996) used the engineering method for measuring port productivity in Israeli ports (1966-1990) by means of changes in various explanatory factors. He grouped in 6 explanatory factors (volume, labour, capital, technology, management and externalities) and investigated their contributions to total productivity, labour productivity, building productivity and equipment productivity. The finding was that the port technical changes and behavioural phenomena significantly influence the productivity.

Chadwin *et al*. (1990) classified the theoretical capacity into design capacity, preferred capacity and practical capacity. On the other hand, the empirical engineering production optimum throughput denotes the estimated maximum throughput for the port and is generally measured through comparison between the actual throughput productions of similar sized ports.

Cheon *et al*. (2010) measured impacts of port institutional reforms (ownership and corporate structure) on port efficiency (pure technical efficiency, scale efficiency and efficiency improvement due to technical progress) changes of 98 ports between 1991 and 2004. In order to this, they used 3 inputs (berth length, terminal area, container cranes (tonnage)) and 1 output (container throughput). They found ownership restructuring has contributed to total factor productivity improvements and the restructuring (i.e. private terminal operator) has induced optimized operation and cargo handling services of container terminals, especially for large ports.

Cruz *et al*. (2013) argued both operational performance indicators and physical capacity indicators are important measures for port performance measurement. They empirically investigated performance of Iberian seaports and developed a linear additive multi-criteria analysis (MCA) model with weight deployment by principal component analysis (PCA).

Meanwhile, ports have contributed themselves to the clusters of economic activities, where cargo handling, logistics and manufacturing activities take place (De Langen, 2004). De Langen (2002) defined a cluster as ‘a population of geographically concentrated and mutually related business units, associations and public (private) organizations centred around a distinctive economic specialization’. According to him, clusters provide effects of agglomeration economies such as cost reduction because of the presence of a large labour pool, the presence of a number of suppliers and customers and the presence of knowledge spill overs within the clusters. He also demonstrated cluster performance normally depends on many factors and measured in added value. In his case study on the economic impacts of a port, which analysed the effects of a port cluster and its performance in the Netherlands, inter alia, over 70,000 people in Rotterdam and over 40,000 people in Amsterdam are directly and indirectly employed respectively.

ESPO (2010) identified 6 socio-economic indicators in the pre-selection phase and reduced them to 2 indicators including direct employment and direct added value for European seaport performance measurement (ESPO, 2011).

Sánchez *et al*. (2003) used principal component analysis (PCA) in order to examine the crucial variables of waterborne transport cost in terms of port efficiency levels in Latin American ports.

Ducruet *et al*. (2007) argued that an average wage level of the transport and warehousing sector is a good indicator to measure the economic prosperity of the port area. According to their results from an empirical analysis of the US port counties, the average wage in large port counties and economically specialised port counties shows a much higher level than other port counties. In addition, the freight-related sector was a higher wage level than other sectors such as manufacturing, trade and logistics.

The comparison studies to measure port efficiency at an inter-port level have frequently used frontier models such as linear programming techniques (i.e. non-parametric approach, data envelopment analysis (DEA)) (Roll and Hayuth, 1993, Tongzon, 2001, Barros and Athanassiou, 2004, Cullinane and Wang, 2006a) and parametric (econometric) approach (i.e. stochastic frontier analysis (SFA)) (Cullinane *et al*., 2002, Cullinane *et al*., 2006). The techniques use quantitative data input (i.e. technical or physical container terminal/port specification) to yield port/terminal efficiency and productivity as well as port's economic and social contributions. The DEA approach in the port industry has firstly been attempted by Roll and Hayuth (1993). The study used three input factors (manpower, capital, cargo uniformity) of the cross-sectional data (1993) and four output factors (cargo throughput, level of service, users' satisfaction, ship calls) to measure port efficiency of 20 ports in two regions. The average efficiency was 78.2 representing region 1 with 93.4 and region 2 with 86.1, respectively.

Tongzon (2001) applied the same non-parametric approach (i.e. DEA) to provide an efficiency measurement of 4 Australian and 12 other international container ports. Two outputs and six inputs of the cross-sectional data in 1996 were applied for two DEA types (i.e. DEA-CCR and DEA-BCC). The output measures were the total number of containers loaded/unloaded in TEUs (cargo throughput) and the number of containers moved per working hour per ship (ship working rate). Whereas, the input measures were production resources of the land, labour and capital including the number of berths, the number of cranes and tugs, the number of port authority employees, the terminal area, and the amount of delay time. He found that the operational port efficiency is not solely determined by port size or scale. In addition, average CCR efficiency was 59.5 while BCC was 93.1.

Barros (2003) applied DEA-CCR and analysed the economic efficiency of Portuguese seaport authorities to test whether subsidy by government is the optimal tool for port economic prosperity using panel data of 5 Portuguese ports from 1999 to 2000. For this, he used 12 outputs including throughputs, ship calls and market share and 2 inputs: labour and book value of assets. He found that the subsidy by the Maritime Port Agency is not an effective way to improve port efficiency and effectiveness.

Barros and Athanassiou (2004) compared the efficiency of 2 Greek and 4 Portuguese ports using DEA-CCR and DEA-BCC. They used panel data during 1998-2000 for the international benchmarking procedure to find the best practice port and to compare against each other. They selected 2 inputs: labour and capital and 4 outputs: the number of vessel visits, movement of freight, cargo handled and containers handled.

Park and De (2004) used an alternative four-stage DEA-CCR and DEA-BCC to investigate the efficiency of 11 Korean seaports using cross-sectional data of the year 1999. The four-stage DEA that they used can divide the port overall efficiency into four stages including productivity (cargo throughput and number of ship calls: stage 1), profitability (revenue: stage 2), marketability (customer satisfaction: stage 3) and overall efficiency (stage 4). They used two inputs (berthing capacity and cargo handling capacity) and two outputs (cargo throughputs and number of ship calls) on the first stage. The first stage outputs (cargo throughputs and number of ship calls) were used for second stage inputs, second stage output (revenue) was used for third stage input and third stage output (customer satisfaction) was used for fourth stage input in order to measure overall port efficiency. They argued that the alternative DEA is a powerful tool to measure both the efficiency of seaports for each stage (i.e. productivity, productivity and marketability) and the overall efficiency of seaports.

Cullinane *et al*. (2004) argued that the DEA approach with cross-sectional data as inputs do not represent the complexity and the dynamic nature of port production. In order to tackle this problem, they recommended DEA-CCR and DEA-BCC windows analysis that can capture the fluctuations of container port efficiency over time. A sample under examination consisted of 25 international container ports and the data used were panel data between 1992 and 1999. They used a single output including throughput and 5 inputs that are total quay length, terminal area, number of quay cranes/yard cranes/straddle carriers, number of workers and book value of assets. The similar studies were conducted by Cullinane *et al*. (2005), focusing on the relationship between port privatisation and port efficiency, Cullinane and Wang (2006b) and Wang and Cullinane (2006).

Cullinane and Wang (2006b) measured the efficiency of container terminals in Europe using one output (throughput) and cross-sectional data of the 3 inputs (terminal length, terminal area and number of cranes) in the year 2002. The study included 69 European container terminals with annual throughput of over 10,000 TEUs.

Wang and Cullinane (2006) investigated the efficiency of 104 European container terminals with annual throughput over 10,000 TEUs in the context of global supply chain management. A cross-sectional data of 3 inputs related to land and equipment (terminal length, terminal area and equipment costs) in the year 2003 and one output (throughput) were used. The inputs and outputs they used were very similar to the work of Cullinane *et al*. (2004) and Cullinane and Wang (2006b). However, the difference was that the equipment input is represented by equipment costs rather than the number of machines. According to their results, many terminals were significantly inefficient in terms of average score (43%). In addition, large production scale terminals in the British Isles and Western Europe were identified as more efficient than terminals in Scandinavia and Eastern Europe.

Liu (1995) applied SFA to investigate the relationships between port performance and ownership structure in the British ports. He used panel data from 1983 to 1990 for 28 ports and selected turnover as a single output while labour and capital were used as input data. Ownership was represented by dummy variables and was divided into private, trust and municipal. In addition, he considered three more attributes, i.e. size, capital intensity and location. According to the results, there was no clear relationship between port performance and ownership structure.

Notteboom *et al*. (2000) measured the efficiency of container terminals using the Bayesian Stochastic Frontier model. Cross-sectional data in 1994 was used to measure the efficiency of 36 European container terminals and 4 Asian container terminals. Container throughput was used for output, while input was 3 factors of production resources, i.e. docks, surface and cranes. They concluded that the degree of efficiency of north European container terminals is slightly higher than southern terminals. In addition, terminals located in hub ports were associated with higher efficiency while those in feeder ports were found to be less efficient.

Cullinane and Song (2003) investigated productive efficiency levels of Korean and UK ports using SFA. They used unbalanced panel data from 1978 to1996 for empirical investigation of 2 Korean ports and 3 UK ports. The single output, turnover, and 2 labour inputs and 2 capital inputs were selected for the study. They concluded that there is a higher degree of correlation between the productive efficiency and the degree of private sector involvement. Interestingly, the result indicates difference from the ones found by Liu (1995).

Cullinane *et al*. (2006) investigated the technical efficiency of container ports using DEA and SFA models. 57 samples of container ports were assessed using 5 inputs (terminal quay length, terminal area, number of quayside gantries, yard gantries and straddle carriers) and one output (container throughput in TEUs). They found similar technical efficiency ranking of the ports from two methodologies. In addition, a higher efficiency was associated with port scale, a higher private-sector involvement and transhipment ports.

Lin and Tseng (2007) applied five models of DEA (CCR, BCC, SCE, D&G and A&P) and acquired a variety of complementary information from the different models to evaluate the operational efficiency and efficiency trends of major container ports in the Asia-Pacific. 10 samples of container ports were assessed using panel data (1998-2001) of 2 outputs (number of vessel arrivals at port, loading/unloading volumes of containers) and 4 inputs (area of container base, number of gantry cranes, length of container terminals, number of deep-water piers).

Hung *et al*. (2010) investigated the technical efficiency (pure technical efficiency and scale efficiency), the scale efficiency targets, and the variability of DEA efficiency estimates of 31 Asian container ports. In order for this, they used 4 inputs (terminal area, ship-shore container gantry cranes, number of container berths and terminal length) and 1 output (container throughput). Their finding can be summarised as (1) the technical inefficiency of Asian container ports are due to pure technical inefficiencies rather than scale inefficiencies, caused by inefficient management practices (2) in terms of returns to scale (IRS), 71% of the Asian container ports need to consider their expansion (3) East Asian container ports are more efficient than ports in other Asian areas (i.e. Northeast Asia and Southeast Asia).

The most recent attempt in applying DEA to measure the efficiency of ports/terminals was made by Wu and Goh (2010). They investigated the efficiency of port operations in emerging markets (BRIC and the Next-11) with the more advanced markets (G7) using DEA and A&P (Andersen and Pertersen) models. Unlike other DEA or SFA studies, they applied A&P to differentiate the relative strengths and weaknesses of already efficient ports, adjusting the discriminatory power of DEA, in ranking the relative port efficiency. The efficiency of port operations was assessed using 3 inputs (terminal area, total quay length and number of pieces of equipment) and one output (number of containers). They found that the efficiency level of ports in emerging markets including Shanghai in China, Chittagong in Bangladesh, and Santos in Brazil exceeds those in advanced markets.

DEA has become as one of the most popular approaches to assessing port/terminal efficiency (Cullinane and Wang, 2010). However, potential problem associated with the number of inputs/outputs in relation to sample size has been proposed (Panayides *et al*., 2009). According to them, in terms of the number of inputs/outputs and sample size, the efficiency results can be biased. Furthermore, previous studies generally use cargo throughput as an output, however, the single output may fail to reflect the overall efficiency of port/terminal in changing market conditions. To this end, there is a need for a new port performance measurement tool to deal with different types of inputs and outputs.

The studies with regard to port efficiency and productivity are further summarised in Table 2.2-Table 2.3.

Table 2.2 Port efficiency and productivity measurement studies (1)

Author (date)	Findings	Collected indicators
UNCTAD (1976)	Suggestion of a set of indicators for port performance measurement	Financial Operational
Suykens (1983)	Identification of crucial indicators influenced in port productivity	Labour, physical lay-out, equipment, etc.
Kim and Sachish (1986)	First application of total factor productivity (TFP) to the port industry	Containerization, economies of scale and output growth
Tongzon and Ganesalingam (1994)	Investigation of ASEAN port performance and efficiency	Operational Customer-oriented
Tongzon (1995a)	Establishing proper performance models and identification of determinants that influence the port's performance and efficiency	Cargo size (or throughput) Terminal efficiency
Tongzon (1995b)	Introduction of a systematic approach for port performance measurement	Throughput, vessel calls, vessel size and cargo exchange, infrastructure, nature and role of the port, port functions
Sachish (1996)	Engineering method for measuring productivity (total productivity, labour productivity, building productivity and equipment productivity)	Volume, labour, technology, capital, management and externalities
Talley (1988, 1994, 2006)	Introduction of methodologies to measure the economic optimums and engineering optimums	Technical efficiency, cost efficiency, effectiveness Throughput Physical capacity
De Langen (2002, 2004)	The benefit of cluster and investigation of cluster performance	Value-added (direct and indirect employment)
Sánchez *et al*. (2003)	Identification of relationship between cost variables and port efficiency using principal PCA	Port efficiency factors (time inefficiency factor, productivity factor, stay per vessel factor), transport costs factor
Ducruet *et al*. (2007)	Investigation of port economic prosperity in the USA.	Average wage level
Cruz *et al*. (2013)	Identification of logistics resources as important indicators in port performance and development of a MCA with weight deployment by PCA.	Operational Physical

Table 2.3 Port efficiency and productivity measurement studies (2)

Author (date)	Method and Data	DMUs	Collected indicators
Roll and Hayuth (1993)	DEA Cross-sectional data (1993)	20 ports	Inputs (manpower, capital, cargo uniformity) Outputs (throughput, service level, users' satisfaction, ship calls)
Tongzon (2001)	DEA-CCR and DEA-BCC Cross-sectional data (1996)	4 Australian 12 international container ports	Inputs (berths/cranes/employees /tugs in number, the terminal area and delay time) Outputs (cargo throughput, ship working rate)
Barros (2003)	DEA-CCR Panel data(1999-2000)	5 Portuguese ports	Inputs (labour and book value of assets) 12 outputs (throughputs, ship calls, market share, etc.)
Barros and Athanassiou (2004)	DEA-CCR and DEA-BCC Panel data (1998-2000)	2 Greek 4 Portuguese ports	Inputs (labour and capital) Outputs (number of ships, movement of freight, cargo handled, containers handled)
Park and De (2004)	Four-stage DEA-CCR and DEA-BCC Cross-sectional data (1999)	11 Korean ports	Inputs (cargo throughput, number of ship calls, revenue, customer satisfaction) Outputs (productivity, profitability, marketability, overall efficiency)
Cullinane *et al*. (2004)	DEA-CCR and DEA-BCC windows analysis Panel data (1992-1999)	25 international container ports	Inputs (quay length, terminal area, number of quay cranes/yard cranes/straddle carriers, number of workers and book value of assets) Outputs (throughput)
Cullinane and Wang (2006b)	DEA-CCR and DEA-BCC Cross-sectional data (2002)	69 European container terminals	Inputs (terminal length, terminal area and number of machine) Outputs (throughput)
Wang and Cullinane (2006)	DEA-CCR and DEA-BCC Cross-sectional data (2003)	104 European container terminals	Inputs (terminal length, terminal area and equipment costs) Outputs (throughput)
Liu (1995)	SFA Panel data (1983-1990)	28 UK ports	Inputs (labour and capital) Outputs (turnover)
Notteboom *et al*. (2000)	Bayesian Stochastic Frontier model Cross-sectional data (1994)	36 European terminals 4 Asian terminals	Inputs (docks, surface and cranes) Outputs (throughput)

Table 2.3. Continued

Author (date)	Method and Data	DMUs	Collected indicators
Cullinane and Song (2003)	SFA Unbalanced panel data (1978-1996)	2 Korean Ports 3 UK ports	Inputs (2 labour inputs and 2 capital inputs) Outputs (turnover)
Cullinane *et al*. (2006)	SFA Cross-sectional data (2001)	57 international ports	Inputs (terminal quay length, terminal area, number of quayside gantries, yard gantries and straddle carriers) Outputs (throughput)
Lin and Tseng (2007)	DEA (CCR, BCC, SCE, D&G and A&P) Panel data (1998-2001)	10 ports in the Asia-Pacific region	4 inputs (area of container base, number of gantry cranes, length of container terminals, number of deep-water piers) and 2 outputs (number of vessel arrivals at port, loading/unloading volumes of containers)
Hung *et al* (2010)	SFA Cross-sectional data (2003)	31 Asian container ports	4 inputs (terminal area, ship-shore container gantry cranes, number of container berths and terminal length) and 1 output (container throughput)
Wu and Goh (2010)	DEA (CCR, BCC A&P) Cross-sectional data (2005)	15 (BRIC and the Next-11) 7 (G7)	3 inputs (terminal area, total quay length and number of pieces of equipment) and one output (number of containers)

2.3.2 Port effectiveness measurement

Compared to port efficiency and productivity studies, research focusing on port effectiveness was lacking until the mid-2000s. In this regard, Schellinck and Brooks (2014) defined “efficiency is *doing things right* while effectiveness is *doing the right things*”. In this context, the notion of ‘the right things’ refers to the delivery of the desired results to port stakeholders who have different performance objectives. The effectiveness for port users, for example, denotes their satisfaction relating to services delivered by ports. Hence, port effectiveness should be measured by taking into account different port stakeholders’ perspectives (Brooks, 2006). Furthermore, the effectiveness-oriented port operators and authorities (PAs) tend to provide more customer-focused services and they deem service quality as an important measure (Brooks and Pallis, 2008).

The study conducted by Roll and Hayuth (1993) was one of the first investigations in port performance measurement into effectiveness research which included effectiveness performance indicators such as users' satisfaction for their DEA output. Tongzon and Ganesalingam (1994) used service reliability and vessel waiting time to measure customer-oriented services.

Brooks (2006) investigated suitable constructs and measures to assess port devolution program performance. She found that studies on port performance measurement have more narrowly focused on measuring port/terminal efficiency but have little studied on whether ports are effective or meet port stakeholders' needs. According to her contention, both internal measures (i.e. port/terminal financial and non-financial and operational measures) and external measures (i.e. customer perspectives) need to be used for port performance measurement. Especially, user satisfaction is one of the most important indicators to identify customers' needs. However, amongst the 42 ports in 10 countries only a few ports use the service quality indicators for performance measures.

Brooks and Pallis (2008) developed a conceptual port reform performance framework integrating various relevant port performance indicators under existing port governance models. They argued both efficiency and effectiveness measures need to be used for measuring port performance because these indicators are different but related. For instance, a terminal operator can improve cargo handling efficiency either by an increase in the number of quay cranes or an increase in the movement of quay cranes, which accordingly leads to vessel turnaround time reduction. It results in a high customer satisfaction due to reduced cargo loading/unloading operation from vessel to shore (and vice versa). Furthermore, they investigated industrial practices that port authorities in five countries (Italy, Canada, Korea, USA and the UK) used for their performance measurement.

The European Sea Ports Organization recently conducted a project named "Port Performance Indicators: Selection and Measurement (PPRISM)" (see PPRISM WP 1, 2010; WP 2, 2011) and identified the relevant PPIs in five categories, i.e. environmental performance, supply chain performance and connectivity, throughput and market structure, socio-economic impacts and governance. The project aims to create a standard toolkit and dashboard of European ports with respect to the five categories.

Brooks *et al*. (2011) investigated customer needs of three port user groups (i.e. carriers, cargo interests and suppliers of services) and proposed a performance measurement framework. This was conducted from different customers' perspectives.

The upgraded research was conducted by Schellinck and Brooks (2014) and examined the importance-performance (I-P) gap between real performance and users' expectation on each measure to address port users' requirements. Based on results, this study suggested crucial determinants perceived by port users on service satisfaction, competiveness and effectiveness.

Further study was conducted by Brooks and Schellinck (2013); they examined effectiveness issues of supply chain participants (beneficial cargo owners, shipping lines and supply chain partners) in Canada and the U.S. and measured port performance using I-P gap analysis. The big I-P gap denotes inefficiency or inadequacy and the ones needing to be improved in order to meet users' needs or expectations. Based on the results, decision makers can identify their strengths and weaknesses and can prioritise their investment strategies to improve port performance. This study is similar to their previous studies (Schellinck and Brooks, 2014) in terms of methodology and measures used. However, this study analysed the port effectiveness issues with a bigger sample size from different port users, consequently the results are more representative. The relevant indicators are collected and summarised in Table 2.4.

Table 2.4 Port effectiveness measurement studies

Author (date)	Findings	Collected indicators
Roll and Hayuth (1993)	One of the first investigations in port performance measurement into effectiveness research	Customer satisfaction (part of the output on DEA model)
Tongzon and Ganesalingam (1994)	Investigation of the customer-oriented measures as one of their efficiency measurement categories	Customer-oriented measures Reliability Vessel waiting time.
Brooks (2006)	Suggestion of a set of indicators (efficiency and effectiveness) and investigation of industrial practices on the nature and prevalence of the port performance measures in ports	10 financial indicators 6 vessel operations indicators 13 container operations indicators 9 other internal and external indicators
Brooks and Pallis (2008)	Development of port reform performance conceptual framework integrating various relevant port performance indicators under existing port governance models	14 financial indicators 7 vessel operations indicators 13 container operations indicators 10 other internal and external indicators
ESPO (PPRISM WP 1, 2010; WP 2, 2011)	Identification of the port performance indicators within 5 different fields to monitor contributions of the European port sector to the society, the environment and the economy	2 market trends and structure indicators 2 socio-economic indicators 4 environmental indicators 3 logistic chain and operational indicators 3 governance indicators
Brooks *et al.* (2011)	Investigation of the crucial criteria on perception of port effectiveness performance in terms of port users' perspectives	12 general criteria (common) 13 criteria to SC partners 16 criteria to shipping line 9 criteria to cargo interests
Schellinck and Brooks (2014)	Identifying and prioritizing performance improving investment based on I-P gap analysis and NPE scores	12 general evaluation criteria 9 evaluation criteria to cargo interests
Brooks and Schellinck (2013)	Guidance for port managers on performance-improving investment decisions by focusing on I-P gap analysis and NPE scores	6 general criteria (common) 13 criteria to shipping line 9 criteria to SC partners 5 criteria to cargo interests

2.3.3 Supply chain management approach

The studies of port performance measurement have been conducted by focusing on port centric logistics as moderators and their integrations in supply chains (Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004). A number of papers acknowledged the significance of the roles of ports/terminals in the context of supply chains and suggested empirically significant results (Carbone and Martino, 2003, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013). This approach is based on the viewpoint that the port is one of the most important logistics nodes but also a transport solution provider in supply chains (Marlow and Paixão Casaca, 2003). In addition, ports should be integrated with other logistics players in supply chains (Carbone and Martino, 2003, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al.*, 2013).

Carbone and Martino (2003) conducted a case study of the port of Le Havre in Renault's (French automotive company) supply chain, particularly its business process. They argued that the port can become an integrated logistics platform in supply chains by means of value creation to customers and accomplishment of customers' requirements (i.e. reliability, punctuality, frequency, availability of information and security). According to them, the relationship between focal firms, customer satisfaction, information and communication technologies (ICTs) and performance indicators are important roles of the terminal operators to secure port supply chain integration.

Marlow and Paixão Casaca (2003) are pioneers who first applied the concept of 'leanness' and 'agility' in the context of port performance measurement and argued ports need to be proactive rather than reactive in supply chains. They introduced lean port networks both between seaports and between seaports and inland ports. The collaborative attitudes and information sharing between players in the networks are crucial kernels. Thus, the efficient multimodal systems are an antecedent condition to become an agile port. They also proposed a two-stage implementation process with a two-tier performance measure in order to develop an agile port. In their framework, both human elements and intelligent application of knowledge are more important factors than technology and capital.

Bichou and Gray (2004) suggested a conceptual port performance measurement framework in the context of logistics and supply chain management. They explained that port is a key to link to various logistics, trade and supply flows and channels in an integrated channel management system. The integrated port management system encompasses internal logistics integration and external SCM integration. The former is linked to operational management for measuring operational productivity (namely efficiency), while the latter is linked to strategic management for measuring values to the customer (namely effectiveness). The port management system is composed of port service providers and users who are regarded as sub-members of the port management system, not part of the external world. In this regard, they argued that port performance measurement should be conducted by linking port/terminal operations with landside logistics systems.

Bichou (2006) conducted a critical review on port performance measurement and proposed a conceptual benchmarking model in the context of SCM. He emphasized that the port performance literature failed to link quayside operations with landside systems, which underlines a major gap between most performance studies and real business practices. In order to overcome the research gap, he outlined and illustrated the basis and benefits of the logistics and supply chain approach to port performance benchmarking.

De Langen *et al*. (2007) suggested the necessity of including port-related employment and value-added services as port performance indicators (PPIs) and distinguished them into three different but complementary types of ‘port products’: *Cargo transfer product*, *Logistics product and Port manufacturing product*. Cargo transfer product represents the backbone role of a port, e.g. terminal handling, towage, pilotage, customs and other activities regarding transfer or transit of goods from vessels to other transport modes (or vice versa); logistics product refers to the storage and value added logistics activities, e.g. repacking, labelling, quality inspection; and port manufacturing product measures goods produced by manufacturing facilities in a port area.

Song and Panayides (2008) conceptualized measures for port/terminal integration in the supply chain and empirically tested the impact of port/terminal integration on port competitiveness, applying multiple regression analysis. They identified six parameters conceptualising port integration from relevant literature: use of technology for data sharing, relationships with shipping lines, value-added services, relationships with inland transport providers, transport mode integration and channel integration practices and performance. These parameters were used to investigate correlations with port competitive measures (i.e. cost, quality, reliability, responsiveness and customization). They found positive relationships between value-added services and prices, value-added services and customization, relationship with shipping line and reliability and responsiveness, use of technology for data sharing and quality.

Panayides and Song (2009) defined measures of terminal supply chain integration (TESCI) in global supply chains and developed a model to measure TESCI using confirmatory factor analysis. The measures include information and communication system, value-added services, multimodal systems and operations and supply chain integration practices.

Woo *et al*. (2011a) investigated port evolutionary changes currently taking place in the port industry and developed a port performance framework that reflects these changes. They identified critical indicators for the framework through analysing literature review and confirmed the validity and reliability of the framework using confirmatory factor analysis (CFA). Like Bichou (2006) and Brooks (2006), they also emphasized the importance of the external measures such as service quality, logistical elements including value-add service in additions to the internal measures for measuring both efficiency and effectiveness of port performance. They found 8 aspects of port evolutionary changes and these aspects were then aggregated into 3 groups with regard to external perspectives, internal operational perspectives and logistical perspectives.

Woo *et al*. (2013) investigated the effects of integration of seaports into supply chains on port performance. They used a structural equation model (SEM) to measure the relationship between supply chain integration of seaports and port performance. The indicators were identified from the supply chain and seaport operations, port performance and management literature. An empirical investigation for Korean ports, using data from terminal operators, shipping companies and freight forwarding companies was conducted. According to the results, they found a clear positive relationship between supply chain integration of seaports and both effectiveness and efficiency of seaport performance.

Table 2.5 summarises the performance measurement studies relating to SCM.

Table 2.5 Performance measurement studies adopted SCM concept

Author (date)	Findings	Collected indicators
Carbone and De Martin (2003)	Port operators should contribute value creation to customers and satisfy customer requirements for their competitiveness	Relationship between port operators and focal firm Supplied service to satisfy customer requirements Information and communication technologies (ICTs) Performance indicators
Marlow and Paixão (2003)	Framework for developing lean port and agile port performance measurement	16 Multimodal process 14 Port discharge process 11 Ship process 5 Road infrastructure process
Bichou and Gray (2004)	Framework of port performance in terms of conceptualizing ports from a logistics and SCM approach	Internal logistics integration External SCM integration
Bichou (2007)	Port performance benchmarking in the light of supply chain management (SCM) considerations	Internal logistics integration External SCM integration
Largen *et al.* (2007)	Categorization of PPIs in terms of port product that is different but complementary	Cargo transfer product Logistics product Port manufacturing product
Song and Panayides (2008)	Conceptualization of measures for port/terminal integration in the supply chain and implication of port/terminal integration on port competitiveness	Use of technology for data sharing Relationship with shipping lines Value-added services Integration of transport modes Relationship with inland transport providers Channel integration practices and performance
Panayides and Song (2009)	Terminal supply chain integration (TESCI) in global supply chains and validation of the defined measure to infer implications for maritime logistics	Information and communication system Value-added services Multimodal systems and operations Supply chain integration practices
Woo *et al.* (2011a)	Investigation of port evolutionary changes and development of a port performance framework that reflects these changes	External (5 Service quality, 3 Customer, orientation, 4 Service price) Internal (8 Efficient operation, 3 Safety and security) Logistics (2 Connectivity, 2 Value-added service, Port cooperation and networking)
Woo *et al*. (2013)	The integration of seaports into supply chains has a positive impact on both the effectiveness and the efficiency of seaport performance	Port supply chain orientation (4 organizational relationships, 3 human resources, 4 top management support) Port supply chain integration (4 information and communication system, 3 long-term relationships, 4 valued-added logistics services, 4 inter-modal transport services, 4 supply chain integration practices) Port performance (effectiveness: 5 service quality, 3 customer orientation, 3 service price; efficiency: 4 sea and land operations, 3 cargo operation)

2.3.4 Benchmarking (Best practices)

Benchmarking by reference to the successful practices and outcomes of other ports/terminals is a key approach in a wide range of port performance measurement contexts. Benchmarking (or best practice) has been considered as the best way to monitor a firm's own performance and to learn from the competitors (Cassell *et al*., 2001). The principles or beliefs of benchmarking that can lead to superior performance on a continuous basis encouraged companies to benchmark on the best performer in the industry. The term benchmarking can be traced back to the late 1970s, when the Xerox Corporation, a pioneer of benchmarking in the US, compared its manufacturing costs with those of domestic and foreign competitors (Camp, 1992). The benchmarking philosophy, indeed, has been adapted from the Japanese word *dantotsu* which means striving to be the best of the best (Camp, 1992). Benchmarking is not just comparison, emulating or stealing but a process of searching out the basis for creative breakthroughs (Elmuti and Kathawala, 1997). The definition of benchmarking is defined with various manners but the core concept is essentially expressed within a similar idea with the term of "best practices" for organisational continuous performance improvement (Camp, 1992, Partovi, 1994, Elmuti and Kathawala, 1997).

Elmuti and Kathawala (1997, p. 229) defined benchmarking as:
Benchmarking is the process of identifying the highest standards of excellence for products, services, or processes, and then making the improvements necessary to reach those standards - *commonly called "best practices".*

Partovi (1994, p. 25) described benchmarking as:
The research for the best industry practices which will lead to exceptional performance through the implementation of these best practices.

Camp (1989)'s study '*the search for the best practices that lead to superior performance'* and Camp (1992, p. 3) denoted:
Benchmarking is the continuous process of measuring products, services and practices against the company's toughest competitors or those companies renowned as industry leaders.

However, the performance improvement or business excellence cannot be achieved through simply imposing "best practices", instead the "best practices" should be incorporated into their own style. Benchmarking types have been defined in various manners but they are generally classified in terms of the following questions: 1) what is compared and 2) what the comparison is being made against (McNair and Leibfried, 1992, Bhutta and Huq, 1999). Bhutta and Huq

(1999) demonstrated three different types of benchmarking with regard to the first question: performance benchmarking, process benchmarking and strategic benchmarking.

- Performance benchmarking is the comparison of performance measures for the purpose of determining how good our company is as compared to others.
- Process benchmarking is the comparison of methods and processes in an effort to improve the processes in our own company.
- Strategic benchmarking is undertaken when an attempt is being made to change the strategic direction of the company and the comparison with one's competition in terms of strategy is made.

For the second question, a number of studies classified benchmarking into four types: internal benchmarking, external or competitive benchmarking, functional or industry benchmarking and process or generic benchmarking (McNair and Leibfried, 1992, Lema and Price, 1995, Elmuti and Kathawala, 1997, Bhutta and Huq, 1999). Even though the definitions of each types are slightly different, they may agree on the following demonstrations by Bhutta and Huq (1999).

- Internal benchmarking is comparing the performance of similar business units or business process within an organisation (i.e. between departments/divisions) in order to determine the internal performance standards.
- Competitive benchmarking is comparing the performance of an organisation with direct competitors in which comparisons are mostly targeted on specific products, practices or services, work process and administrative methods.
- Functional benchmarking is comparing the performance of an organisation with an industry leader or the best functional operations of certain organisations; the benchmarking studies that concentrate on a specific function in two or more organisations.
- Generic benchmarking is an application of the best work process benchmarking that compares the similar procedures and functions in two or more dissimilar organisations.

As seen in Table 2.6, the combination of the performance benchmarking and competitive benchmarking looks more relevant than others and hence can bring better outcomes in this study. This justifies a logical approach why benchmarking approach between the relevant peer groups of ports has been applied for port performance measurement.

Table 2.6 Types of benchmarking and their mutual relevance

	Internal	Competitive	Functional	Generic
Performance	M	**H**	M	L
Process	M	L	H	H
Strategic	L	H	L	L
Relevance/value:		High: H	Medium: M	Low: L

Source: Adapted from McNair and Leibfried (1992)

2.3.5 Summary and shortcomings of previous studies

The previous studies on port performance measurement can be summarised in terms of their research scopes, methods, and layer of study areas. The early era of the port performance studies mostly focused on investigating port/terminal efficiency and productivity for internal and external benchmarking, particularly at a single-port level (Talley, 1988, Talley, 1994, Talley, 2006), at a country level (Liu, 1995, Sachish, 1996, Barros, 2003, Park and De, 2004) and international level (Roll and Hayuth, 1993, Tongzon and Ganesalingam, 1994, Tongzon, 1995a, Tongzon, 1995b, Barros and Athanassiou, 2004, Cullinane and Wang, 2006a). These studies, however, are more focused on the sea side operations than the landside operations and failed to link quayside operations with landside systems (Bichou, 2006).

Over time ports' activities and strategies have continuously been adapted to an evolutionary changing environment in order to survive themselves in a highly competitive environment as well as achieve competitive advantages. The port evolutionary changes were introduced by previous studies (Notteboom and Winkelmans, 2001, Carbone and Martino, 2003, Woo *et al*., 2011a) and some of them suggested the eye-catching issues arising in the port industry (Beresford *et al*., 2004, ESPO, 2010, ESPO, 2011, Woo *et al*., 2011a). For instance, the issues such as supply chain integration, lean/agile perspectives, customer-oriented practices, and value-added activities have been addressed (Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, Bichou, 2006, De Langen *et al*., 2007, Brooks and Pallis, 2008, Song and Panayides, 2008, Panayides and Song, 2009, Brooks and Schellinck, 2013, Schellinck and Brooks, 2014, Woo *et al*., 2013).

In the light of the applied methodologies, the literature which attempts to identify performance indicators (Tongzon, 1995a, Brooks, 2006); to develop an equation model (Talley, 1988, Talley, 1994, Talley, 2006); to apply parametric or econometric approaches such as a cost or a production frontier function (Gonzalez and Trujillo, 2008) and SFA (Cullinane *et al*., 2002, Cullinane *et al*., 2006); to apply non-parametric approach such as DEA (Roll and Hayuth, 1993, Tongzon, 2001, Barros and Athanassiou, 2004, Cullinane and Wang, 2006a); to measure port evolutionary changes using structural equation modelling (SEM) (Woo *et al*., 2011a, Woo *et al*., 2013); and to investigate perception difference between ports and port users on criteria using importance-performance gap (Brooks and Schellinck, 2013, Schellinck and Brooks, 2014) has been undertaken.

However, the literature reviewed above has tended to focus on limited parts or specific areas of ports and not as a whole. These fragmented approaches failed to take into account all related issues encompassing ports, indicating that further studies are needed to overcome the shortcomings of previous studies. They are summarised as follows:

Firstly, most of the studies that used performance metrics and index failed to deal with both quantitative data and qualitative data. For example, the studies based on DEA or SFA approaches mostly used only quantitative indicators as the input data (Cullinane *et al*., 2004, Cullinane *et al*., 2006, Wang and Cullinane, 2006), while most studies dealing with effectiveness indicators employed only qualitative data (Brooks and Schellinck, 2013, Schellinck and Brooks, 2014). In complex port/terminal systems, decisions are usually made on multiple uncertain attributes. Thus, port performance measurement should involve multiple indicators of both quantitative and qualitative nature which is called multiple criteria decision making (MCDM) problems.

Secondly, the studies failed to deal with the inherent uncertainties in data. The problems relating to uncertainties in data are unavoidable in port/terminal operational contexts (Yeo *et al*., 2014). The decision problems in port performance measurement involve multiple PPIs of both a quantitative and qualitative nature in MCDM, which makes it difficult to fully take into account all PPIs in question in one framework. Consequently, this study needs to deal with the inherent data uncertainties in port performance measurement contexts.

Thirdly, there were few previous studies on interdependencies among the PPIs on port performance. Previous studies categorized the indicators depending on the characteristics of decision criteria and then only suggested priorities of the indicators without thoroughly considering interrelationships among them. Given complex port activities and operations, decision makers may require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improve port/terminal performance. Therefore, it needs to identify interdependencies among the PPIs.

Lastly, studies on PPIs improvement and maintenance strategies are lacking. Previous research mostly focused on defining the most important indicators or their combination for ensuring port efficiency and selecting the competitive port as well as suggesting benchmark performance between the terminals/ports. Hence, it needs to develop a sound framework for prioritising port performance improvement strategies under the port's own dynamic business environment.

Figure 2.3 details the designed analytical logic in this study that follows the related questions of 'what to measure', 'how to measure' and 'how to control and improve' container port performance in order to fill the research gaps.

Figure 2.4 details the conceptual framework for port performance measurement systems. This study addresses the development of a systematic approach to address the multi-stakeholder dimension in port performance measurement. This was achieved by integrating a multi-stakeholder dimension in a port performance measurement framework which takes into account the corresponding PPIs. The multi-stakeholder dimensional approach including financial and non-financial measures is adopted to represent port relevant issues. In addition, the existing problems in measuring port performance are controlled by various quantitative techniques. The port performance measurement systems represent an effective performance measurement tool and offer a diagnostic instrument based on the use of a multi-dimensional set of performance measures to ports/terminals to satisfy the port stakeholders.

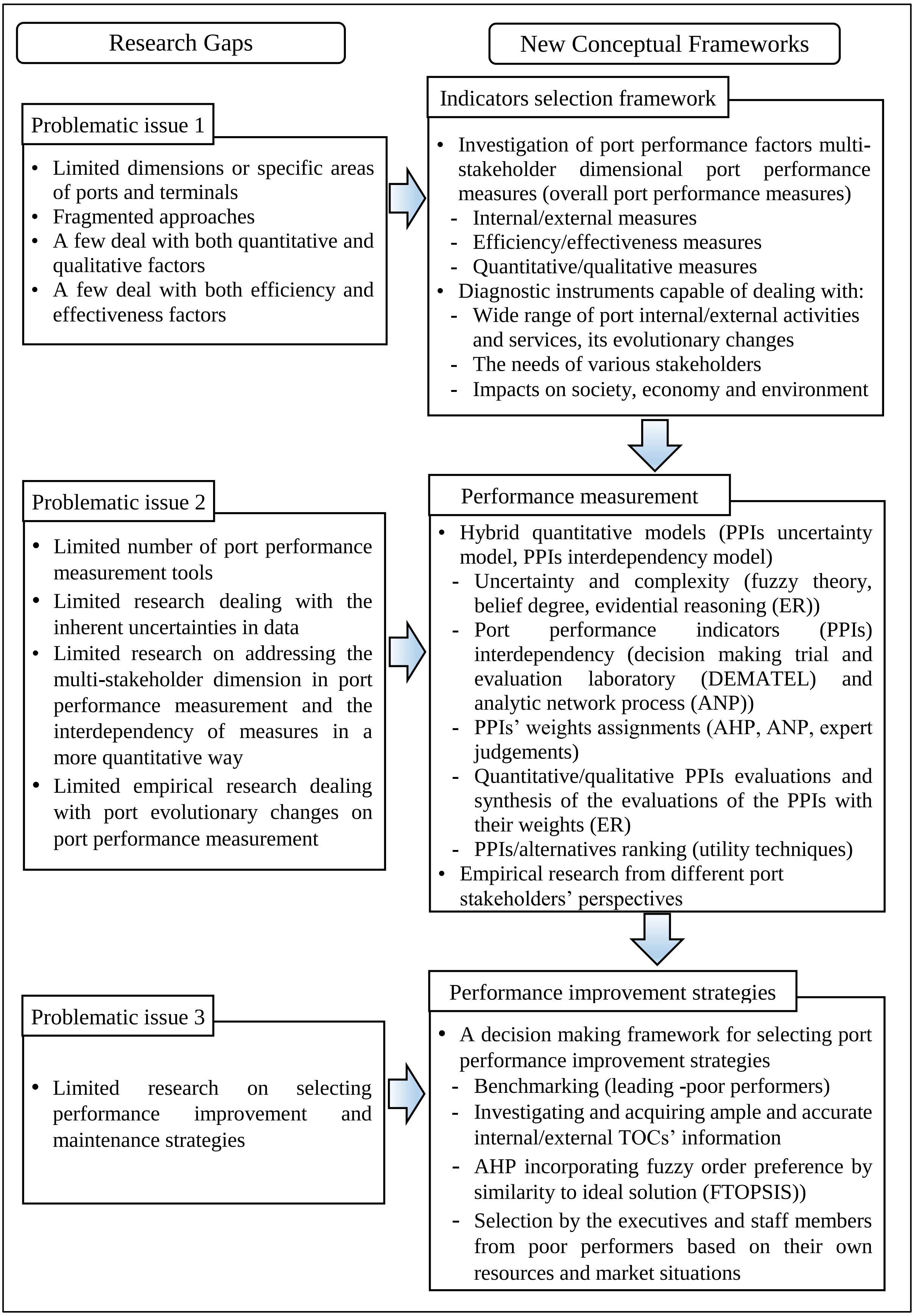

Figure 2.3 The designed analytical logic in this study

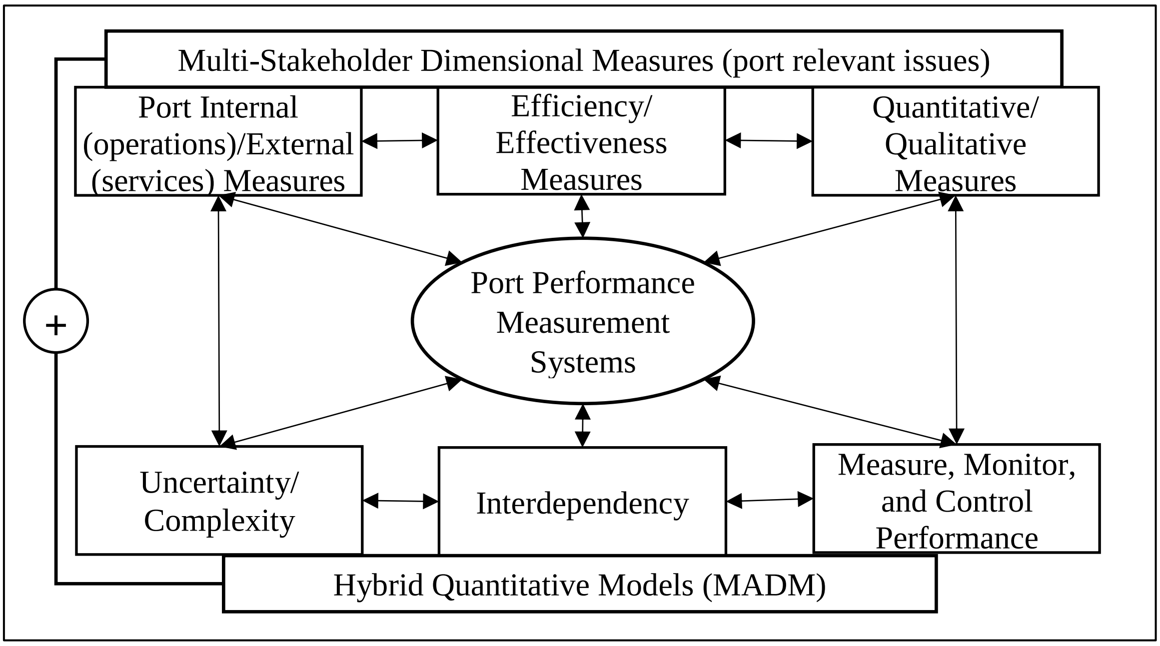

Figure 2.4 Conceptual diagram for port performance measurement systems

CHAPTER 3 RESEARCH METHODOLOGY

This chapter describes how the research will be conducted in order to fill the research gap identified from previous studies. Thus, this chapter makes a link between the previous chapter 2 (literature review) and the following chapters 4 (port performance indicators selection), 5-6 (port performance measurement) and 7 (performance improvement strategy). This chapter mainly deals with the whole issue of the research framework, including research strategy and design, research methods, data collection and analysis techniques.

3.1 RESEARCH STRATEGY AND DESIGN

A research strategy or design means a general research plan or method to respond to research questions and to seek the validity of the research (Lewis *et al.*, 2007, Bryman and Bell, 2011). The methodological issues classified by Woo *et al.* (2011b), Sachan and Datta (2005) and Mentzer and Kahn (1995) are shown in Table 3.1. Woo *et al.* (2011b) classified the research strategy in seaport research into two categories: analytical approach (i.e. conceptual, mathematical, and statistical) and empirical approach (i.e. experimental, statistical, case study). On top of that, they classified the research method into 9 categories: survey, interview, economic modelling, mathematical modelling, simulation, case study, conceptual work, archival analysis and content analysis. The data analysis techniques used in seaport research are classified into 17 categories: descriptive statistics, regression, data envelopment analysis, logit model, stochastic frontier analysis, input-output analysis, multi-criteria decision making, factor analysis, analysis of variance (ANOVA), shift-share analysis, error correction model, structural equation modelling, total factor productivity, cluster analysis, t-test, correlation, time series analysis.

Sachan and Datta (2005) divided the research design in logistics and SCM research into 5 categoris: empirical quantitative, empirical qualitative, desk research qualitative, desk research quantitative and empirical triangulation. The research method used in logistics and SCM research is classified into 7 catagories: survey, simulation, interviews, math modelling, case studies, conceptual model and others (literature review, insights from the industry, etc.). The data analysis techniques used in logistics and SCM research are classified into 13 categories: descriptive analysis, regression, factor analysis, discriminant analysis, correlation analysis, cluster analysis, conjoint, multiple analysis of variance (MANOVA), path analysis, DEA, logit model, SEM, other (e.g. case study).

Table 3.1 Research strategies, methods and data analysis techniques used in port research

Reference	Research strategy	Research method	Data analysis technique
Woo *et al.* (2011b) 'Sea port research'	*Analytical approach* Conceptual Mathematical Statistical *Empirical approach* Experimental Statistical Case studies	Survey Interview Economic modelling Math modelling Simulation Case study Conceptual work Archival analysis Content analysis	Descriptive statistics Regression Data envelopment analysis (DEA) Logit model Stochastic frontier analysis Input-output analysis Multi-criteria decision making (MCDM) Factor analysis Analysis of variance (ANOVA) Shift-share analysis Error correction model Structural equation modelling Total factor productivity Cluster analysis *T*-test Correlation Time series analysis
Sachan and Datta (2005) 'Logistics and SCM research'	Empirical quantitative Empirical qualitative Empirical triangulation Desk quantitative Desk qualitative	Survey Simulation Interviews Math model Case study Conceptual models Others	Descriptive analysis Regression Factor analysis Discriminant analysis Correlation analysis Cluster analysis Conjoint Multiple analysis of variance (MANOVA) Path analysis DEA Logit model SEM Other (e.g. case study)
Mentzer and Kahn (1995) 'Logistics research'	Normative literature/ Literature review Exploratory study Methodology review Hypothsis testing	Surveys Simulation Interviews Archival study Math model Case study	Descriptive statistics Regression Discriminant analysis MANOVA Path analysis Other (e.g. Cost analysis)

Mentzer and Kahn (1995) classified the state of logistics research into 4 categories: normative literature/literature review, exploratory study, methodology review, hypothsis testing. The research method used in logistics research is classified into 6 catagories: survey, simulation, interviews, archival study, math modelling, case studies. The data analysis techniques used in logistics research are classified into 13 categories: descriptive statistics, regression, discriminant analysis, manova, path analysis, other (e.g. cost analysis).

Research strategy (or designs) that the researchers consider are whether it is based on empirical work (i.e. experimental, statistical, case studies (Woo *et al*., 2011b); empirical quantitative, empirical qualitative, empirical triangulation (Sachan and Datta, 2005); exploratory study and hypothsis testing (Mentzer and Kahn, 1995)) or desk research (conceptual, mathematical, statistical (Woo *et al*., 2011b); desk quantitative, desk qualitative (Sachan and Datta, 2005); normative literature/ literature review, methodology review (Mentzer and Kahn, 1995)). Quantitative research includes mathematical, statistical, empirical quantitative, desk quantitative, exploratory study, hypothsis testing while qualitative research includes conceptual, desk qualitative, normative literature/ literature review and methodology review. Quantitative research is concerned with positivism, while interpretivism is related to the description and interpretation and uses qualitative methods (Bryman and Bell, 2011). In other words, quantitative research is more of quantification in the data collection and analysis and entails a deductive approach. Qualitative research is more of words-based rather than quantitative data collection and analysis and entails an inductive approach.

Based on the literature review conducted in chapter 2 and methodological issues classified by Woo *et al.* (2011b), Sachan and Datta (2005) and Mentzer and Kahn (1995), the research strategies, methods and data analysis techniques in each chapter are determined to respond to the research questions. The choice of appropriate methodological considerations must be driven by the research questions and objectives. This study follows the related questions of 'what to measure', 'how to measure' and 'how to control and improve' port performance. Chapter 4 aims to select a set of PPIs that are most crucially needed to be used for measuring port performance. In chapters 5 and 6, port performance measurement models with different disciplines (i.e. PPIs independency and PPIs interdependency) are developed in order to deal with the challenges in port performance measurement. In chapter 7, a performance improvement model is established to prioritise the performance improvement strategies for a port of poor performance.

Neely *et al*. (1995) referred the performance measurement (PM) to "the set of metrics used to quantify both the efficiency and effectiveness of actions." Bourne *et al*. (2003) explained the PM as "the use of a multi-dimensional set of performance measures for the planning and management of a business." Brooks and Pallis (2008) argued that both efficiency and effectiveness measures (i.e. both quantitative and qualitative PPIs) have to be used when measuring port performance because these indicators are different but related. Using either quantitative or qualitative PPIs is not sufficient to measure and diagnose performance (Beamon, 1999). In the academic research, researchers generally need to invest huge time and efforts to collect both quantitative data (e.g. secondary data of financial and terminal operational data) and qualitative data (e.g. primary data collection through questionnaire or interview). Terminal operators or port authorities are reluctant to provide the quantitative data which are confidential and sensitive for their business. In this regard, previous studies have excluded those data from their investigation when there is incomplete information (Lin and Tseng, 2007). In the industry, however, a set of quantitative PPIs have generally been utilised because the data can be readily available, or because the qualitative PPIs are too ambiguous to interpret them in a meaningful way. Accordingly, quantitative and qualitative data cannot be used frequently together despite the need for port performance measurement in both academia and industry. To this end, port performance measurement needs to involve multiple dimensions with both quantitative and qualitative PPIs in order to offer diagnostic instruments to decision makers.

From the discussion, port performance measurement can be viewed as a typical multi-criteria decision making (MCDM) problem under uncertainty as it involves multiple criteria of both quantitative and qualitative features to solve multi-dimensional and complicated problems. This study uses a MCDM approach as a data analysis technique. There are a variety of techniques in the context of MCDM such as analytic hierarchy process (AHP), analytic network process (ANP), the weighted sum model (WSM), the weighted product model (WPM), technique for order preference by similarity of ideal solution (TOPSIS), evidential reasoning (ER) (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). In general, MCDM problems can be often assessed imprecisely due to uncertain and incomplete data related to different quantitative and qualitative determinants (Yang *et al*., 2009). However, since Zadeh (1965) introduced the fuzzy sets theory, the extened and modified types of MCDM approachs have been developed for solving fuzzy multi-criteria decision making problems

(Chen, 2000, Yang, 2001, Yang and Xu, 2002, Liou *et al*., 2007, Wang and Chang, 2007, Shieh *et al*., 2010, Yang *et al*., 2011, Buyukozkan and Cifci, 2012).

In the MCDM applications, the evaluations of PPIs and their importance should be conducted separately and then synthesised. With regard to this, applying a mixed methodology (i.e. hybrid approach) is essential. A mixed methods study refers to "the collection or analysis of both quantitative and/or qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research" (Creswell *et al*., 2003, p. 212). According to Creswell and Clark (2007), triangulation that uses different methods, techniques and data sources in the same study can offset weaknesses in each. Therefore, this study partially adopts a triangulation approach; more than one method to collect data, such as interviews, questionnaires, and documents, more than one data sources and more than one method to analyse the data. Accordingly, each chapter first applies a conceptual approach to justify the philosophical background of the PPIs' selection and the methodologies used. In addition, a series of iterations and feedbacks with the port industry, academics and other related experts are conducted through interviews and questionnaire surveys in order to acquire the construct validity of the PPIs model and to validiate the proposed models.

As shown in Table 3.2, this study adopts conceptual (PPIs' conceptual justification, port performance modelling framework), mathematical (port performance measurement modelling, port performance improvement modelling) and empirical (container terminals/ports in Korea), questionnaire surveys (PPIs' weights assignments, qualitative PPI's data collection, documentation (secondary data for quantitative PPIs' data collection) and semi-structured interview (PPIs' construct validity) approaches. The research strategies and methods in each chapter of this thesis are denoted in Table 3.2.

- Research strategies: analytical (conceptual and mathematical) and empirical (statistical and Korean container terminals/ports cases)
- Research methods: survey, interview, mathematical modelling, conceptual work
- Data analysis technique: multiple criteria decision making (MCDM)

Table 3.2 Research strategies and methods

	Research strategy	Research method	Description
Chapter 4	Conceptual	Interview	PPIs' conceptual justification Construct validity (semi-structured interview)
Chapter 5	Conceptual Mathematical	Survey Mathematical modelling Conceptual work	PPIs' weights assignments (AHP questionnaire survey) Qualitative PPIs' data collection (questionnaire survey) Quantitative data collection (documentation (secondary data)) Port performance measurement modelling (mathematical) Port performance modelling framework (conceptual) Model validity test (12 container terminals in Korea)
Chapter 6	Conceptual Mathematical	Survey Mathematical modelling Conceptual work	PPIs' weights assignments (DEMATEL, ANP questionnaire survey) Qualitative data collection (questionnaire survey) Quantitative data collection (documentation (secondary data)) Port performance measurement modelling (mathematical) Port performance modelling framework (conceptual) Model validity test (4 ports in Korea)
Chapter 7	Conceptual Mathematical	Survey Interview Mathematical modelling Conceptual work	PPIs' improvement strategies (structured interview) Weights of strategies (AHP questionnaire survey) Qualitative data collection (TOPSIS questionnaire survey) Performance improvement strategies modelling (mathematical) Performance improvement strategies framework (conceptual) Model validity test (Busan Port)

3.2 DATA COLLECTION METHODS

This study conducts three forms of the data collection methods: online/offline documentations (secondary data collection), interviews (primary data collection) and questionnaire surveys (primary data collection). The secondary data of the quantitative PPIs is collected from terminal operating companies and information systems/databases managed by port authorities, governments and credit rating agencies to test the validity of the proposed performance frameworks (chapters 5 and 6). Semi-structured interviews are undertaken to acquire the construct validity of the research model (chapter 4), while structured interviews are undertaken to identify the list of PPIs improvement strategies (chapter 7). The questionnaire surveys are conducted to assign the PPIs' weights (chapters 5 and 6), to evaluate the performance of the qualitative PPIs with respect to each container terminal/port (chapters 5 and 6), to assign the weights of PPIs'improvement strategies (chapter 7) and to evaluate the preference strateges (chapter 7). In a survey research, a sample of the population is crucial because the success of this kind of research is dependent on the representativeness of the sample with respect to a target population of interest to the researcher (Bryman and Bell, 2011).

3.2.1 Sampling of the interviews

Interviews can fall into three categories in accordance with an extent of structure: unstructured, semi-structured and structured interviews (Bryman and Bell, 2011). With unstructured interviews, an interviewer has no predetermined list of questions, representing minimum control over how an interviewee answers. This approach can gather rich data but can take a long time. Structured interviews are thoroughly controlled by an interviewer. In structured interviews, the questions are fixed and all interviewees are asked exactly the same context of questions, in the same order. Semi-structured interviews refer to a context in which an interviewer has a series of questions on specific topics to be covered, but allowing the interviewer to ask further questions in accordance with what are seen as significant replies. Semi-structured interview is frequently used when the interviewer wants to probe deeply into a topic and to understand exhaustively the answers provided (Saunders *et al.*, 2012).

This study employs a semi-structured interview approach because the situations which the interview aimed to explore is to be made within the research questions (i.e. what to measure: dimensions and PPIs (chapter 4) and PPIs hierarchy model that this study intended to develop (chapter 4)). Qualitative interviews such as semi-structured interviews are an appropriate method for an exploratory study to seek what is taking place and to find out new insights (Saunders *et al.*, 2012). The PPIs' pre-selection in chapter 4 shows conceptual justifications of the selection process based on the literature review and industrial practices. However, there are still problems such as overlap among the PPIs. In this case, an empirical evidence or an exploration are suggested to justify the selection process (Kuiper 2005). Hence, semi-structured interview is applied, attempting to assess the suitability of the potential indicators and to test the feasibility of the selected indicators.

From previous disscusion, port performance measurement demands a stakeholder-driven approach to cover the wide-ranging objectives and desired results of stakeholders. Therefore, this study targets the port industry as the population. Bryman and Bell (2007) suggested various techniques for the sampling design such as a probability sampling method (simple random, systemic, stratified random and multi-stage cluster samplings) and a non-probability sampling method (convenience, purposive, snowball and quota samplings). The probability sampling method is a sample that has been selected using some form of random selection to minimise a sampling error. The non-probability smapling method is that a sample that has not been selected using a random selection method. The former is suitable for large-scale studies concerned with representativeness, while the latter is more suitable for in-depth qualitative research (Saunders *et al.*, 2012). This study uses purpositive sampling and snowball smpling. In purposive sampling, it is assumed that a researcher relies on his or her own knowledge when choosing members of population to be included in the sample, and, in snowball sampling, a researcher makes initial contact with a small group of people who are relevant to the research topic and then uses these to establish contacts with others (Saunders *et al*. 2012). A panel of 10 experts are selected for semi-structured interviews. They are 6 industrial experts who have been working in shipping and port industries more than 15 years with Ph.D. (1 expert from a shipping line), M.Sc. (3 experts from a terminal operator, a shipping line and a forwarder, respectively) and BA (2 experts from a terminal operator and a forwarder, respectively) degrees, 2 professors who have more than 15 years teaching and research experience and 2 experts from governments/port authorities (1 department manager and 1 managing director) who have been working for port logistics departments. An information sheet described the definitions of PPIs and calculations for quantitative PPIs was provided in advance to avoid any difficulties on their judgements. The details of sample selection process, related questions and interview administration are explaind in chapter 4. For further information, please refer to chapter 4.3.

This study also employs a structured interview approach to investigate the performance improvement strategies (chapter 7). A sample of the population to identify potential performance improvement strategies in chapter 7 is determined based on representativeness of a relevant peer group of ports in Asia. This study assumes that benchmarking the best practices of the leading ports in Asia is helpful in identifying the potential performance strategies to improve the weak PPIs in poor performer. To this ends, a sampling for the interviews was determined based on the previous studies that investigated port performance ranking among a relevant peer group of ports (Tongzon and Ganesalingam, 1994, Cullinane *et al*., 2006, Lin and Tseng, 2007, Hung *et al*., 2010, Wu and Goh, 2010, Yeo *et al.*, 2014). The detals of interview plan, sampling and related questions are described in chapter 7. For further information, please refer to chapter 7.3.3.

3.2.2 Questionnaire surveys

Questionnaire surveys can be considered as one of the main instuments for collecting data to measure the opinion and behaviour of individuals (Bryman and Bell, 2011). This study employs different types of structured questionnaire surveys for data collection (i.e. AHP questionnaire for PPIs' weight, qualitative PPIs' data collection, DEMATEL and ANP questionnaires for PPIs' interdependency and weight, TOPSIS questionnaire). A questionnaire as an efficient tool to collect data is composed of structured questions that become data and can be statistically analysed. The structured questions have been generally chosen after considerable testing with a view to provoking a particular group of people into reliable responses (Collis and Hussey, 2009).

The advantages of the questionnaire over other data collecting methods are: cheaper to administer, quick to administer, absence of interviewer effects, no interviewer variablitity and convenience for respondents (Bryman and Bell, 2011). In addition, thanks to advanced technologies, a considerable number of questionnaire surveys have been conducted through email and website. These online methods provide potential respondents with greater flexibility and control, as they can complete it when they have free time and respond it at a speed way (Saunders *et al.*, 2012). In contrast, there are disadvantages of the questionnaire surveys: low response rates (bias broblems), cannot prompt (no way to help respondents with questions they find difficult to understand and hence to answer), cannot ask many questions that are not salient to respondents (respondent fatigue), great risk of missing data, cannot collect additional data (Bryman and Bell, 2011). In order to avoid these disadvantages, questionnaires need to be easier to answer (closed questions), have easy-to-follow designs, be shorter (Bryman and Bell, 2011). A sampling of different types of structured questionnaire surveys is described in following sections.

3.2.2.1 Sampling of the PPIs' weight assignments survey

Each PPI presents various internal and external container port activities and environments. In general, the PPIs' importance perceived by each port stakeholder can be different in terms of their objectives and interests. Therefore, the weights of the PPIs should be measured, which can be obtained through either a simple rating method or pair-wise comparisons (Yang and Xu, 2002). This study considers the PPIs' two disciplines: PPIs' independencies and interdependencies. The former is measured by the AHP technique while the latter is measured by a hybrid approach of an ANP incorporating a DEMATEL technique. The survey was conducted through an online survey tool as well as distributed by e-mails. The sampling of both approaches is described as follows.

The same panel of 10 experts in the previous survey participated in the judgements in the DEMATEL survey for investigating interdependencies among the 6 dimensions. However, in the second DEMATEL survey for investigating interdependencies among the 16 principal-PPIs, 8 experts* (2 terminal operators, 1 liner company, 1 forwarder, 2 academics and 2 government representatives) among the 10 experts in the previous survey responded (chapter 6).

For the ANP survey to investigate the intensity of the interdependencies among the all PPIs including 6 dimensions and 16 principal-PPIs, 4 experts* (1 terminal operator, 1 shipping line, 1 forwarder, 1 academic) among the 10 experts in the previous survey responded (chapter 6). It is noteworthy that local weights of 60 PPIs for ANP can be obtained by AHP in chapter 5.

For the AHP survey to investigate the PPIs' independent weights, 5 experts* (1 terminal operator, 1 shipping liner, 1 forwarder, 1 academic, 1 port authority) among the 10 experts in the previous survey responded.

For the AHP survey to investigate the relative weights of strategies, 4 experts (1 terminal operator, 1 liner company, 1 port authority, 1 academic) among the 10 experts in the previous survey responded.

Table 3.3 Response details (Expert judgements)

	PPIs independencies	PPIs interdependencies	
	AHP (participants)	DEMATEL (participants)	ANP (participants)
6 dimensions	5* (chapter 5)	10 (chapter 6)	4* (chapter 6)
16 principal-PPIs	5* (chapter 5)	8 (chapter 6)	4* (chapter 6)
60 PPIs	5* (chapter 5)	-	5* (chapter 6)
38 strategies	4* (chapter 7)		

* The judgements by the other experts were incomplete, however the number of judgement is sufficient to provide a reasonable weight outcome (Buyukozkan and Cifci, 2012).

3.2.2.2 Sampling of the questionnaire survey

This study addresses the multi-stakholder dimension in port performance measurement. Port performance measurement demands a stakeholder-driven approach to cover the wide-ranging objectives and desired results of stakeholders. This can be achieved by integrating a multi-stakeholder dimension in a port performance measurement framework which takes into account the PPIs. Moreover, PPIs evaluations need to be conducted with inputs from associated stakeholders. 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.

To this end, for port performance measurement frameworks in chpaters 5 and 6, the qualitative PPIs were collected using questionnaire results obtained from three groups of terminal operators (TO), port users (i.e. shipping lines and freight forwarders, PU) and port administrators (i.e. port authority and government, AD) to assess their own associated PPIs for each port/terminal performance measurement (chapers 5 and 6). Terminal operators are invited to assess the supporting activities (SA), terminal supply chain integration (TSCI), safety and security (SSS) and environment (EVS). Port users assess users' satisfaction (UA) and terminal supply chain integration (TSCI). Administrators judge on sustainable growth (SG). The survey was conducted through an online survey tool as well as distributed by e-mails.

Chapter 7 aims to propose a decision making framework for selecting port performance improvement strategies. For the selection of port performance improvement strategies in a fuzzy order preference by similarity to ideal solution (FTOPSIS) method, the evaluators from 3 terminal operating companies (TOCs) in a case port (i.e. Busan North Port) were invited to evaluate the preference strategy for Busan North Port's performance improvement. The eight evaluators (total twenty-four) including four senior managers (representing the group of decision makers) in the top management level of each TOC took part in the evaluation process.

The response details of each questionnaire survey is explained in the corresponding chapters (chapters 5, 6 and 7), accordingly. For further information, please refer to sections 5.4.1, 6.3.1 and 7.3.4.

3.2.3 Research ethics

Ethical issues, such as anonymity, confidentiality, privacy and deception occur, in particular, when collecting primary data through interviews and questionnaires. The relevant issues such as data collection, analysis, storage and presentation has been reviewed and approved by Liverpool John Moores University Research Ethics Committee (REC) in advance before commencing interviews and questionnaire surveys. Liverpool John Moores University Research Ethics Guidelines were strictly applied throughout the interviews and questionnaire surveys.

3.3 RESEARCH FRAMEWORK

3.3.1 Port performance indicators selection

This study develops a systematic approach to address the multi-stakeholder dimension in port performance measurement. Port performance measurement demands a stakeholder-driven approach to cover the wide-ranging objectives and desired results of stakeholders. This can be achieved by integrating a multi-stakeholder dimension in a port performance measurement 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. Using only one dimension (e.g. financial measures) in a performance measurement setting is no longer sufficient to cover all related issues for the new business environment (Miller and Vollmann, 1985, Fry and Cox, 1989). As a consequence, 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).

Seaports are integrated process platforms where a number of 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 port performance measurement framework need to reflect these performance aspects. Moreover, PPIs evaluations need to be conducted with inputs from associated stakeholders. 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.

The objective of the proposed PPIs selection framework is to identify most crucially needed PPIs for each group of port stakeholders and to develop a powerful performance measurement tool. In the framework, various disciplines such as uncertainty and interdependency among the PPIs are considered to deliver more practical applications in port performance measurement. As seen in Figure 3.1, the needs of different stakeholders are investigated in the first phase and their associated PPIs are derived in the second phase. To this end, this study will identify crucial interests in major (container) ports investigating stakeholders' goals and objectives, and discuss them with port stakeholders. For example, PPIs related to the cost efficiency of cargo handling operations in the port might be of crucial importance for port service providers (i.e. terminal operators). However, these PPIs might not be 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 with a guaranteed service quality level. Conflicts of interests between stakeholders require them to interpret others' assertiveness rightly. Consequently, the analysis of their interests and needs on various dimensions of port activities becomes essential. The multi-stakeholder dimension will be covered 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 literature review and an analysis of industrial practices the associated PPIs will identify and then get confirmed by the panel of experts to assess the suitability of the potential indicators and to test the feasibility of the selected indicators (Bagozzi *et al*., 1991; Okoli and Pawlowski, 2004).

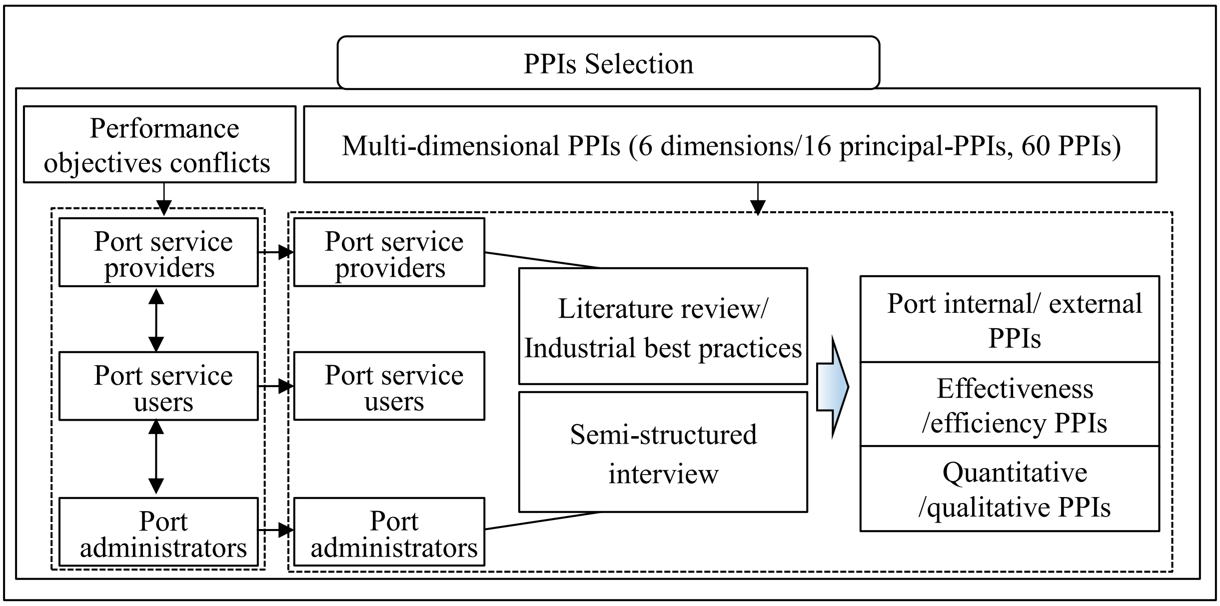

Figure 3.1 Port performance indicators (PPIs) selection framework

3.3.2 Quantitative port performance measurement models

Numerous methodologies have been applied for measuring port performance. They are varied from a heuristic method to a mathematical model, including a heuristic approach to identify performance indicators (Brooks, 2006), technical and economic efficient equations (Talley, 2006), the parametric or econometric approaches such as a cost or a production frontier function (Gonzalez and Trujillo, 2008), a stochastic frontier analysis (SFA) (Cullinane *et al*., 2002); a non-parametric approach such as data envelopment analysis (DEA) (Cullinane and Wang, 2006b); a confirmatory fact analysis (CFA) and a structural equation modelling (SEM) (Woo *et al*., 2011a, Woo *et al*., 2013); and an importance-performance gap to investigate perception difference between ports and port users on PPIs (Brooks and Schellinck, 2013). However, the applied methodologies have shortcomings to deal with the aforementioned problems such as inherent uncertainties in data (evaluation of PPIs) and incapability of dealing with both quantitative and qualitative data in a unified manner.

This study argues that there is a need for a new performance measurement framework not just to meet the needs of port stakeholders, but also to enrich the diagnostic tools available to support decision-making in complex port/terminal systems operating in an uncertain environment. In such systems, decision-makers typically need to assess the level of uncertainty and complexity in the port or terminal environment. The decisions are usually made on multiple uncertain attributes (i.e. MCDM). Consequently, this study needs to deal with the inherent data uncertainties which are unavoidable in port/terminal operational contexts. Furthermore, it needs to identify interdependencies among the PPIs.

Given complex port activities and operations, decision makers may require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improve port/terminal performance. However, scholars and practitioners have done little on the analysis of interdependencies among the factors (i.e. PPIs). In order to tackle the problems, it needs sophisticated tools that are proven to be successfully applicable for dealing with MCDM problems under uncertainty and interdependency caused by container ports/terminals' complexity.

There is a limited approach to selecting performance improvement and maintenance strategies. We can identify the strengths and weaknesses of the container ports/terminals through the proposed port performance measurement models. The poor PPI score needs to be improved with reference to the associated PPI performance in a leading performer. Therefore, the framework for modelling PPI improvement strategies needs to be developed to improve their performance. The measurement of PPIs' improvement strategies is a typical MCDM under uncertainty based on the principle that the higher the weights (or the performances) are, the more desirable the alternatives. The weights/performance ratings assigned to/against criteria are mostly obtained through subjective judgements and the scores are synthesised as a single value for each alternative to select the best solution from the alternatives. In this study, a hybrid approach of AHP and fuzzy TOPSIS for solving MCDM problems under a fuzzy environment is applied to address the choice of terminal operating companies' (TOCs) strategies for improving performance. Figure 3.2 demonstrates an overview of the proposed frameworks relating to port performance measurement.

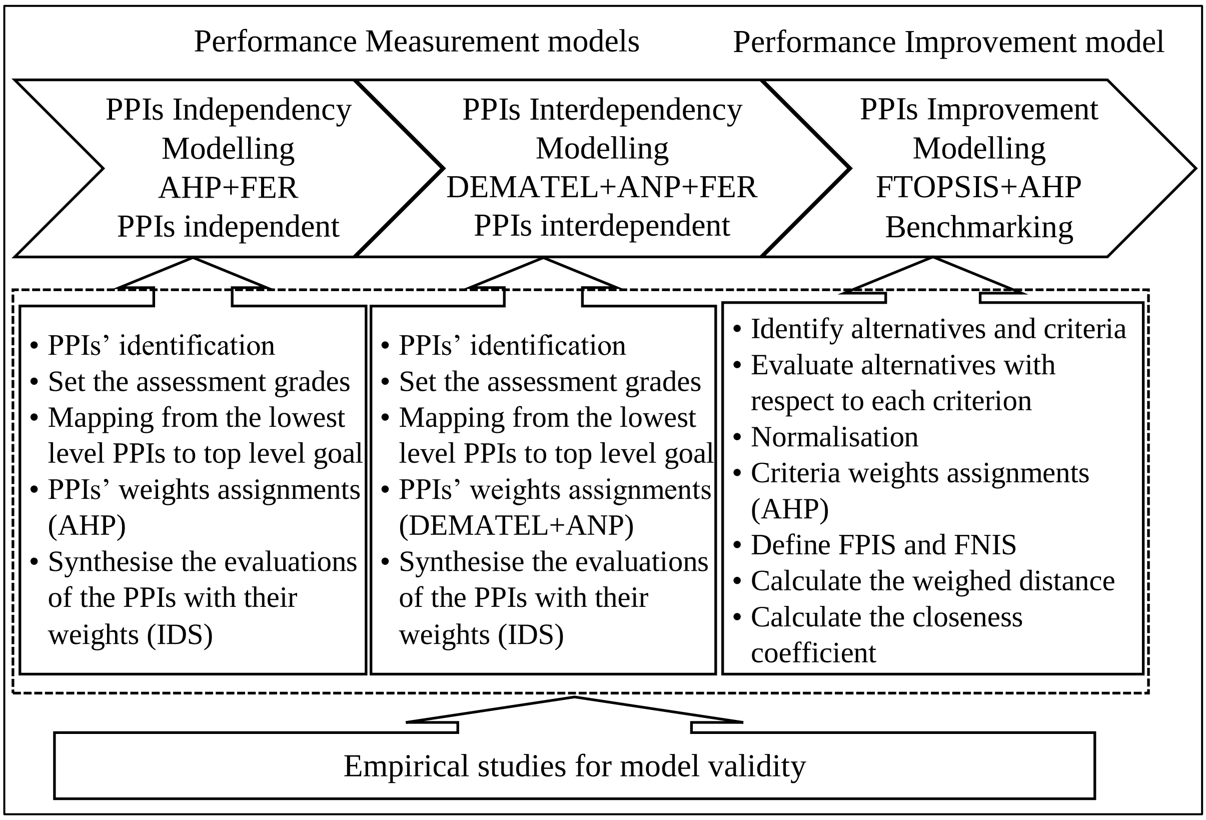

Figure 3.2 Port performance measurement frameworks

3.3.3 Validity and reliability of MCDM methods

Validity refers to the extent which the method is likely to yield accurate results that the user assures, which can be interpreted on a rational-axiomatic, empirical, or measurement theoretical basis (Hobbs *et al*., 1992, Satty and Ergu, 2015). Reliability refers to the quality of a method and its findings that yield consistent results, with minmal variability, over repeated applications, which makes it noteworthy to decision makers (Garcia-Hernandez, 2015, Satty and Ergu, 2015). An MCDM method should yield a valid outcome that is generally useful for different types of decisions (Satty and Ergu, 2015). Any kind of MCDM method involves definition of criteria and evaluation of the alternatives with respect to each criterion. The validity and reliability in an MCDM method relate to the whole process of development of the decision structure (e.g. a set of criteria at a decision hierarchy) and evaluation of alternative for each criterion (Satty and Ergu, 2015). The whole process should be relaiable to minimise doubt and uncertainty no matter which kind of MCDM method is used.

Satty and Ergu (2015) argued that an MCDM method should be capable of building a comprehensive decision structure, concerning breadth, depth and merits. Garcia-Hernandez (2015) noted that the common challenges such as overlapping classifications can be generated when identifying attributes (i.e. PPIs). He suggested to avoid classifications that markedly overlap and if overlapping classifications are kept, to add a sensitivity analysis maintaining only non-overlapping classfications. In the methodological research, the validity and reliability of measures are examined, in particular, a model of measures can be developed by the validation of measures. Various types of validity can be used for measurement validity (or construct validity): content validity, convergent validity, discriminant validity unidimensionality, reliability, and nomological validity (Bryman and Bell, 2011). To the best of researhers's knowledge, the construt validity in MCDM methods has been rarely conducted in a statistical way (e.g. Tseng (2009)), but the selection of criteria and the development of a decision structure in MCDM methods have been conducted based on literature review and industrial practices (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).

The validity and reliability of MCDM methods generally rely on appropriate evaluation of the criteria (i.e. PPIs' performance with respect to alternatives) and appropriate weight assignments (i.e. PPIs weights) and then accurately incorporate them into a single value for each alternative to select the best solution/rank from the alternatives (i.e. ports or terminals). The methods should provide the capability to deal with the ranking of tangibles as well as intangibles and with rank preservation and reversal (Satty and Ergu, 2015). The different evaluations of each criterion for the alternatives should be aggregated by a merging function in order to obtain the final priorities of the alternatives (Satty and Ergu, 2015). They suggested that a MCDM mthod would be trustworthy when the method satisfies four major concerns: truth value (internal validity), applicability (external validity), consistency, and neutrality (objectivity). They also defined the validity of MCDM method as "A method is rated low if it uses cardinal measurement model with a simple structure; medium if it uses cardinal measurement model but does not provide rigorous mathematical axioms; high if it uses a cardinal measurement model with a mathematical logical procedure and mathematical axioms (Satty and Ergu, 2015, p. 12)".

In MCDM methods, sensitivity analysis is a commonly suggested method to validate the feasibility and robustness of MCDM methods (Satty and Ergu, 2015). Sensitivity analysis refers to the study of how the uncertainty in the output of a model can be assigned to different sources of uncertainty in its inputs (Saltelli, 2002). Due to the different sources of uncertainty in the inputs (e.g. the evaluation alternatives for each criterion, the weights of the criteria and the type and parameters of the preference functions, etc.) in MCDM methods, the results obtained from the methods should be interpreted with cares (Wolters and Marechal, 1995). Wolters and Marechal (1995) presented three types of sensitivity analysis in the context of MCDM methods "to determin: 1) the sensitivity of a ranking to specific changes in the evaluations of all alternatives on certain criteria; 2) the influence of specific changes in certain criterion-scores of an alternative; 3) the minimum modification of the weights required to make an alternative ranked first". The first and second type of sensitivity analysis enable for MCDM methods in dynamic circumstances, while the third type enables to analyse the total weight space.

To validate the feasibility and robustness of the proposed models in chapters 5 and 6, this study will conduct sensitivity analysis, which would make the findings more robust.

CHAPTER 4 DISCUSSION ON THE SELECTION OF PORT PERFORMANCE INDICATORS

This chapter explores a conceptual discussion on the selection of port performance indicators (PPIs) taking reference from broader areas in port and shipping, logistic and supply chain management (SCM), and strategic management and industrial best practices. Semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators. To guide the conceptual development of PPI selection, six dimensions with 16 principal PPIs and 60 PPIs are identified as particularly relevant factors for port performance measurement to incorporate multiple objectives of key stakeholders.

4.1 INTRODUCTION

The primary objective of this chapter is to select a set of PPIs for port performance measurement. From the literature on performance measurement systems and measures in chapter 2, this study adopts the concept of the performance measurement defined by Neely *et al*. (1995) and Bourne *et al.* (2003).

- The set of metrics used to quantify both the efficiency and effectiveness of actions
- The use of a multi-dimensional set of performance measures for the planning and management of a business

However, the existing literature on port performance measurement tends to focus on limited dimensions of port performance measurement or specific areas of ports. The extant port literature mainly introduces lists of PPIs to measure the productive and allocative efficiency of port/terminal operations (i.e. operational efficiency), focusing more on terminal quayside operations via the application of DEA and stochastic frontier models (Tongzon, 1995; Cullinane *et al*., 2002; Talley, 2006; González and Trujillo, 2009). Compared to port efficiency studies, existing studies focusing on port effectiveness (i.e. 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, port performance measurement should consider the different natures of PPIs.

The potential PPIs which are most crucially needed to be used for measuring port performance can be identified through industrial best practices and the broader areas of literature on port and shipping, logistic and supply chain management (SCM), and strategic management. In addition, this study investigated crucial interests in major container ports investigating their missions, visions, goals, and objectives and discussed them with port stakeholders. The key words of the missions, visions, goals, and objectives in the major ports in the world mostly include 'socio-economic responsibility', 'environment performance (green port)', 'operational performance (strategy and management)', 'integration of port and supply chain (port centric logistic)', 'customer satisfaction' and 'safety and security' and so on[1]. Therefore, the selection of PPIs has been done through a literature review and industrial practices in a pre-selection phase and then the semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators (Okoli and Pawlowski, 2004). Once pre-selection of the PPIs through the literature review and current industry practice is completed, the interviews are conducted to assess the suitability of the potential indicators and to test the feasibility of the selected indicators.

Through the construct validity, finally, 60 PPIs in the lowest level are significant as representing indicators for container port performance measurement under 16 Principal-PPIs and 6 dimensions (Table 4.25). The dimensions relate to 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 (i.e., HR, technology, etc.) 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 for socio-economic sustainable growth (sustainable growth, SG). It is noteworthy that the discussions on each dimension are to identify PPIs for container terminals, focusing on their internal and external activities, but the PPIs are assessed by associated port stakeholders. Thus, the term container port performance refers to the performance of a collection of container terminals in port area. In the next section, pre-selection of PPIs with their definitions based on the literature review and industry current practice is explored and the potential PPIs identified. In section 4.3, semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators and then the complete form of the decision making tree is demonstrated.

[1] Author visited websites of the ports of Busan, Hong Kong, LA/Long Beach, Rotterdam and Singapore on May 10, 2013.

4.2 PRE-SELECTION OF PORT PERFORMANCE INDICATORS

4.2.1 Core activities (operational)

According to Porter (2008), in order to create competitive advantages, the activities of a business can be classified into two dimensions: core (or primary) activities and supporting activities. The former is directly related to the production and delivery of products or services, while the latter is a strong relationship between the core activities externally and the supporting activities themselves internally. However, it is not easy to apply Porter's value chain framework to the port industry because port systems, unlike general manufacturing industries, are completely different in light of a multifaceted situation such as a variety of operational and strategic activities provided by different actors and organizations. In line with his definition, there is no doubt that the backbone role of seaports refers to vessel operation, cargo operation and other activities regarding cargo transfer or transit from ports to vessels and other transport modes (or vice versa). The first dimension of the core activities focuses on the performance measurement of service providers' activities. This is a basic and crucial aspect of a port function, which is required to be taken into account to measure port performance. Therefore, measuring the performance of internal terminal activities has traditionally and frequently been addressed by scholars and industry practitioners using different types of definition and taxonomy such as efficiency, productivity, utilization, effectiveness, etc.

In order to measure the activities (CA), this category is divided in three broad sub-indicators including output (OPC), productivity (PDC) and lead-time (LTC). These indicators are directly related to efficiency and outcome of port activities and facilities, in particular for vessel and cargo operations. A couple of UNCTAD monographs (UNCTAD, 1976, De Monie, 1987) strengthened the importance of operational indicators for port performance measurement. From the initial study by UNCTAD (1976), many studies applied these indicators for port performance measurement as a part of their research or as a whole (UNCTAD, 1976, Talley, 1988, Talley, 1994, Talley, 2006, Tongzon and Ganesalingam, 1994, Tongzon, 1995a, Tongzon, 2001, Cullinane *et al*., 2002, Cullinane and Wang, 2006a, Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, Brooks, 2006, Woo *et al*., 2011a, Cullinane *et al*., 2006).

Table 4.1 shows the potential indicators for the core activity dimension. The indicators measured can be measured based on the quantitative data gained internally from port/terminal operators.

Table 4.1 Port operational performance indicators

Author (date)	Category	Collected indicators
UNCTAD (1976)	Operational	Arrival rate, waiting time, service time, turn-round time, tonnage per ship, fraction of time berthed ships worked, number of gangs employed per ship per shift, etc.
De Monie (1987)	Productivity	The duration of a ship's stay in port (ship waiting time, ship's time at berth, berth occupancy), the quality of the cargo-handling (berth throughput, ship output, gang output)
Roll and Hayuth (1993)	Input Output	Manpower, capital, cargo uniformity Cargo throughput, level of service, users' satisfaction, ship calls
Tongzon and Ganesalingam (1994)	Operational efficiency	Containers per net crane hour, twenty foot equivalent units (TEUs) per crane and TEUs per berth meter
Talley (1994)	Shadow price	Cargo handling rate, average delay to ships waiting berths, average delay to ships whilst alongside berths, truck time and queuing
Tongzon (1995a)	Operational efficiency (cargo size, terminal efficiency)	Location, frequency of ship calls, port charges, economic activity and terminal efficiency, container mix, work practices, crane efficiency, and vessel size and cargo exchange
Tongzon (1995b)	Operational efficiency	Total throughput, number of commercial ship visits, vessel size and cargo exchange, nature and role of the port, port functions and infrastructure
Tongzon (2001)	Input Output	The number of berths, the number of cranes, the number of port authority employees, the terminal area, the amount of delay time Cargo throughput, ship working rate
Cullinane *et al*. (2002)	Input Output	Terminal quay length, terminal area, number of cranes Turnover from container terminal service
Cullinane *et al*. (2006)	Input Output	Terminal length, terminal area, number of quayside gantries, yard gantries and straddle carriers Cargo throughput
Marlow and Paixão Casaca (2003)	Port discharge process Ship process	Ship's waiting time to be berthed, berth availability, ship's waiting time to start discharging operations, etc. Ship's time spent in route deviations, total time delays, ship's capacity utilisation, etc.
Brooks (2006)	Vessel operations Container operations	Average turnaround time/per vessel, average vessel calls per week, average vessel waiting time at anchor, hours of equipment downtime per month, length of quay in metres, etc. Average vessel turnaround time/per 100 lifts, average yard dwell time in hours, container port throughput, growth in TEU throughput, lifts per crane hour, yard hectares to quay metres, etc.
De Langen *et al*. (2007)	Cargo transfer product	Terminal handling, towage, pilotage, customs
Talley (2006)	Engineering and Economic optimum	Throughput, capacity related variables Throughput, cost related variables
ESPO (2010)	Market trends and structure	Maritime traffic, call size (the ratio of maritime traffic and vessel traffic)
Woo *et al*. (2011a)	Internal efficient operation	Throughput, throughput per hectare, throughput per worker, throughput per crane, ship waiting time, ship working time, port related service time, cargo time
Cruz *et al*. (2013)	Operational Physical	Container throughput, number of ships handled, capacity utilization, ship rate, market share Berths, terminal area, storage area, cranes, other equipment, cargo capacity

4.2.1.1 Output

The outputs generally considered are production, throughput and profit (Bichou, 2006). Output thus refers to the total quantity of work performed in a container port over a period of time without considering the resources utilised (De Monie, 1987). Most studies used the production and throughput as a substitute for output indicators. Examples of output indicators (Table 4.2) which were commonly used in previous studies are annual traffic or throughput (De Monie, 1987, Talley, 1988, Talley, 1994, Talley, 2006, Roll and Hayuth, 1993, Tongzon, 1995a, Tongzon, 1995b, ESPO, 2010, Woo *et al*., 2011a). In addition, financial indicators are generally considered as a part of output indicators when they are expressed in monetary units. However, the underlining goal of a company in general is to achieve a good financial performance and condition. In light of this, financial indicators have always been considered as one of most important tools to measure and evaluate an organization's performance (Bichou, 2006, Brooks, 2006).

Table 4.2 Potential indicators for output

Category	Related indicators	Reference
Output	Throughput, growth in TEU throughput, maritime traffic, call size, the number of vessel calls, vessel output, berth output, crane output, yard output, etc.	(UNCTAD, 1976, Roll and Hayuth, 1993, Tongzon, 1995a, Cullinane *et al*., 2006, Brooks, 2006, ESPO, 2010, Woo *et al*., 2011a, Cruz *et al*., 2013)

4.2.1.2 Productivity

Productivity is one of the most important criteria guiding port choice by shipping lines (Murphy *et al*., 1992). Modern container ports essentially require a higher operational productivity with a higher service quality due to increased vessel sizes, growing throughput volumes and more stringent customer needs. Beškovnik (2008) classified the container terminal activities into a combination of five subsystems: berth, crane, yard, gate and labour. It is noteworthy that productivity in a modern container terminal can be achieved by a well-established operational plan under a given terminal capacity. For instance, the operation of the quay cranes is more dependent on the equipment operational plan between quay and yard areas rather than the quay crane itself. In light of this, terminal operators have always exerted all possible efforts on improving terminal productivity to survive in an uncertain maritime logistics environment.

The term productivity refers to how efficiently resources (i.e. labour, equipment and land) are being used. According to The Tioga Group (2010), productivity, a combined result of operational efficiency and resource utilization, can be increased by either increasing utilization or increasing operational efficiency. The utilization indicator measures a ratio between actual use of resources and maximum possible use of these resources or how intensively port resources are used over a period of time. Therefore, productivity is not a simple indicator but a ratio (or percentage) of the combined two base-indicators and is measured by unit of output (i.e. throughputs) per unit of input (i.e. port superstructure, equipment, labour). In other words, the productivity indicator is used to measure rate of operational activity per unit of resource in unit time (Soberón, 2012). Therefore, productivity indicators which were commonly used in previous studies (Table 4.3) are in the forms of annual traffic or throughput per berth, crane, yard and labour in a unit time (De Monie, 1987, Roll and Hayuth, 1993, Tongzon and Ganesalingam, 1994, Tongzon, 2001, ESPO, 2010, Woo *et al*., 2011a). The potential sub-indicators of productivity are shown in Table 4.3.

Table 4.3 Potential indicators for productivity

Category	Related indicators	Reference
Productivity (efficiency + utilization)	Tonnage per ship, fraction of time berthed ships worked, number of gangs employed per ship per shift, tons per ship hour in port, tons per ship hour at berth, tons per gang-hour	UNCTAD (1976)
	Ship productivity (ton per ship waiting and working time), cargo productivity (ton per gang, berth working hour, berth occupancy)	De Monie (1987)
	Output (cargo throughput, level of service, users' satisfaction, ship calls) per input (manpower, capital, cargo uniformity)	Roll and Hayuth (1993)
	Containers per net crane hour, twenty foot equivalent units (TEUs) per crane and TEUs per berth metre	Tongzon and Ganesalingam (1994)
	Output (container throughputs) per input (the number of berths, the number of cranes, the number of tugs, the number of port authority employees, the terminal area of the port)	Tongzon (2001)
	Output (container throughputs) per input (terminal quay length in metres, terminal area in hectares and the number of pieces of cargo handling equipment)	Cullinane *et al*. (2006)
	Average turnaround time/vessel (in hours), revenue per tonne handled, average revenue per TEU, container port throughput (TEU/metre of quay/year, lifts per crane hour, employment per tonne handled, employment per TEU handled, etc.)	Brooks (2006)
	The ratio of maritime traffic and vessel traffic	ESPO (2010)
	Throughput per hectare, throughput per worker, throughput per crane	Woo *et al*. (2011a)

4.2.1.3 Lead-time

The lead-time refers to the speed at which activities are performed. This term gained more attention 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 (2001, 2004) stressed that companies achieving a higher competitiveness through a combination of speed and variability reduction and productivity improvement would have a higher performance than that when focusing on only one aspect. In the container port industry, reduction of lead-time of vessel, cargo and truck is a challenging task. For instance, it needs a huge capital and resource investment in acquisition of state-of-the-art systems and facilities to reduce vessel turnaround time in port. It is noteworthy that reduction of vessel time in port is more important than reduction of lead-time of land-side transport modes. The related indicators that previous studies used are shown in Table 4.4.

Table 4.4 Potential indicators for lead time

Category	Related indicators	Reference
Lead- time	Waiting time, service time, turn-round time	UNCTAD (1976)
	Vessel round time (vessel waiting + vessel working time)	De Monie (1987)
	Ship's waiting time	Tongzon and Ganesalingam (1994)
	Containers per working hour per ship (ship working rate)	Tongzon (2001)
	Ship's waiting for berthing, ship's waiting for loading/ discharging operations, cargo waiting to transit from one mode to another (time in storage and time from quay to storage), transferring cargo from storage to net mode of transport, time spent in carrying out logistics activities required by customers that add value, time for goods to be cleared (if such is to be done at port level), time spent by cargo awaiting departure of next mode of transport, overall time of cargo in port	Marlow and Paixão Casaca (2003)
	Average ship turnaround time, average vessel waiting time at anchor, equipment downtime per month, , average yard dwell time, departure cut-off time	Brooks (2006)
	Cargo waiting time between modes, cargo working time between modes	Woo *et al.* (2011a)

4.2.2 Supporting activities

Supporting activities (i.e. HR management, technology, culture) are crucial to improve organizations' effectiveness or efficiency (Porter, 2008). Accordingly, internal resources maintained successfully lead to achieving common organisational objectives. According to

(UNCTAD, 1992) the port administrative efficiency in third generation ports compared to the second generation ports has been enhanced due to advanced information and communication technology. In addition, port organization was also enlarged since the post-1980s era (Beresford *et al.*, 2004). The organizational enlargement has directly led to increasing fixed costs such as labour cost. Therefore, modern container ports can create competitive advantage through the management of internal and external information, indicating a need for heavy investments in tangible and intangible assets.

Regardless of the industry type, linking tangible and intangible resources to performance is one of the most challenging management concerns (Heskett and Schlesinger, 1994). Kaplan and Norton (2000) stressed that desired strategic outcomes could be achieved by appropriate deployment and effective utilisation of intangible assets in the information era. They also commented that investment in only one of those assets but not all would lead the organization to fail. In other words, both tangible and intangible items should be linked to the firm's strategy together. Kaplan and Norton (1992), in their initial study on "the balanced scorecard-measures that drive performance" suggested three categories of intangible assets in the dimension of learning and growth (Kaplan and Norton (2000):

- *Human capital: the skills, talent and knowledge that a company's employees possess.*
- *Information capital: the company's databases, information systems, networks and technology infrastructure.*
- *Organization capital: the company's culture, its leadership, how aligned its people are with its strategic goals and employees' ability to share knowledge.*

These intangible assets linking to the company's strategy and performance in the balanced scorecard strategy maps show how important they are as a fundamental value for improving organizational performance (Kaplan and Norton, 2000). In addition, the importance of these perspectives can be easily found in the studies on HR (human resources), organizational culture and knowledge management. 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). A higher worker commitment and loyalty leads to a better workplace performance (Brown *et al.*, 2011). Various studies on the performance effects of IT investment found a statistically significant relationship between information and technology (IT) usage and firm performance (Weill, 1992, Keramati, 2007). From these perspectives, the supporting activities (SA) are constituted by HR capital (HCS), organizational capital (OCS) and information capital (ICS) in terminal operating companies. The related indicators which previous studies used are as shown in Table 4.5.

Table 4.5 Supporting activities performance indicators

Author (date)	Category	Collected indicators
Weill (1992)	Information technology	IT investment (strategic, informational, and transactional), conversion effectiveness (top management commitment to IT, previous firm experience with IT, user satisfaction with systems)
Ulrich (1997)	Human resources	Staffing, training and development, performance systems, safety and health, labour relations, internal communication, diversity
Sheng and Mykytyn Jr (2002)	Information technology	IT investment, quality of data
Marlow and Paixão Casaca (2003)	Human resources	Skills, capabilities, training and education
Kaplan and Norton (2004)	Human capital Information capital Organization capital	Skills, training, knowledge Systems, databases, networks Culture, leadership, alignment, teamwork
Alavi *et al*. (2006)	Organizational culture	Collaboration, trust, sharing, learning and openness
Keramati (2007)	Information technology	IT usage is IT in communication, IT in production and operations, IT in decision and IT in administration and pecuniary affairs
Brown *et al*. (2011)	Human resources	Worker commitment, loyalty
Woo *et al*. (2013)	Human resources	Workforce has a good understanding of new logistics environments Workforce has the capabilities to develop new logistics services Offering constant education opportunities about supply chain integration to enhance the workforce's capabilities

4.2.2.1 Human capital

This indicator measures the strength of human resources, whether employees have the right level of skills to perform their jobs (Kaplan and Norton, 2004). According to Becker (1964), human capital resources include the training, experience, judgement, intelligence, relationships and insight of individual managers and workers in a company (Barney, 1991). There is a need for 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 the most to enhancing the organization's internal processes and performance (Kaplan and Norton (2004). Marlow and Paixão Casaca (2003) also emphasised that the port needs investment in intangible assets such as human resources in order to respond to the volatile demands caused by market uncertainty. In the other words, the skills and capabilities of human capital can be improved through training and education. The potential indicators for HCS which previous studies used are shown in Table 4.6.

Table 4.6 Potential indicators for Human capital

Category	Related indicators	Reference
Human capital	Training, experience, judgement, intelligence, relationships and insight of individual managers and workers in a company	Becker (1964)
	Staffing, training and development, performance systems, safety and health, labour relations, internal communication, diversity	Ulrich (1997)
	Skills, capabilities, training and education	Marlow and Paixão (2003)
	Skills, training, knowledge	Kaplan and Norton (2004)
	Worker commitment, loyalty	Brown *et al.* (2011)
	Workforce's understanding on environments workforce's capabilities, education opportunities	Woo *et al*. (2013)

4.2.2.2 Organisation capital

The organisational capital resources encompass a company's formal reporting structure; formal and informal planning, controlling, and coordinating systems; internal and external relationships (Barney, 1991). Successful firms commonly attain 1) an excellent *culture* in which employees understand the mission, vision, goal and core values that are needed to execute the firm's strategy; 2) an excellent *leadership* at all levels; 3) a clear *alignment* between the firm's objectives and individual, team and departmental goals and incentives; 4) an excellent *teamwork*, in particular, sharing knowledge and collaboration throughout the organization Tomer (1987).

Kaplan and Norton (2004) investigated the mediating role of knowledge management in the relationship between organisational culture, structure, strategy, and organisational effectiveness. They found that knowledge management fully mediates in positive relationship between organisational culture and organisational effectiveness while partially mediates in positive relationships between organisational structure, strategy, and organisational effectiveness. In knowledge management studies, organisational capital (context) was identified in various disciplines: structure, size, learning, culture, inter-organizational relationships (Zheng *et al*., 2010); organisational structure (coordination, centralization, formalization and specialization) (Dewett and Jones, 2001); culture, structure and strategy (Willem and Buelens, 2009). The related indicators which previous studies used are shown in Table 4.7.

Table 4.7 Potential indicators for organisation capital

Category	Related indicators	Reference
Organisation capital	Formal reporting structure; formal and informal planning, controlling, and coordinating systems; internal and external informal relations	Tomer (1987)
	Structure, size, learning, culture, inter-organizational relationships	Dewett and Jones (2001)
	Culture, leadership, alignment, teamwork	Kaplan and Norton (2004)
	Structure: centralization, coordination, formalization and specialization	Willem and Buelens (2009)
	Culture, structure and strategy	Zheng *et al.* (2010)

4.2.2.3 Information capital

This indicator measures how adequate the IT portfolio of infrastructure and applications supports the internal processes (Zheng *et al*., 2010). The infrastructure consists of hardware (i.e. central servers and communication networks) and managerial expertise (i.e. standards, disaster planning and security), whilst the applications comprise transaction-processing application (i.e. ERP system) and analytic applications for promoting analysis, interpretation and sharing of information and knowledge.

Kaplan and Norton (2004) tested empirically on the performance effect of IT investments in 33 manufacturing firms. They found, in particular, heavy transactional IT investment is significantly and consistently associated with strong firm performance (sales growth, return on assets and labour productivity). Weill (1992) discussed the moderating role of IT (information efficiencies and information synergies) in the relationship between organizational characteristics (structure, size, learning, culture and inter-organizational relationships) and organizational outcomes (organizational efficiency and organizational innovation). Dewett and Jones (2001) investigated the relationship both between IT investment and firm performance and between quality of data and firm performance. They found the companies that manage quality of data show a better performance than the companies that do not. Sheng and Mykytyn Jr (2002) analysed IT effects on firm performance and found statistically significant relationship between the IT usage index and the firm performance index. The index he used for IT usage is IT in communication, IT in production and operations, IT in decision support and IT in administration and pecuniary affairs. The related indicators which previous studies used are shown in Table 4.8.

Table 4.8 Potential indicators for information capital

Category	Related indicators	Reference
Information capital	IT investment (strategic, informational, and transactional) Conversion effectiveness (top management commitment to IT, previous firm experience with IT, user satisfaction with systems, the turbulence of the political environment within the firm)	Weill (1992)
	IT investment, quality of data	Sheng and Mykytyn (2002)
	Systems, databases, networks	Kaplan and Norton (2004)
	IT in communication, IT in production and operations, IT in decision support and IT in administration and pecuniary affairs	Keramati (2007)

4.2.3 Financial strength

There is no doubt that the port sector is an intensive capital and cost driven industry. A heavy initial capital spending for port superstructure, state-of-the-art systems and equipment and is unavoidable and the capital is generally raised from financial institutions and investors through project finance. Thus financial performance is one of the most important issues which concerns port managers and investors. Financial performance indicators are related to investigating port revenue and cost, port financial strength and weakness. Therefore, this indicator (or financial productivity) has been frequently used in port performance measurement studies (UNCTAD, 1976, Bichou and Gray, 2004, Talley, 2006, Brooks, 2006, PWC, 2010). There are various indicators to measure financial performance. 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) suggested 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 comprehensive performance measuring systems based on the balanced scorecard (BSC). Brooks (2006) identified specific revenue and cost items that are widely used by port operators in 42 ports located in ten different countries. PWC (2010) investigated the performance of the global shipping industry and used ten financial key performance indicators (KPIs) including profitability and short and long-term liability measures. As shown in previous studies, ratio analysis has usually been used to investigate firms' profitability, liquidity and solvency (Table 4.9). In this study, financial indicators are divided into two categories: profitability (PFF) and liquidity & solvency (LSF).

Table 4.9 Financial performance indicators

Author (date)	Category	Collected indicators
UNCTAD (1976)	revenue and cost	Total tonnage worked, berth occupancy revenue per ton of cargo, cargo handling revenue per ton of cargo, labour expenditure, capital equipment expenditure per ton of cargo, contribution per ton of cargo, total contribution
Marlow and Paixão (2003)	Cost	Annual costs incurred by the port, annual cost of sea transport, ship costs by unit of cargo carried
Su *et al*. (2003)	Solvency Profitability Return on investment	Debt to total assets ratio, fixed assets to equity ratio Operating margin ratio, profit margin ratio, growth on revenue Return on total assets, return on fixed assets
Bichou and Gray (2004)	Internal logistics process Supply chain process	Profit, revenue, cost, total cost analysis, value-add Profit from each channel (cargo trade channel, mode logistics channel, customer/supplier supply channel)
Brooks (2006)	Profitability Liquidity and solvency Return on investment	Ancillary revenue as % of gross revenue, average days accounts receivable, growth in profit (before taxes), port-related profit as % of port-related revenue, terminal charges as a % of gross revenue, yield % on shares Capital expenditure as % of gross revenue, debt: equity ratio, interest coverage ratio Return on capital employed
Talley (2006)	Economic optimum	Throughput, cost related variables
PWC (2010)	Profitability Return on investment Solvency and liquidity	EBIT, net sales Return on net operating assets, working capital/net sales, net fixed assets/net sales, return on capital employed Solvency and current ratio

4.2.3.1 Profitability

Profitability measures a firm's ability to generate profit relative to land, labour and capital inputs. In practice, financial indicators such as revenue growth, operating profit margin and net profit margin are predominantly used for measuring a firm's profitability.

Revenue is the sum of money that a company actually gains during a certain period and is calculated as the price at which goods or services are sold multiplied by the number of units or amount sold. Revenue growth is one of most frequently used financial indicators to measure 'how fast a company is expanding during the basic period compared to the year before'. Operating profit margin is to measure the profit from a company's core business operations which excludes any earning from the company's investment and the effect of interests and taxes. Net profit, referred to as net income for the year, is a good indicator to measure the net profitability after deducting all costs. In the income statement, the indicator of a company's financial performance is calculated in the following process and calculations.

- Revenue - cost of sales = gross profit
- Gross profit - general and administrative expenses = operating profit
- Operating profit + (other income-other expenses) = profit from operations
- Profit from operations + (finance income – finance costs) – income tax expense = profit for the year

The related indicators which previous studies used are shown in Table 4.10.

Table 4.10 Potential indicators for profitability

Category	Related indicators	Reference
Profitability	Operating margin ratio, profit margin ratio, growth on revenue, Return on total assets, return on fixed assets	Su *et al*. (2003);
	Ancillary revenue as % of gross revenue, average days accounts receivable, growth in profit (before taxes), port-related profit as % of port-related revenue, terminal charges as a % of gross revenue	Brooks (2006)
	EBIT, net sales	PWC (2010)

4.2.3.2 Liquidity and Solvency

Even though a company is profitable, it can sometimes encounter cash flow problems. That is a vital reason why liquidity and solvency should be managed. Liquidity measures a firm's ability to pay its short term liabilities and to meet its unexpected cash requirement without disrupting the normal operations of its business. Solvency measures the firm's ability to pay its long term obligations and to continue its viable operations after financial adversity. Companies such as banks that invest in or lend money to terminal operators are particularly interested in the solvency ratio. The related indicators which previous studies used are shown in Table 4.11.

Table 4.11 Potential indicators for liquidity and solvency

Category	Related indicators	Reference
Liquidity and Solvency	Solvency: debt to total assets ratio, fixed assets to equity ratio	Su *et al*. (2003)
	Solvency: debt to total asset ratio, EBITDA/net finance cost Liquidity: current ratio	PWC (2010)

4.2.4 Port users' satisfaction

The aforementioned PPIs can be measured based on the information gained internally from terminal operators. Researchers have pointed to the problems linked to the use of only the information for overall port performance measurement (Brooks, 2006, Pallis and Vitsounis, 2008). They argued that both efficiency and effectiveness outputs have to be used when measuring port performance because these indicators are different but related. Therefore, it needs to be taken into account externally generated information to represent port users' stance. Previous studies mainly investigated whether a service quality delivered by ports meets port users' needs in terms of timing, quantity and quality (Brooks and Pallis, 2008). In addition, it needs to include an indicator to measure port agility, or the speed with which the port service provider responds to and flexibly meets customers' special requests (Brooks and Schellinck, 2013). These are underpinned by the growing number of studies using the SERVQUAL on service quality in the port industry (Ugboma *et al*., 2004, Pantouvakis *et al*., 2008). Brooks and Schellinck (2013) used various port service prices as a service quality measure. Service cost is considered as one of most important criteria which affects port selection by port users and determines port competitiveness when service quality is ascertained (Yeo *et al*., 2014). Consequently, low port service charges are a key driver to attract customers (Woo *et al*., 2011a). Therefore, it needs to give extra attention on the perspectives of the port users on developing a rational port performance framework. The indicators of user perspectives are mostly expressed qualitatively rather than quantitatively and measured by externally generated information. The related indicators which previous studies used are shown in Table 4.12.

The customers' satisfaction indicator is divided into two categories: service fulfilment (SFU) and service costs (SCU).

Table 4.12 Port users' satisfaction indicators

Author (date)	Category	Collected indicators
Roll and Hayuth (1993)	Effectiveness	Users' satisfaction
Tongzon and Ganesalingam (1994)	Customer orientation	Reliability and vessel waiting time
Brooks *et al*. (2011)	Effectiveness (common criteria)	Provision of accurate information, overall quality of cargo handling, overall reliability of the port, provision of adequate information, port is safe, port is secure, incidence of cargo damage, etc.
	Effectiveness (supply chain partners)	Efficiency of documentary processes, incidence of delays, accessibility of port for pick-up and delivery, availability of capacity, invoice accuracy, speed of stevedores' cargo loading/unloading, etc.
	Effectiveness (shipping line)	Capability of dockworkers, speed of stevedores' cargo loading/unloading, timely vessel turnaround, incidence of delays, timeliness of maritime services, overall cost of using the port, invoice accuracy, etc.
	Effectiveness (cargo interests)	On-schedule performance, terminal operator responsiveness to requests, overall cost of using the port, cost of rail/truck/warehousing, etc.
Woo *et al.* (2011a)	Customer orientation	Responsiveness, flexibility, annual number of clams
	Service quality	Timeliness, reliability, lead time, cargo damages, accuracy of information
	Service price	Total port charge, cargo handling charge, port related service charge, port facility usage charge
Brooks and Schellinck (2013)	Effectiveness (common criteria)	Overall reliability of the port, Terminal operator responsiveness to special requests, Port authority responsiveness to special requests, Provision of adequate, on-time information, Incidence of cargo damage, Port security
	Effectiveness (supply chain partners)	Overall reliability of the port, availability of labour (do we have to wait to find someone?), efficiency of documentary processes incidence of delays, accessibility of port premises for pick-up and delivery (gate congestion), etc.
	Effectiveness (shipping line)	Overall reliability of the port, incidence of delays, availability and capability of dockworkers, provision of adequate, on-time information, speed of stevedore's cargo loading/unloading, timely vessel turnaround, etc.
	Effectiveness (cargo interests)	Overall reliability of the port, availability and capability of employees (can they accommodate our needs?), terminal operator responsiveness to special requests, port authority responsiveness to special requests, etc.

4.2.4.1 Service fulfilment

Service fulfilment indicator has become an important issue that reflects effectiveness of the port management practices with respect to service quality and customer satisfaction. In other words, the indicator measures whether port service delivered by ports meets port users' needs in terms of on-time, right quantity and right quality. In addition, the indicator is also to measure port agility, i.e. how terminal operator rapidly responds to and flexibly provides services for customers' special requests. Woo *et al*. (2011a) well identified port users' (three user groups of carriers, cargo interests and supplier of services) needs with the extent to which criteria are important to them in terms of the services received and how they evaluate port effectiveness. The effectiveness indicators that they suggested were identified through both literature review and survey to port users. The related indicators which previous studies used are shown in Table 4.13.

Table 4.13 Potential indicators for service fulfilment

Category	Related indicators	Reference
Service fulfilment	Overall reliability of the port, availability and capability of employees, responsiveness to special requests, provision of adequate, on-time information, document accuracy, incidence of cargo damage, incidence of delay	Woo *et al.* (2011a); Brooks *et al*. (2011); Brooks and Schellinck (2013)

4.2.4.2 Service costs

Port service prices have traditionally been considered as one of the most important criteria which affect port users on port selection and determine the level of port attractiveness. Thus, the service prices have been used as a negotiation tool for shipping lines who seek to secure cost savings in ports in order to reduce total logistics costs. Shipping lines have become bigger and bigger through the ways of consolidation such as mergers and acquisitions (M&A) and strategic alliances in order to yield economies of scale. The consolidation brought a considerable bargaining power to shipping lines and the market power shifted from ports to shipping lines. Therefore port service charges which shipping lines always attempt to negotiate for a lower price are a key driver to attract customers (Brooks and Schellinck, 2013). According to Woo *et al*. (2011a), ports which offer lower port charges can have competitive advantages particularly when they provide similar level quality services compared to the competitors. The related indicators which previous studies used are shown in Table 4.14.

Table 4.14 Potential indicators for service costs

Category	Related indicators	Reference
Service costs	Annual costs incurred by the port, annual cost of sea transport, ship costs by unit of cargo carried	Marlow and Paixão (2003)
	Total port charge, cargo handling charge, port related service charge, port facility usage charge	Woo *et al.* (2011a)
	Overall cost of using the port, Cost of rail/truck/warehousing	Brooks *et al*. (2011); Brooks and Schellinck (2013)

4.2.5 Terminal supply chain integration

A significance of the port/terminal roles in supply chain contexts has been acknowledged (Carbone and Martino, 2003, Marlow and Paixão Casaca, 2003, Bichou and Gray, 2004, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013). In this context, higher integration and coordination between the players in supply chains lead to a higher competitiveness (Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013). Notteboom and Winkelmans (2001) argued that ports could achieve sustainable competitive advantages through providing value-added logistics, intermodal transport services and advanced information systems. Notteboom and Rodrigue (2005) stressed that competitive advantages of ports can be gained from the intensive use of containers, inter-modal transport systems and information/communication systems (ICS), resulting in the enlarged port's spatial reconfiguration and functional logistics links between seaports. Furthermore, ports should be integrated with other logistics players in supply chains, indicating that integration is not only limited on setting up systems and processes, but also on the functional activities (Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2013).

Terminal supply chain integration (TSCI) is defined as "the extent to which the terminal establishes systems and processes and undertakes functions relevant to becoming an integral part of the supply chain as opposed to being an isolated node that provides basic ship-shore operation" (Panayides and Song, 2009, p.134). To achieve this, ports should provide a reliable and adequate multimodal process such as sea/land side connectivity and multimodal transport integration to attain port trade competitiveness (Notteboom and Winkelmans, 2001, Notteboom and Rodrigue, 2005, UNCTAD, 2006, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2011a, Woo *et al*., 2013). A port is an intersectional logistics node where three modes (i.e., ships, road and rail) cross to move goods to sea or land bilaterally. Woo *et al*.

(2011a) argued that the promotion of an efficient intermodal system is a strongly demanded role of ports in the 21st century. In addition, ports should provide value-added services that they provide in the context of facilitating further the objectives of the supply chain system (Panayides and Song, 2009). De Langen *et al*. (2007) highlighted the necessity of including value added services as a part of the PPIs, suggesting three different but complementary types of 'port products'. Further, ICS integration cannot be excluded for TSCI, which measures the establishment and use of seamless communication systems and the degree of collaboration with other partners (Bichou and Gray, 2004, Panayides and Song, 2009). Marlow and Paixão Casaca (2003) demonstrated that integrated IT systems would contribute to total cost reduction in supply chains. Song and Panayides (2008) suggested that integrated IT systems lead to facilitating information exchange/sharing between partners.

Therefore, port/terminal supply chain integration perspectives should be included as critical criteria for port performance measurement. The related indicators which previous studies used are shown in Table 4.15. Port/terminal supply chain integration is divided into 4 categories: intermodal transport systems (ITST), value-added services (VAST), information and communication integration (ICIT) and supply chain integration practices (SCIPT).

Table 4.15 Port/terminal supply chain integration indicators

Author (date)	Category	Collected indicators
Song and Panayides (2008)	Use of technology for data sharing	Integrated electronic data interchange (EDI) for communication, integrated information systems (IT) to share data, computerized port service systems
	Relationships with shipping lines	Strategic partner, mutual trust, work together for higher service quality, work together to reduce costs
	Value-added services	Adequate facilities for adding value to cargos, capacity of hinterland and foreland for road/rail access, capacity to launch new tailored services, quick on taking decisions, a variety of services to handle the transferring of cargo, etc.
	Integration of transport modes	Adequate connectivity/operability for the ship/rail interface, adequate connectivity/operability for the ship/road interface, adequate connectivity/operability for the ship/inland waterway interface
	Relationships with inland transport providers	integrated electronic data interchange, integrated information systems, computerized port service systems, meeting with inland transport operators, etc.
	Channel integration practices and performance	Evaluation of the performance of the transport modes, evaluation of alternative routes for more efficient transportation of cargos, collaboration with other channel members, etc.

Table 4.15 Continued

Author (date)	Category	Collected indicators
Panayides and Song (2009)	Information and communication system	Integrated EDI for communication, integrated IT to share data, computerized port service systems, latest IT in the industry
	Value-added services	Facilities to add value to cargos, service adaptation to customers, launch tailored services, services to handle inter-mode transfers, capacity to efficiently convey cargo, tailored services to market segments
	Multimodal systems and operations	Connectivity for multimodal interface, reliability for multimodal operations, cost-effective multimodal operations, efficient multimodal operations
	Supply chain integration practices	Evaluate alternative routes for efficient transportation, collaborate with channel members for channel optimization, identify competing channels for cargos that might flow through port, benchmark logistics/SCM options vis-à-vis competing ports, identify least cost options for transport of cargos to hinterland destinations
Woo *et al.*, (2013)	Information and communication system	Providing information concerning shipment and cargo tracking, Using integrated EDI to communicate with partners in the supply chain, Adopting computerized service systems for supply chain operations, Using the latest IT technology to support supply chain goals
	Long-term relationships	Reducing channel complexity to closely work with a selected set of supply chain members, We have facilitated a strong and long-term supply chain relationship fostering cooperation with each other Having guidelines for developing and maintaining LTR with supply chain members
	Value-added services	Having adequate facilities for adding value to cargos, Capable of adapting a service to meet the customers' specifications, Capable of launching new tailored services should the need arise, Capable of delivering services tailored to different market segments
	Inter-modal transport services	Having the capacity to convey cargo through the most diversified routes/modes in the least possible time, Having reliable service operations for the multimodal interface, Providing cost-effective multimodal operations, Evaluating alternative routes for the more efficient multimodal transport of containers via our terminal
	Supply chain integration practices	Collaborating with other supply chain partners to plan for greater supply chain optimization, seeking to identify other competing supply chains for containers that might flow through our terminal, comparing the cost and time of cargos flowing through our port and those of the cargos flowing through other competitive ports, seeking to identify least cost options for the transport of cargos to hinterland destinations

4.2.5.1 Intermodal transport systems

A port is a bilateral logistics intersection place where four modes such as ocean ships, short-sea/river ships, road and rail transportations cross to move goods to sea or land sides. In 2007, seaborne trade through ports accounted for approximately 90% and 70% of global trade in terms of volume and value, respectively (Nam and Song, 2011). In the light of this, ports need to provide an adequate connectivity to both sea side and land side and the well-established operations between each transport mode. This is a very critical determinant of a port's trade competitiveness. In practice, the importance of this aspect can be easily found from many studies (Notteboom and Winkelmans, 2001, Notteboom and Rodrigue, 2005, UNCTAD, 2006, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al*., 2011a, Woo *et al*., 2013). UNCTAD (2006) emphasised that connectivity and transport integration are among the most important factors and play an increasingly important role in the recent global geography of trade changes. Woo *et al*. (2011a) suggested that the promotion of an efficient intermodal system is an essential role of port authorities in the 21st century in order to secure cargo under highly competitive port conditions. Marlow and Paixão Casaca (2003) argued that agile ports entail a reliable and adequate multimodal process which is at the heart of lean port competitiveness. The indicators used by Song and Panayides (2008), Panayides and Song (2009) and Woo *et al*. (2013) are as shown in Table 4.16.

Table 4.16 Potential indicators for intermodal transport system

Category	Related indicators	Reference
Intermodal transport systems	Adequate connectivity/operability for the ship/rail interface, adequate connectivity/operability for the ship/road interface, adequate connectivity/operability for the ship/inland waterway interface	Song and Panaides (2008)
	Connectivity for multimodal interface, reliability for multimodal operations, cost-effective multimodal operations, efficient multimodal operation	Panayides and Song (2009)
	Having the capacity to convey cargo through the most diversified routes/modes in the least possible time, having reliable service operations for the multimodal interface, providing cost-effective multimodal operations, evaluating alternative routes for the more efficient multimodal transport of containers via our terminal	Woo *et al*. (2013)
	Maritime connectivity, intermodal connectivity and quality of customs procedures.	ESPO (2010)

4.2.5.2 Value-added services

Panayides and Song (2009, p135) defined value-added services as *"the ability of the port to add value to the services that it provides in the context of facilitating further the objectives of the supply chain system"*. Ports have contributed themselves to the clusters of economic activities, where value-adding activities take place (De Langen, 2004). The similar stance such as the dynamic nodes in the complex international production/distribution network and the integrated transport centres and logistics platforms for international trade can be identified from the WORKPORT model (Beresford *et al*., 2004). This leads ports to change their functional role from the simple cargo loading/discharging place to one of the most important nodes in global logistics supply chains. For example, logistics facilities such as warehousing have been more incorporated into the specific requirements of their users with higher quality storage equipped with air-conditioning, high-rack storage and computerized control rather than the simple warehousing functions previously provided (UNCTAD, 1992, Beresford *et al*., 2004). Other evidence is found that a number of newly developed ports, especially in Asia, have developed dedicated areas for attracting logistics facilities and manufacturing facilities within the port area in order to provide value-added services. De Langen *et al*. (2007) provided the necessity of including value added services as a part of the PPIs and distinguished them into three different but complementary types of 'port products': cargo transfer product (e.g. terminal handling, towage, pilotage, etc.), logistics product (e.g. repacking, labelling, quality inspection, etc.) and port manufacturing products (e.g. goods produced by manufacturing facilities in a port area). The indicators used by previous studies for value-added services include different contexts of operation, capacity and facility on cargos, transport modes and services as shown in Table 4.17.

Table 4.17 Potential indicators for value-added services

Category	Related indicators	Reference
Value-added services	Adequate facilities for adding value to cargos, capacity of hinterland and foreland for road/rail access, capacity to launch new tailored services, quick on taking decisions, a variety of services to handle the transferring of cargo, etc.	Song and Panaides (2008)
	Facilities to add value to cargos, service adaptation to customers, launch tailored services, services to handle inter-mode transfers, capacity to efficiently convey cargo, tailored services to market segments	Panayides and Song (2009)
	Having adequate facilities for adding value to cargos, capable of adapting a service to meet the customers' specifications, capable of launching new tailored services should the need arise, capable of delivering services tailored to different market segments	Woo *et al*. (2013)

4.2.5.3 Information and communication systems

Panayides and Song (2009, p135) defined ICS as *"the establishment and use of seamless communication systems that facilitate efficient servicing of supply chain operations and achievement of supply chain goals"*. The importance of ICS, core factor for seaport terminal integration among partners in supply chains, has been emphasised by scholars (Marlow and Paixão Casaca, 2003, Song and Panayides, 2008, Panayides and Song, 2009, Woo *et al.*, 2013). Marlow and Paixão Casaca (2003) demonstrated that integrated IT systems would contribute to total cost reduction in supply chains through improving data processing treatment and avoiding document duplication. Song and Panayides (2008) suggested that integrated information technology is crucial for facilitating information exchange/sharing between partners in the supply chain. Woo *et al*. (2013) also emphasised that integrated ICS can be achieved by not only setting up systems and processes but also the activity undertaken through ICS (i.e. information sharing). The related indicators which previous studies used are shown in Table 4.18.

Table 4.18 Potential indicators for information and communication systems

Category	Related indicator	Reference
Information and communication systems	Integrated electronic data interchange (EDI) for communication, integrated information systems (IT) to share data, computerized port service systems	Song and Panaides (2008)
	Integrated EDI for communication, integrated IT to share data, computerized port service systems, latest IT in the industry	Panayides and Song (2009)
	Providing information concerning shipment and cargo tracking, using integrated EDI to communicate with partners in the supply chain, adopting computerized service systems for supply chain operations, using the latest IT technology to support supply chain goals	Woo *et al*. (2013)

4.2.5.4 Supply chain integration practices

Supply chain integration practices are a crucial category of the port/terminal supply chain integration (Panayides and Song, 2009). Song and Panayides (2008) and Panayides and Song (2009) identified SCIP as collaboration with other partners for planning and organising processes and procedures beyond its boundaries and monitoring/comparing performance of services (Bichou and Gray, 2004), seeking more cost and time-effective routes and process (Notteboom and Rodrigue, 2005). According to Woo *et al*. (2013), interviewees perceived

SCIP as the business practices changing from being reactive, fragmented and intra-organisational to being proactive, integrated and inter-organisational. The indicators used by previous studies are shown in Table 4.19.

Table 4.19 Potential indicators for supply chain integration practices

Category	Related indicators	Reference
Supply chain integration practices	Evaluation of the performance of the transport modes, evaluation of alternative routes for more efficient transportation of cargos, collaboration with other channel members, identify competing channels for cargos that might flow through port, benchmark logistics/SCM options vis-à-vis competing ports, identify least cost options for transport of cargos to hinterland destinations	Song and Panaides (2008)
	Evaluate alternative routes for efficient transportation, collaborate with channel members for channel optimization, identify competing channels for cargos that might flow through port, benchmark logistics/SCM options vis-à-vis competing ports, identify least cost options for transport of cargos to hinterland destinations	Panayides and Song (2009)
	Collaborating with other supply chain partners to plan for greater supply chain optimization, seeking to identify other competing supply chains for containers that might flow through our terminal, comparing the cost and time of cargos flowing through our port and those of the cargos flowing through other competitive ports, seeking to identify least cost options for the transport of cargos to hinterland destinations	Woo *et al.* (2013)

4.2.6 Sustainable growth performance indicators

Sustainability is referred to as the intersection of social, environmental and economic performances that deliver long-term effectiveness for the natural environment, society and firm (Carter and Rogers, 2008). Despite increasingly adopting the term sustainability, there has been little emphasis on the issue in the maritime industry (Lam, 2015). Due to legislation and the requirement to fulfil corporate social responsibility (CSR), ports' roles in the 21st century era are required to enhance environment, safety and security and social and economic responsibility (ESPO, 2010). Hence, ports need to pay more attention to promote long-term sustainable growth with ecological health and social and economic contributions.

Woo *et al*. (2013) investigated the economic impacts (value added, direct and indirect employment, etc.) of ports on the regional and national economy, which analysed effects of clustering and performance in the Netherlands. De Langen (2002) identified a shortlist of socio-economic, environmental and governance indicators and investigated the performance of the European port sector on the society, the environment and the economy. ESPO (2010) and Brooks *et al*. (2011) identified 2 safety and security indicators as common evaluation criteria of port users' perception. Brooks and Schellinck (2013) identified 3 safety and security indicators for their port performance framework that reflects port evolutionary changes. The related indicators which previous studies used are shown in Table 4.20. Sustainable growth performance is divided into 3 categories: safety and security (SSS), environment (EVS) and social engagement (SES).

Table 4.20 Sustainable growth performance indicators

Author (date)	Category	Collected indicators
De Largen (2002)	Socio-economic	Value added on national and regional socio-economy
IMO and ILO (2003)	Safety and security	ISPS code (detect/assess security threats, preventive measures against security incidents)
ESPO (2010)	Socio-Economic impact Environmental Governance	Employment, value added Carbon footprint, total water consumption, amount of waste and environmental management Reporting corporate and social responsibility and autonomous management
Woo *et al.* (2011a)	Safety and security	Compliance with regulation, number of accidents, number of accidents prevented
Brooks *et al*. (2011)	Safety and security	Port is safe, port is secured
Brooks and Schellinck (2013)	Safety and security	Port is safe, port is secured

4.2.6.1 Safety and security

The significance of safety and security issues has been enhanced with national and international concerns since the terrorist attacks of 11 September 2001. Hence, a number of international conventions and legislations have been introduced to improve the safe and security levels of international maritime trade. The initial movement started in the United States (the Trade Act of 2002, the Maritime Transportation Security Act 2002, Presentation of Vessel Cargo Declaration to Customs (24-hour-rule), the Custom Trade Partnership Against Terrorism (C-TPAT), the Container Security Initiative (CSI) and Operation Safe Commerce (OSC)), and then the International Maritime Organization (IMO) adopted the International Ship and Port Facility Security (ISPS) Code in 2002 and implemented it in 2004. In addition, the European parliament and council established regulation on enhancing security of ship and port facilities in March 2004 (REGULATION (EC) No 725/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL). These legislations focus on improving and enhancing the safety and security of port and shipping industries through a tighter control of incoming containers, pre-inspection of selected loading containers. In a long term stance, an appropriate safety and security scheme is a powerful role for improving port efficiency and competitiveness (Beresford *et al*., 2004, Woo *et al*., 2011a). It highlights that the safety and security issue is an important criterion in the container port performance measurement. The related indicators which previous studies used are shown in Table 4.21.

Table 4.21 Potential indicators for safety and security

Category	Related indicator	Reference
Safety and security	ISPS code (detect/assess security threats, preventive measures against security incidents)	IMO and ILO (2003)
	Compliance with regulation, number of accidents, number of accidents prevented	Woo *et al.* (2011a)
	Port is safe, port is secured	Brooks *et al*. (2011)
	Port is safe, port is secured	Brooks and Schellinck (2013)

4.2.6.2 Environment

Recently, port stakeholders have paid significant attention to port environmental issues to minimise environmental pollution during its operation and development. Peris-Mora *et al*. (2005) stressed that the port authority should have a set of strategic indicators for environment performance in designing the long-term transport policy. Furthermore, monitoring on port environmental conditions is a key part of maintaining port operations related to ship navigation and cargo handling and implementing environmental management systems (EMS) to prevent any risky situations (Darbra *et al*., 2009). In general, EMS is a useful application for periodical assessment through the comparison of the current situation with that corresponding to previous years as well as the evaluation of the opportunities for improvement (Darbra *et al*., 2005).

However, this issue in port performance literature has rarely been addressed by researchers and practitioners. ESPO (2010) classified 19 environmental performance indicators (EPIs) into high significance measures and 31 EPIs into medium significance measures for port performance measurement and then identified the final 7 EPIs for performance measurement. The EPIs cover a wide range of emissions, energy and water consumption and noise issues.

Table 4.22 Potential indicators for environment

Category	Related indicator	Reference
Environment	Carbon footprint, total water consumption, total energy consumption, amount of waste, waste recycle and environmental management, water/air/land pollution	Peris-Mora *et al*., 2005; Darbra *et al*., 2009; ESPO, 2010

4.2.6.3 Social engagement

Social engagement is referred to as the measurement of corporate social responsibility (CSR) in terms of employment creation and reporting corporate social responsibility. These two indicators are extracted from the project of ESPO (2010). Employment creation in CSR is one of the most frequently used indicators in order to measure regional economic impacts. According to Bichou (2006), studies regarding port impacts on society and economy in general are measured by gross added value (i.e. direct, indirect) on port hinterlands and foreland areas. Grewal and Darlow (2007) suggest the key concerns and issues for CSR engagement including financial and time costs, risks involved with disclosure, how to engage in CSR, standardisation and value of the process. De Langen (2002)'s study is a good example of the port economic impacts, which analysed port cluster impact in the Netherlands, inter alia, over 70,000 persons and over 40,000 persons are directly and indirectly employed in Rotterdam and Amsterdam port areas, respectively. ESPO (2010) identified 6 socio-economic indicators in the pre-selection phase and then reduced them to 2 indicators including direct employment and direct added value (ESPO, 2011). In addition, the studies suggested the importance of information disclosure to enhance community integrity (ESPO, 2010, ESPO, 2011).

Table 4.23 Potential indicators for social engagement

Category	Related indicator	Reference
Social engagement	Reporting corporate and social responsibility and autonomous management, Employment Regional GDP	De Langen (2002, 2007), ESPO (2010, 2011)

4.2.7 Potential port performance indicators

The potential PPIs which were rigorously extracted from literature review in the previous sections are shown in Table 4.24. However, there are still problems such as overlap among the PPIs. For example, some PPIs (i.e. vessel working time at berth, throughput/number of cranes, crane productivity, labour productivity, vessel turnaround, vessel waiting time, truck turnaround, container dwell time) in CA have been also used as indicators to measure service quality (i.e. availability and capability of employees, accessibility of port premises for pick-up and delivery, capability of dockworkers, speed of stevedores' cargo loading/unloading, timely vessel turnaround, timeliness of maritime services, on-schedule performance). In addition, simiar natures of PPIs can be found throughout the dimensions. For example, PPIs such as throughput/number of cranes, crane productivity (lift/hr), speed of stevedores' cargo loading/unloading are overlap, representing the measurement of the crane productivity. The potential PPIs need to be clarified and classified appropriately to represent their associated upper-level indicators. To validate feasibility and suitability of the potential indicators, a semi-structured interview is applied since the approach is a suitable method for an exploratory study to find out new insights, in particular, for in-depth qualitative research. An empirical evidence or an exploration can justify the suitability and the feasibility of the selected indicators.

Table 4.24 Potential port performance indicators

Dimension	Principal-PPIs	PPIs	literature
Core activities (CA)	Output (OPC)	Throughput (TEUs) Vessel calls (number) Capacity of vessel calls (tons) Throughput growth (TEUs/year) Vessel call size growth (tons/no. of vessels)	UNCTAD, 1976; De monie, 1987; Roll and Hayuth, 1993; Tongzon, 1995a; 1995b; Marlow and Paixão Casaca, 2003;Cullinane *et al*., 2006; Brooks, 2007; Woo *el al*., 2011a
	Productivity (PDC)	Vessel working time at berth Ship load rate (throughput/average vessel capacity) Berth utilization (throughput/berth length) Berth occupancy (ship time at berth/terminal operation time) Throughput/number of cranes Throughput/terminal area Crane productivity (lift/hr) Yard utilization (throughput /area of container yard) Labour productivity (TEU/employee)	
	Lead time (LTC)	Vessel turnaround (ship staying time in port (hr)) Vessel waiting time (vessel waiting time to be berthed, vessel waiting time to start discharging operations) Containers per working hour per ship Truck turnaround (truck staying time in port (minute)) Container dwell time (container staying time in port (day)) Cargo waiting to transit from one mode to another (time in storage and time from quay to storage) Transferring cargo from storage to net mode of transport Time spent in carrying out logistics activities required by customers that add value Time for goods to be cleared (if such is to be done at port level) Time spent by cargo awaiting departure of next mode of transport	

Table 4.24 Continued

Dimension	Principal-PPIs	PPIs	literature
Supporting activities (SA)	Human capital (HCS)	Knowledge and skills Capabilities Training and education Commitment and loyalty Workforce's understanding on environments Experience Judgement Intelligence Staffing Performance systems	Barney, 1991; Heskett and Schlesinger, 1994; Marlow and Paixão Casaca, 2003; Kaplan and Norton 2004; Albadvi *et al*., 2007; Brown *et al.*, 2011; Woo *et al*., 2013
	Organisation capital (OCS)	Culture Structure Leadership Size Formal reporting structure Formal and informal planning, controlling, and coordinating systems Inter-organizational relationships Alignment Teamwork	
	Information capital (ICS)	IT systems Database Networks IT investment (strategic, informational, and transactional) Conversion effectiveness (top management commitment to IT, previous firm experience with IT, user satisfaction with systems, the turbulence of the political environment within the firm) Quality of data IT in communication IT in production and operations IT in decision support IT in administration and pecuniary affairs	
Financial strength (FS)	Profitability (PFF)	Revenue growth operating profit margin (operating profit/revenue) Net profit margin (net income/revenue) Return on total assets Return on fixed assets Ancillary revenue as % of gross revenue Average days accounts receivable Port-related profit as % of port-related revenue, Terminal charges as a % of gross revenue	Su *et al*., 2003; Bitchou and Gray, 2004; Brooks, 2007; PWC 2010
	Liquidity & Solvency (LSF)	Current ratio (current assets/current liabilities) EBITDA/net finance cost Fixed assets to equity ratio Debt to total asset (total debt/total assets) Debt to equity (total debt/owner's equity)	

Table 4.24 Continued

Dimension	Principal-PPIs	PPIs	literature
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 Availability and capability of employees Accessibility of port premises for pick-up and delivery (gate congestion) Capability of dockworkers Speed of stevedores' cargo loading/unloading Timely vessel turnaround Timeliness of maritime services On-schedule performance Flexibility Annual number of clams	Marlow and Paixão, 2003; Woo *et al.*, 2011a; Brooks and Schellinck, 2013
	Service costs (SCU)	Overall service cost Cargo handling charges Cost of terminal ancillary services Annual costs incurred by the port Annual cost of sea transport Ship costs by unit of cargo carried Port facility usage charge	
Terminal supply chain integration (TSCI)	Intermodal transport systems (ITST)	Sea-side connectivity Land-side connectivity Reliability of multimodal operations Efficiency of multimodal operations Adequate connectivity/operability for the ship/rail interface Adequate connectivity/operability for the ship/road interface Adequate connectivity/operability for the ship/inland waterway interface Cost-effective multimodal operations	Song and Panaides, 2008; Panayides and Song, 2009; ESPO, 2010; Woo *et al.*, 2013
	Value-added services (VAST)	Facilities to add value to cargos Service adaptation to customers Capacity to provide different value-added services Tailored services to customers Capacity of hinterland and foreland for road/rail access Quick on taking decisions A variety of services to handle the transferring of cargo Capable of delivering services tailored to different market segments	
	Information/ communication integration (ICIT)	Integrated EDI for communication Integrated IT to share data Computerized port service systems Collaborate with Channel members for channel optimisation Latest port IT systems Providing information concerning shipment and cargo tracking	

Table 4.24 Continued

Dimension	Principal-PPIs	PPIs	literature
Terminal supply chain integration (TSCI)	Supply chain integration practices (SCIP)	Evaluate alternative routes for efficient transportation Collaborate with channel members for channel optimization Identify competing channels for cargos that might flow through port Benchmark logistics/SCM options vis-à-vis competing ports Identify least cost options for transport of cargos to hinterland destinations	Song and Panaides, 2008; Panayides and Song, 2009; ESPO, 2010; Woo *et al*., 2013
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 Compliance with regulation Number of accidents Number of accidents prevented Detect/assess security threats Preventive measures against security incidents	De Largen, 2002; IMO, 2002; Peris-Mora *et al*., 2005; Darbra *et al*., 2009; ESPO 2010; Woo *et al.,* 2011a
	Environment (EVS)	Energy consumption Waste recycling Environnent management programmes Water pollution Land pollution Air pollution	
	Social engagement (SES)	Employment Regional GDP Disclosure of information	

4.3 SELECTION OF PORT PERFORMANCE INDICATORS

4.3.1 Administration of the interviews

For the selection of PPIs from the potential PPIs identified in the pre-selection section, the semi-structured interviews are applied to assess the suitability of the potential indicators and to test the feasibility of the selected indicators (Okoli and Pawlowski, 2004). Using purpositive and snowball smplings, the researcher contacted to twenty-five 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 to the consent letters, but in order for fair representation from each group 1 expert from government was invited. A panel of ten experts[2] were asked to review the potential PPIs under 17 principal-PPIs and 6 dimensions. 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. The interviews were undertaken for 1 month between March and April in 2014. Each interview lasted 1-2 hours and recorded by note-taking. The transcript of the interviews was used for PPIs selection. The aim of the semi-structrued interviews in this study is to identify appropriate PPIs for port performance measurement, but also whether the PPIs represent appropriately their associated upper-level PPIs. In other words, this survey is to investigate whether the PPIs can signify a number of properties such as its usability, adaptability and relevance to the port commuitiy for port performance measurement. This will be helpful for decision makers to focus on critical issues which need constant monitoring. In practice, it is quite common for companies to have 50 to 60 measures, both financial and non-financial (Hon, 2005).

Before asking the related questions, the researcher explained to the interviewees the problems in the potential PPIs. The researcher also explained types of PPIs (i.e. quantitative and qualitative), data types (i.e. primary and secondary) and data collection methods. For example, the quantitative data (i.e. CA and FS) can be collected from terminal operating companies and information systems/databases managed by port authorities and Korean government (i.e. secondary data). The qualitative PPIs are collected using questionnaire results obtained from three groups of terminal operators (TO: judgement on SA, TSCI, SSS, EVS), users (i.e. shipping lines and freight forwarders, PU: judgement on US, TSCI) and

[2] See the interviewees' detail in chepter 3.

administrators (i.e. port authority and government, AD: judgement on SG) to assess their own associated PPIs to measure each port's performance (i.e. primary data). The researcher also mentioned that the six dimensions for port performance measurement are intertwined in practice. With regard to 'employment' in SG, for example, an alternative port can be judged with a good performance on the 'employment' PPI when the port has a huge contribution to create an employment opportunity or maximises employment to fulfil CSR. However, the situation could simultaneously deteriorate the FS of the firm, leading to increased costs and can have an adverse effect on 'labour productivity (throughput /number of employee)' in CA. In this regard, the mixed use of benefit and cost PPIs needs to be taken into account to represent interests of different port stakeholders in the context of port performance measurement. Due to the complexity of the PPIs hierarchy, a number of PPIs, different types of PPIs, different types of data and data collection methods, the researcher needed to explain and manage interview process efficiently to sovle given problems that the interviews intended to do.

At the stage of each interview, general issues in port performance measurement such as a multi-stakeholder dimension were discussed to get to the more specific questions this study intened to ask. The following questions were asked to grasp a common understanding about the mult-stakeholder dimension with both quatitative and qualitative PPIs. The researcher asked further questions depending on the responses given by the interviewees.

To explore the mult-stakeholder dimension approach, and the questions are:

"Do you think a stakeholder-driven approach in port performance measurement is useful to cover the wide-ranging objectives and desired results of stakeholders?"

The main questions in the interviews were asked to identify and classify the PPIs which can represent their associated dimensions and principal-PPIs, and they were:

"In terms of the mult-stakeholder dimension approach, do you think the dimensions and their associated principal-PPIs are well classified?", and

*"Could you tell me whether each PPI represents their associated upper-level PPIs?", a*nd,

"Could you identify and classify the PPIs to represent their associated dimensions and principal-PPIs? if necessary, modification, removal, division and combination are allowable"

4.3.2 Findings from the interviews

Previous literature suggests that performance measurement has become an important tool in stakeholder management and to achieve a sustainable competitive position (Notteboom and Winkelmans, 2003, Dooms and Verbeke, 2007, Woo *et al.*, 2011a). Most interviewees mainly agreed with the importance of the multi-stakeholder dimension in port performance measurement. They mainly mentioned that,

Under the fierce rivalry in the port industry, stakeholder-driven management practices are crucial to secure long-term relations with key stakeholders. With respect to this, performance measurement has become an important tool in stakeholder management because shippinglines have a market bargaining power. If they are dissatisfied with TOCs' services, they will shift a port call.

A professor mentiond that,

There are many important criteria in applying the Multi-stakeholder dimensiton in port performance measurement. The relevance of indicators to specific stakeholder groups have to be sufficiently dealt with to represent the interests of different stakeholders.

An expert from a shipping line mentioned that,

TOCs provide their terminal performance reports when a shippingline gives a public notice of a bid to see appropriate TOC for cargo operations, on some occasions, the performance report is highly evaluated.

However, the experts from TOCs and PA mentioned that,

I do believe that the the mult-stakeholder dimension in port performance measurement (or port management) is important. In practices, TOCs or PAs have generally utilised a set of terminal productivity and efficiency PPIs because the data can be readily available, or because the qualitative PPIs are too ambiguous to interpret them in a meaningful way.

This implies that the experts have similar views on the multi-stakeholder dimension in port performance measurement. The main challenges are: how the relevant PPIs to specific stakeholder groups have to be dealt with; how the PPIs are measured, controlled, managed and interpreted because the challenging multi-stakeholder environment complicates port performance measurement.

Questions 2, 3 and 4 were used to obtain the construct validation for the decision tree, identifying appropriate PPIs that can represent their upper-level PPIs.

Examples of interviewees' main comments are shown as follows:

- *TOs are not concerned with most PPIs in SCIP, but 3PLs may be. And recommended to combine SCIP and ICIT. Only 'collaboration with channel members for channel optimization' is combined to ICIT.*
- *'throughput (TEUs)' and 'throughput growth (TEUs/year) are overlap. 'vessel calls (number)', '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)'. Some interviewees preferred to use 'throughput (TEUs)', 'vessel calls (number)', 'capacity of vessel calls (tons)' for OPC. For a longitudinal study, however, other experts suggested to use 'throughput growth (TEUs/year) and 'vessel call size growth (tons/no. of vessels)' to investigate the improvement of ports/terminal within different timeframes. In addition, the latter would be better in setting assessment grades.*
- *'vessel working time at berth' and 'vessel waiting time' are a part of 'vessel turnaround (ship staying time in port (hr))'. Due to the difficulty of data collection of the former two PPIs, experts suggested using 'Vessel turnaround (ship staying time in port (hr))' to measure vessel lead-time.*
- *Some PPIs in SFU such as 'accessibility of port premises for pick-up and delivery (gate congestion)', 'speed of stevedores' cargo loading/unloading', 'timely vessel turnaround', 'timeliness of maritime services', 'on-schedule performance', etc. are more correlated with PDC and LTC.*
- *The PPIs of the EVS were originally defined as 'air pollution', 'land pollution' and 'water pollution', 'energy consumption', 'waste recycling' and 'environment management systems' but the experts commented that the implementation schemes for reducing the specified sources of pollution are more important than the pollutions themselves.*
- *With regard to the quantitative PPIs for port performance measurement, majority of the interviewees mentioned that a researcher should take into account the collectability of the data. If you cannot collect the data, you cannot measure it. If you cannot measure it, you cannot control, manage and improve it.*

4.3.3 Selection of port performance indicators

Through the iterations and feedbacks, some PPIs were modified, removed, divided and combined to one delegate PPI from the duplicated and correlated PPIs. A PPIs-decision tree is constructed in the form of a multilevel hierarchy for container port/terminal performance measurement (Table 4.25). The hierarchical decision model is a good application for effectively presenting MCDM problems. On top of that, in a complex decision making situation, the hierarchical decision model is a useful tool and enables the complexity to be simplified (Yeo *et al*., 2014). Furthermore, the model easily adds or modifies new data in a flexible and instant way (Sen and Yang, 1995, Yang *et al*., 2009b). In the hierarchical model, the overall goal is shown in the first level. The second level has 6 dimensions of core (operational) activities (CA), supporting activities (SA), financial strength (FS), users' satisfaction (US), terminal supply chain integration (TSCI), and sustainable growth (SG). In addition, the dimensions can be further broken down to their individual associated sub-PPIs in order to facilitate the measurement. If a sub-PPI is still too difficult to evaluate directly, it may be further decomposed into more detailed indicators. The decomposition process reaches until a point where the indicators can be directly evaluated using objective (quantitative) data or by experts' judgements.

Table 4.25 The hierarchy of port performance indicators (PPIs)

Dimension	Principal-PPIs	PPIs	literature
Core activities (CA)	Output (OPC)	Throughput growth (TEUs/year) Vessel call size growth (tons/no. of vessels)	UNCTAD, 1976; De monie, 1987; Roll and Hayuth, 1993; Tongzon 1995a; 1995b; Cullinane *et al*., 2006; Brooks, 2007; Woo *el al*., 2011a
	Productivity (PDC)	Ship load rate (throughput/average vessel capacity) Berth utilization (throughput/berth length) Berth occupancy (ship time at berth/terminal operation time) Crane productivity (lift/hr) Yard utilization (throughput /area of container yard) Labour productivity (TEU/employee)	
	Lead time (LTC)	Vessel turnaround (ship staying time in port (hr)) Truck turnaround (truck staying time in port (minute)) Container dwell time (container staying time in port (day))	
Supporting activities (SA)	Human capital (HCS)	Knowledge and skills Capabilities Training and education Commitment and loyalty	Barney, 1991; Heskett and Schlesinger, 1994; Marlow and Paixão Casaca, 2003; Kaplan and Norton 2004; Albadvi *et al*., 2007; Brown *et*
	Organisation capital (OCS)	Culture Leadership Alignment Teamwork	

	Information capital (ICS)	IT systems Database Networks	*al.*, 2011; Woo *et al.*, 2013
Financial strength (FS)	Profitability (PFF)	Revenue growth Operating profit margin (operating profit/revenue) Net profit margin (net income/revenue)	Su *et al.*, 2003; Bitchou and Gray, 2004; Brooks, 2007; PWC 2010
	Liquidity & Solvency (LSF)	Current ratio (current assets/current liabilities) Debt to total asset (total debt/total assets) Debt to equity (total debt/owner's 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
	Service costs (SCU)	Overall service cost Cargo handling charges Cost of terminal ancillary services	
Terminal supply chain integration (TSCI)	Intermodal transport systems (ITST)	Sea-side connectivity Land-side connectivity Reliability of multimodal operations Efficiency of multimodal operations	Song and Panaides, 2008; Panayides and Song, 2009; ESPO, 2010; Woo *et al.*, 2013
	Value-added services (VAST)	Facilities to add value to cargos Service adaptation to customers Capacity to provide different value-added services 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.*, 2011a
	Environment (EVS)	Carbon footprint Water consumption Energy consumption Waste recycling Environment management programmes	
	Social engagement (SES)	Employment Regional GDP Disclosure of information	

CHAPTER 5 A NOVEL PORT PERFORMANCE MEASUREMENT: PPIs UNCERTAINTY MODEL

This chapter aims to propose a new conceptual PPI measurement model using a hybrid approach of a FER and an AHP. The AHP is used to determine the relative weights of the PPIs. Furthermore, the FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs. An analysis of 12 container terminals in 4 major ports in South Korea is conducted as real cases to validate the proposed framework. The empirical results indicate that the hybrid approach attempting to use quantitative modelling for dealing with the uncertainties can be successfully fulfilled.

5.1 INTRODUCTION

Chapters 2 and 3 have investigated the related question of 'what to measure' for container port performance. With regard to the question of 'how to measure port performance', this chapter develops a conceptual port performance measurement model that represents a powerful performance measurement tool and offers a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner.

Decision-makers typically need to assess the level of uncertainty and complexity in the port/terminal environment. The decisions are usually made on multiple uncertain attributes. Consequently, this chapter needs to deal with the inherent data uncertainties which are unavoidable in port/terminal operational contexts. The data uncertainty problems in port performance measurement can probably be caused by 1) there are different types of port performance assessments (numbers, linguistic terms or stochastic values) in terms of the features of decision attributes and alternatives; 2) the probability of an imprecise assessment exists in the decision making process due to insufficient information, inability of experts and lack in expertise; and 3) the decision problems in port performance measurement involve multiple PPIs of both a quantitative and qualitative nature in multiple criteria decision making (MCDM), which makes it difficult to fully take into account all PPIs in one framework (Yang and Xu, 2002, Yang *et al*., 2009c, Yeo *et al*., 2014). However previous studies have done little on dealing with the challenges of the uncertainty and complexity in the container port performance context.

This chapter aims at proposing a new conceptual PPI measurement model using a hybrid approach of a fuzzy logic based evidential reasoning (FER) (Yang and Xu, 2002) and analytic hierarchy process (AHP) (Saaty, 1980) for solving MCDM problems to address the challenges (i.e. MADM and uncertainty) in port performance measurement. The AHP is a suitable application when comparing the importance or rating of a criterion against that of other criteria at the same level in the hierarchy decision tree (Saaty, 1980). The combination of fuzzy logic and evidential reasoning is a powerful tool in the case that the task is essentially a process of MADM under uncertainty, requiring analysts to derive rational decisions from uncertain and incomplete data related to different quantitative and qualitative determinants (Yeo *et al.*, 2014). The AHP is used to determine the relative weights of the PPIs. Furthermore, the FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs.

An analysis of 12 container terminals in 4 major ports in Korea is conducted to validate the proposed framework. The empirical results indicate that the hybrid approach attempting to use quantitative modelling for dealing with the uncertainties problems can be successfully fulfilled. This chapter attempting to use quantitative modelling for measuring the uncertainties in port performance measurement is among the pioneering studies.

In the next section, literature with regard to decision making methodologies is introduced. In section 5.3, a FER framework for evaluating PPIs with a detailed description of each step is illustrated. In section 5.4, the proposed framework for applying FER in evaluating port/terminal performance is empirically applied to 12 container terminals in Korea to test the validity and feasibility of the FER model. Finally, this chapter concludes with a discussion of results and recommendation for further research in section 5.5.

5.2 DECISION MAKING METHOD

The MCDM Problems in a complex uncertain situation involve multiple quantitative and qualitative indicators. When solving the problems, the complex and uncertain situations complicate the decision making practices. A hybrid approach of two or more methodologies has been proven to be a powerful supporting tool for solving the complex decision problems. Thus, this chapter reviews various MCDM methodologies in order to apply them to port performance measurement in an uncertain and complex port environment.

5.2.1 Fuzzy theory

5.2.1.1 Fuzzy set theory and membership function

A fuzzy set theory is a powerful tool in dealing with vagueness of human thoughts and expressions in making decisions (Zadeh, 1965). It permits vague information, knowledge and concepts to be used in an exact mathematical manner. Normally, in a fuzzy environment, the assessment grades (i.e. linguistic terms) for criteria are expressed by fuzzy numbers (i.e. triangular or trapezoidal fuzzy numbers) rather than crisp numbers. Furthermore, the fuzzy set theory can be easily combined with other methods for decision making issues.

The most commonly used membership functions in practice are the triangular and trapezoidal due to their simple formulas and computational efficiency (Kaufmann *et al.*, 1985, Kaufmann and Gupta, 1988). In general, the value of the membership function is indicated on the vertical axis with possible number from 0 to 1 while the domain of fuzzy set is indicated on the horizontal axis. The formula of the triangular membership function is shown in Eq. (5.1). In the case ‘m’ is a medium value where $u_A(x)$= 1, the lower and upper bounds are presented by ‘a’ and ‘b’ respectively as shown in Figure 5.1.

$$u_A(x) = \begin{cases} 0, (x < a) \\ \frac{1}{(m-a)}(x-a), (a \le x \le m) \\ 1, x = m \\ \frac{1}{(b-m)}(-x+b), (m \le x \le b) \\ 0, (x > b) \end{cases} \tag{5.1}$$

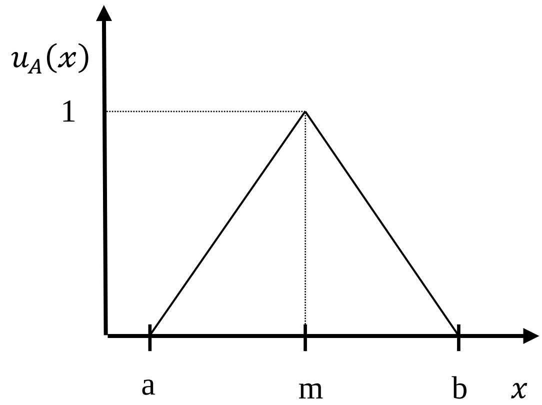

Figure 5.1 Triangular membership function

The formula of the trapezoidal membership function is shown in Eq. (5.2). In the trapezoidal membership function, ‘m’ and ‘n’ are medium values where $u_A(x)$= 1, the lower and upper bounds are presented by ‘a’ and ‘b’ as shown in Figure 5.2.

$$u_A(x) = \begin{cases} 0, (x < a) \\ \frac{1}{(m-a)}(x-a), (a \leq x \leq m) \\ 1, (m \leq x \leq n) \\ \frac{1}{(b-n)}(-x+b), (n \leq x \leq b) \\ 0, (x > b) \end{cases} \tag{5.2}$$

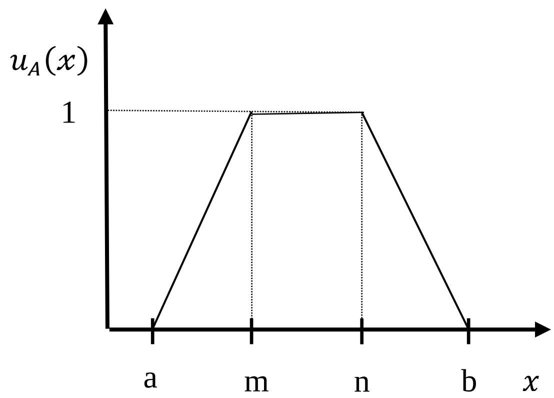

Figure 5.2 Trapezoidal membership function

5.2.1.2 *The algebra of fuzzy set*

Fuzzy membership function makes it possible to incorporate linguistic terms as a media for developing the algebra of fuzzy set theoretic operations, such as unions and intersections. For instance, let *A* and *B* be two fuzzy sets with membership functions of $\mu_A(x)$ and $\mu_B(x)$. The basic fuzzy operations are as follows (Zadeh, 1965):

$$\text{Union: } \mu(A \cup B)(x) = max(\mu_A(x), \mu_B(x)), \forall x$$

$$\text{Intersection: } \mu(A \cap B)(x) = min(\mu_A(x), \mu_B(x)), \forall x \quad (5.3)$$

$$\text{Complement: } \mu(\bar{A})(x) = 1 - \mu(A)(x), \forall x$$

where $\mu(A \cup B)(x)$ is a membership function of the fuzzy set $A \cup B$ while $\mu(A \cap B)(x)$ is a membership function of $A \cap B$. $\overline{\mathrm{A}}$ denotes a complement of *A*, and $\mu(\bar{A})(x)$ is a membership function of $\bar{A}$ while $\mu(A)(x)$ is a membership function of *A*.

Furthermore, if,

$$A = B, \text{ then } \mu_A(x) = \mu_B(x)), \forall x \textit{ (vice versa)}$$

$$A \subset B, \text{ then } \mu_A(x) \leq \mu_B(x)), \forall x \textit{ (vice versa)} \quad (5.4)$$

where '⊂' denotes a subset. From the operations fuzzy sets are always expressed by fuzzy membership function.

5.2.1.3 Operations of fuzzy numbers

Let *A* and *B* be two triangular fuzzy numbers parameterized by triples *(a1, a2. a3)* and *(b1, b2, b3)*, respectively. Then the operations between the two triangular fuzzy numbers can be conducted as follows (Wang and Chang, 2007):

$$A + B = (a1, a2, a3) + (b1, b2, b3) = (a1 + b1, a2 + b2, a3 + b3)$$

$$A - B = (a1, a2, a3) - (b1, b2, b3) = (a1 - b3, a2 - b2, a3 - b1)$$

$$A \times B = (a1, a2, a3) \times (b1, b2, b3) = (a1 \times b1, a2 \times b2, a3 \times b3) \quad (5.5)$$

$$A \div B = (a1, a2, a3) \div (b1, b2, b3) = (a1 \div b3, a2 \div b2, a3 \div b1)$$

Let *A* and *B* be two trapezoidal fuzzy numbers parameterized by quadruples *(a1, a2. a3, a4)* and *(b1, b2, b3, b4)*, respectively. Then the operation between the two trapezoidal fuzzy numbers are seen as follows (Kaufmann *et al.*, 1985, Kaufmann and Gupta, 1988):

$$A + B = (a1, a2, a3, a4) + (b1, b2, b3, b4) = (a1 + b1, a2 + b2, a3 + b3, a4 + b4)$$

$$A - B = (a1, a2, a3, a4) - (b1, b2, b3, b4) = (a1 - b4, a2 - b3, a3 - b2, a4 - b1)$$

$$A \times B = (a1, a2, a3, a4) \times (b1, b2, b3, b4) = (a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4) \quad (5.6)$$

$$A \div B = (a1, a2, a3, a4) \div (b1, b2, b3, b4) = (a1 \div b4, a2 \div b3, a3 \div b2, a4 \div b1)$$

5.2.1.4 Fuzzy rule base

Known as a knowledge-based or rule-based logic, a fuzzy logic system comprises a set of IF-THEN rules. IF-THEN rule is the core of a fuzzy logic system because all other components are easily implemented by fuzzy conditional statements in a reasonable and efficient manner (Sii *et al.*, 2001). In general, the rules are defined by human knowledge or human experts. The rules have two parts: an antecedent part (i.e. fuzzy input) and a consequent part (i.e. fuzzy output). The fuzzy knowledge/rule based IF-THEN rule can be expressed as follows:

$$R^k\text{: IF } x_1 \text{ is } A_1^k \text{ and ... and } x_n \text{ is } A_n^k\text{, THEN } y \text{ is } B^k \tag{5.7}$$

This form of statement is the multi-input-single-output case in which A_1^k ... A_n^k and B^k are input fuzzy sets and output fuzzy set respectively, and x_1 ... x_n and y are the input and output linguistic variables of the fuzzy sets respectively.

In FER based port performance measurement, qualitative input and output can be expressed by linguistic variables with degrees of belief (Yang *et al.*, 2009c, Yeo *et al.*, 2014). From this viewpoint, the above equation can be expressed as follows:

$$\begin{gathered} R^k\text{: } IF\ A_1^k\ and\ A_2^k\ and\ \dots\ and\ A_N^k, THEN\ \{(H_1, B_1^k), (H_2, B_2^k), \dots, (H_M, B_M^k)\} \\ \sum_{j=1}^{M} B_j^k \leq 1 \end{gathered} \tag{5.8}$$

where A_i^k stands for the linguistic term of the i^{th} antecedent PPI used in the k^{th} rule (R^k) and B_j^k represents the degree of belief which belongs to linguistic term H_j.

5.2.2 Analytic hierarchy process

The AHP introduced by (Saaty, 1980) assumes independence of one cluster from another cluster but it does not allow for feedback between clusters in a hierarchy (Saaty, 2004). 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 the decision maker to capture both subjective and objective aspects of a decision (Saaty, 2004). The decision is made based on scores obtained by pairwise comparisons between the criteria, in other words, the higher the score, the more important the criterion.

In this study, relative weights of PPIs' independency 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 measurement, and how much more?" A series of pairwise comparisons are based on the Saaty's nine-point scale ranging from 1 (equal) to 9 (extreme) as shown in Table 5.1. In the $n \times n$ matrix, $n(n-1)/2$ comparisons are required.

Then, the local weights of PPIs can be obtained by following Eqs. (5.9)-(5.11). Let e_{ij}^{l} be the relative importance judgement on the pair of the upper level 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. (5.9).

$$e_{ij} = \frac{1}{m} (e_{ij}^{1} + \cdots + e_{ij}^{l} + \cdots + e_{ij}^{m}) \tag{5.9}$$

Next, the synthesised ith criterion weight comparison between P_i and P_j by m experts can be calculated using Eq. (5.10).

$$\begin{gathered} w_i = \frac{1}{n} \sum\nolimits_{j=1}^{n} \left(\frac{e_{ij}}{\sum_{i=1}^{n} e_{ij}}\right) \\ \sum\nolimits_{i=1}^{n} w_i = 1 \end{gathered} \tag{5.10}$$

Lastly, another critical characteristic of the AHP is the consistency of the pairwise judgements by calculating a CR in Eq. (5.11). Where the value of CR is greater than 0.1 which indicates an inconsistency in the pairwise judgements and the experts needs to revise their pairwise judgements. Therefore, the judgements should inform an acceptable level with the CR of 0.10 or less. Where 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.

$$\begin{gathered} CI = \frac{\lambda_{max} - n}{n-1} \qquad CR = \frac{CI}{RI(Random\ consistency\ index)} \\ \lambda_{max} = \frac{\sum_{j=1}^{n} \frac{\sum_{i=1}^{n} w_i e_{ji}}{w_j}}{n} \end{gathered} \tag{5.11}$$

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 their local weights with the ones of their associated upper level PPIs.

The usage of this methodology is enormous enough regardless of areas, including in the wider maritime and port sector 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) and 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) study, 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 (2005) 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.

Table 5.1 The fundamental scale for making judgements

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate value

Table 5.2 The random index

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Saaty (1980)

5.2.3 Evidential reasoning

5.2.3.1 Introduction

The Evidential Reasoning (ER) approach is a powerful tool in dealing with MCDM under uncertainties. This methodology is developed on the basis of the Dempster-Shafer theory of evidence (D-S theory) which was initially generated by (Dempster, 1967) and further developed by Shafer (1976). The D–S theory was originally used for information aggregation in expert systems as an approximate reasoning tool (Buchanan and Shortliffe, 1984) and then used as a decision-making method under uncertainty (Yager, 1988, Yang and Singh, 1994, Yang, 2001, Yang and Xu, 2002).

Yang and Singh (1994) developed an ER algorithm for hybrid MCDM problems with both qualitative and quantitative attributes under uncertainty. In addition, following a series of research they developed the ER algorithm for MADM under uncertainty; Yang and Sen (1994) updated, Yang (2001) further modified, and Yang and Xu (2002) regenerated continuously and explained a new ER algorithm. The studies utilised a belief structure (i.e. degrees of belief, DoB) in assessing multiple criteria in a bottom level hierarchy and introduced the process of converting the bottom level criteria assessments to their associated top level criterion. Yang (2006) argued the main advantages of the ER approach in dealing with multiple quantitative and qualitative information under uncertainty as follows:

- To handle incomplete, uncertain and vague as well as complete and precise data.
- To provide its users with a greater flexibility by allowing them to express their judgments both subjectively and quantitatively.
- To accommodate or represent the uncertainty and risk that is inherent in decision analysis.
- As a hierarchical evaluation process, to offer a rational and reproducible methodology to aggregate the data assessed.
- To easily obtain the assessment output using mature computing software, IDS.

Since introduction of the fuzzy logic based evidential reasoning (FER) in the 1990s (Yang and Singh, 1994, Yang and Sen, 1994), the use of the FER approach has been widely applied to decision making problems dealing with MADM with both qualitative and quantitative indicators under uncertainty such as general cargo design (Sen and Yang, 1995), marine system safety analysis and synthesis (Wang *et al*., 1995, Wang *et al*., 1996), software safety synthesis (Wang, 1997, Wang and Yang, 2001), executive car assessment (Yang and Xu, 1998), organizational self-assessment (Yang *et al*., 2001), container supply chain risk assessment (Yang, 2006), vessel selection (Yang *et al*., 2009b), risk analysis of a liquefied natural gas carrier (Nwaoha *et al*., 2011) and port selection (Yeo *et al*., 2014). From the studies identified and analysed above, the combination of ER and fuzzy theory can provide a new conceptual model to evaluate PPIs under uncertainty. Application of FER in port performance measurement will be thoroughly discussed in the next section.

5.2.3.2 Evidential reasoning algorithm

The ER approach in this study is used to aggregate all output of DoB (β_j^k) from each rule (R_k) and generate a conclusion (Yang and Xu, 2002). The first step of the ER algorithm is to transform the DoB (β_j^k) into two parts of basic probability mass (i.e. individual assigned belief degrees and individual remaining (unassigned) belief degrees) to aggregate all the output from R_k to generate combined DoB (β_j) in each possible D_j of D using following equations.

$$m_j^k = w_k \beta_1^n \quad (5.12)$$

$$m_D^k = \bar{m}_D^k + \tilde{m}_D^k \quad (5.13)$$

$$\bar{m}_D^k = 1 - w_k \quad (5.14)$$

$$\tilde{m}_D^k = w_k(1 - \sum_{j=1}^{n} \beta_j^k) \quad (5.15)$$

where $m_j^k (j = 1, \ldots, N; k = 1, \ldots, L)$ denotes individual degrees to which the rules (R_k) support the aggregated result D that is assessed to the assessment terms with DoB; $w_k (\sum_{k=1}^{l} w_k = 1)$ indicates relative importance of PPI in R_k; m_D^k represents the individual remaining belief degrees that are not yet assigned for m_j^k that is spilt into $\bar{m}_D^k$ (i.e. the remaining belief values unassigned to any individual evaluation grade caused by relative importance) and $\tilde{m}_D^k$ (i.e. the remaining belief values unassigned to any individual evaluation grade caused by incomplete assessment).

Next, suppose $m_j^{c(k)}$ represents the combined belief degree in D_j by aggregating in R_k, $\tilde{m}_D^{c(k)}$ represents the combined remaining belief degree to any D_j caused by the possible incompleteness in R_k and $\bar{m}_D^{c(k)}$ represents the combined relative importance of PPI in R_k (Eqs. (5.16)-(5.19)). Finally after all assessments are aggregated, the overall combined DoB is generated using normalization process (Eqs. (5.20)-(5.21)).

$$\{D_j\}: m_j^{c(k+1)} = K_{c(k+1)}(m_j^{c(k)} m_j^{k+1} + m_j^{c(k)} m_D^{k+1} + m_D^{c(k)} m_j^{k+1}) \quad (5.16)$$

$$\{D\}: \tilde{m}_D^{c(k+1)} = K_{c(k+1)}\left(\tilde{m}_D^{c(k)} \tilde{m}_D^{k+1} + \tilde{m}_D^{c(k)} \bar{m}_D^{k+1} + \bar{m}_D^{c(k)} \tilde{m}_D^{k+1}\right) \quad (5.17)$$

$$\bar{m}_D^{c(k+1)} = K_{c(k+1)}(\bar{m}_D^{c(k)} \bar{m}_D^{k+1}) \quad 5.18)$$

$$K_{c(k+1)} = \left[1 - \sum_{j=1}^{N} \sum_{\substack{t=1 \\ j \neq t}}^{N} m_j^{c(k)} m_t^{k+1}\right]^{-1}, k = 1, 2, \dots, L-1 \quad (5.19)$$

$$\{D_j\}: \beta_j = \frac{m_j^{c(L)}}{1 - \bar{m}_D^{c(L)}} \quad (5.20)$$

$$\{D_j\}: \beta_D = \frac{\tilde{m}_D^{c(L)}}{1 - \bar{m}_D^{c(L)}} \quad (5.21)$$

where β_j represents the normalized DoB assigned to D_j in the final synthesized conclusion D and β_D indicates the normalized remaining DoB unassigned to any D_j.

It is not straightforward to use the overall result obtained using ER to rank each candidate port/terminal. Thus, utility techniques can be used in order to obtain a single crisp value for the top-level PPI (goal) of each alternative (port/terminal) from the aggregated values (Yeo *et al*., 2014). D_j needs to be given utility values U_j for a crisp ranking index result R_C and β_D. These require to be assigned back to β_1 and β_N for the possible most preferred R_B and the possible worst preferred R_W. Consequently, the larger R_C, the more preferred the associated port/terminal is.

$$R_B = \sum_{j=2}^{N} \beta_j U_j + (\beta_1 + \beta_D) U_1$$

$$R_W = \sum_{j=1}^{N-1} \beta_j U_j + (\beta_N + \beta_D) U_N \quad (5.22)$$

$$R_C = \frac{R_B + R_W}{2}, \text{when } \sum_{j=1}^{N} \beta_j < 1 \text{ or}$$

$$R_C = \sum_{j=1}^{N} \beta_j U_j, \text{when } \sum_{j=1}^{N} \beta_j = 1 \quad (5.23)$$

5.3 THE FUZZY EVIDENTIAL REASONING BASED PORT PERFORMANCE MEASUREMENT FRAMEWORK

In the framework, a hybrid approach of AHP and FER for solving MCDM problems is applied to address the challenges in port performance measurement. The proposed framework for applying FER in evaluating PPIs is composed of the following steps in Figure 5.3.

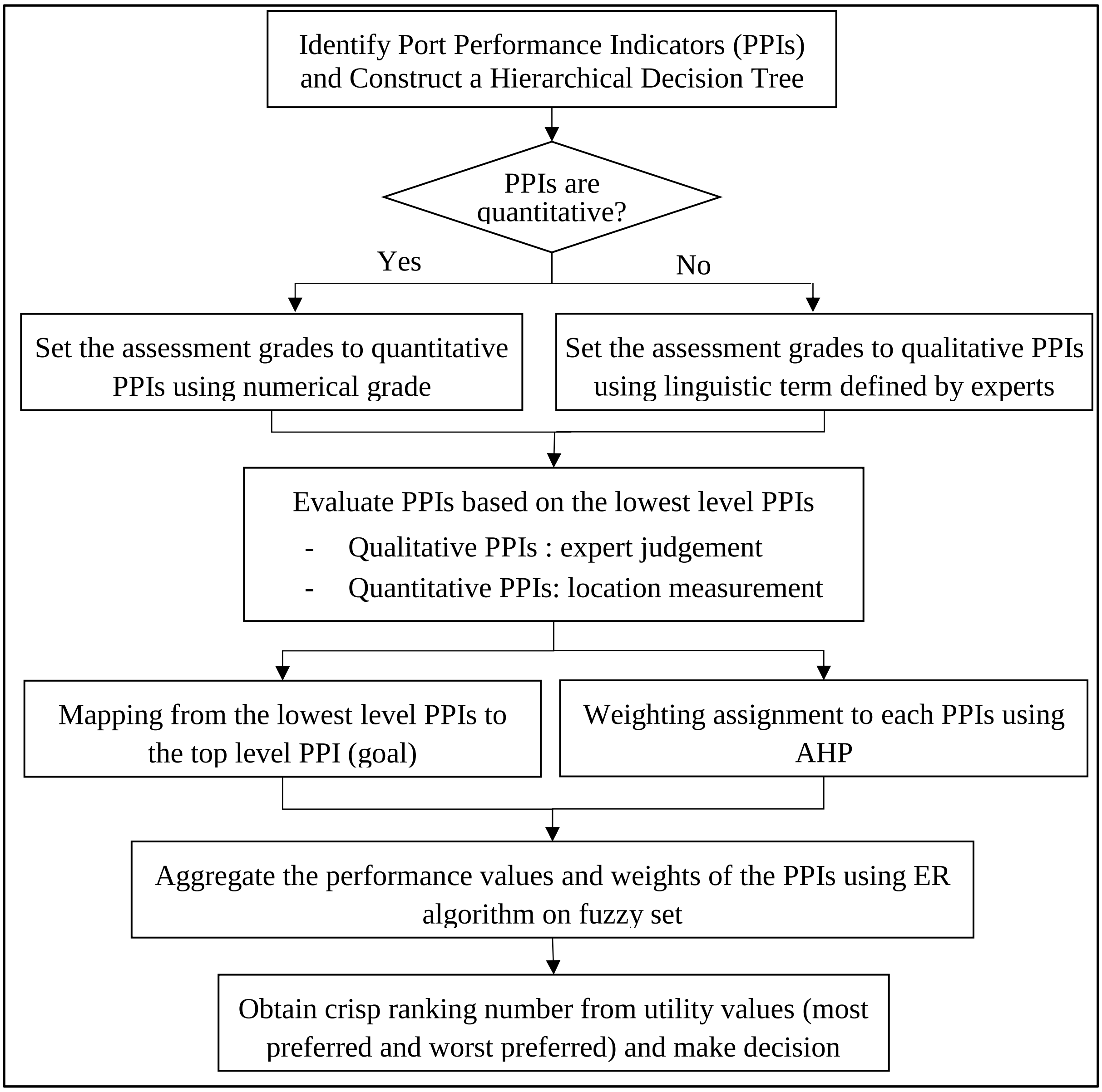

Figure 5.3 Framework for applying FER in evaluating PPIs

5.3.1 Identification of PPIs and development of the measurement grades to PPIs

In this step, PPIs which are most crucially used for measuring port performance are identified. This has been done by literature review and industry practice in a pre-selection phase and then confirmed by a panel of experts to assess the suitability of the potential indicators and to test the feasibility of the selected indicators. The PPIs consist of various types of numeric and subjective indicators to reflect the complexity of port/terminal business environments. The procedure for identification of the PPIs is described in chapter 3.

Based on the hierarchical model in Table 4.25, the assessment grades are allocated to all PPIs. For assessing qualitative PPIs, different sets of measurement grades (linguistic terms) are used and defined by domain experts (Yang, 2001). In this thesis, the sets of linguistic terms are initially developed through interviewing the experts in ports from the Port of Liverpool, Port of Busan, the Liverpool Logistics, Offshore and Marine Research Institute (LOOM) and Korea Maritime University. For example, in order to measure the "loyalty of port employees", a set of the fuzzy linguistic terms {very low, low, medium, high, very high} are defined. If PPI is quantitative nature, it can be assessed using numerical grades (Yang, 2001) based on various data (i.e. consulting reports, journal papers and internal data of terminal operators). From this perspective, a set of quantitative grades, for example, {leq 0%, 5%, 10%, 15%, 20%, geq 25%} for "throughput growth" are developed based on the top 50 world container ports (Containerisation International, 2010-2012).

As seen from the examples of developing various sets of numerical grades for quantitative PPIs, it needs to take reference from the industrial trends or international benchmarking in order to apply the framework to all container terminals in the world. The benchmarking investigation for developing numerical assessment grades is carried out based on the major ports. The selection of major ports in their targeted areas is conducted using container throughputs obtained from the data in the Containerisation International Yearbook (2012). In addition, major hub ports from different countries are also selected for a fair representation of each continent. Data collection is conducted by visiting related web sites of the selected ports, requesting internal/external documents and consultants of terminal operators, port authorities and other bodies who control and administrate ports and previous bench marking studies, etc. However, most terminal operators or port authorities are reluctant to provide the data (e.g. financial data) which are confidential and sensitive for their business[3]. This investigation

[3] This fact from real observations proves the necessity of this study, developing a powerful assessment tool

process takes huge time and efforts. The collected data is not comprehensively perfect but sufficient for setting assessment grades. Based on the data, the assessment grades for quantitative PPIs are developed. It is noteworthy that when it fails to get quantitative data in order to set assessment grades, fuzzy linguistic terms or interval numbers of assessment grades can be used (Xu *et al.*, 2006). The set of measurement grades for qualitative and quantitative PPIs are defined and assigned as shown in the following Table 5.3-Table 5.10. The detailed analysis of the grades with respect to the PPIs is conducted in the following section.

Table 5.3 Assessment grades of the goal and 6 dimensions

Goal	Assessment Grades				
Container Port Performance	Very Poor	Poor	Medium	Good	Very Good
6 dimensions	Assessment Grades				
Core Activities (CA)	Very Poor	Poor	Medium	Good	Very Good
Support Activities (SA)	Very Poor	Poor	Medium	Good	Very Good
Financial Strength (FS)	Very Poor	Poor	Medium	Good	Very Good
Users' Satisfaction (US)	Very Poor	Poor	Medium	Good	Very Good
Terminal Supply Chain Integration (TSCI)	Very Poor	Poor	Medium	Good	Very Good
Sustainable Growth (SG)	Very Poor	Poor	Medium	Good	Very Good

Table 5.4 Assessment grades of the 16 principal-PPIs

16 principal-PPIs	Assessment Grades				
Core Activities (CA)					
Output (OPC)	Very Low	Low	Medium	High	Very High
Productivity (PDC)	Very Low	Low	Medium	High	Very High
Lead Time (LTC)	Very Poor	Poor	Medium	Good	Very Good
Support Activities (SA)					
Human Capital (HCS)	Very Poor	Poor	Medium	Good	Very Good
Organisation Capital (OCS)	Very Poor	Poor	Medium	Good	Very Good
Information Capital (ICS)	Very Poor	Poor	Medium	Good	Very Good
Financial Strength (FS)					
Profitability (PFF)	Very Low	Low	Medium	High	Very High
Liquidity and Solvency (LSF)	Very Poor	Poor	Medium	Good	Very Good
Users' Satisfaction (US)					
Service Fulfilment (SFU)	Very Poor	Poor	Medium	Good	Very Good
Service Costs (SCU)	Very Low	Low	Medium	High	Very High
Terminal Supply Chain Integration (TSCI)					
Intermodal Transport Systems (ITST)	Very Poor	Poor	Medium	Good	Very Good
Value-Added Services (VAST)	Very Poor	Poor	Medium	Good	Very Good
Information/Communication Integration (ICIT)	Very Poor	Poor	Medium	Good	Very Good
Sustainable Growth (SG)					
Safety and Security (SSS)	Very Poor	Poor	Medium	Good	Very Good
Environment (EVS)	Very Poor	Poor	Medium	Good	Very Good
Social Engagement (SES)	Very Poor	Poor	Medium	Good	Very Good

capable of conducting port performance measurement with data in uncertainty.

Table 5.5 Assessment grades of the PPIs under core activities (CA)

PPIs	Assessment Grades					
Output (OPC)						
Throughput volume growth	leq 0%	5%	10%	15%	20%	geq 25%
Vessel call size growth	leq 0%	5%	10%	15%	geq 20%	
Productivity (PDC)						
Ship load rate	leq 25TEU	40TEU	55TEU	70TEU	85TEU	geq100TEU
Berth utilization	leq 300TEU	600TEU	900TEU	1200TEU	1500TEU	geq 1800TEU
Berth occupancy	leq 45%	50%	55%	60-80%	geq 80%	
Crane efficiency	leq 20 lifts	25 lifts	30 lifts	35 lifts	40 lifts	geq 45 lifts
Yard utilization	leq 2TEU	4TEU	6TEU	8TEU	geq 10TEU	
Labour utilization	leq 1000TEU	2000TEU	3000TEU	4000TEU	5000TEU	geq 6000TEU
Lead Time (LTC)						
Vessel turnaround time	geq 5days	4days	3days	2days	leq 1day	
Truck turnaround time	geq 40mins	35mins	30mins	25mins	20mins	leq 15mins
Container dwell time	geq 4weeks	3weeks	10days	7days	5days	leq 3days

Note: leq: less than or equal to; geq: great than or equal to.
TEU: twenty-foot equivalent unit.

Table 5.6 Assessment grades of the PPIs under supporting activities (SA)

PPIs	Assessment Grades				
Human Capital (HCS)					
Knowledge and skills	Very Poor	Poor	Medium	Good	Very Good
Capability	Very Poor	Poor	Medium	Good	Very Good
Training and education opportunity	Very Poor	Poor	Medium	Good	Very Good
Commitment and Loyalty	Very Low	Low	Medium	High	Very High
Organisation Capital (OCS)					
Culture	Very Poor	Poor	Medium	Good	Very Good
Leadership	Very Poor	Poor	Medium	Good	Very Good
Alignment	Very Poor	Poor	Medium	Good	Very Good
Teamwork	Very Poor	Poor	Medium	Good	Very Good
Information Capital (ICS)					
IT systems	Very Poor	Poor	Medium	Good	Very Good
Databases	Very Poor	Poor	Medium	Good	Very Good
Networks	Very Poor	Poor	Medium	Good	Very Good

Table 5.7 Assessment grades of the PPIs under financial strength (FS)

PPIs	Assessment Grades					
Profitability (PFF)						
Revenue growth	leq 0%	2%	4%	6%	8%	geq 10%
EBIT margin	leq 0%	10%	15%	20%	25%	geq 30%
Net profit margin	leq 0%	5%	10%	15%	20%	geq 25%
Liquidity and Solvency (LSF)						
Current ratio	leq 1		Between 1 and 2		geq 2	
Debt to total asset	geq 0.5			leq 0.5		
Debt to equity	geq 2	1.8	1.6	1.4	1.2	leq 1

Table 5.8 Assessment grades of the PPIs under users' satisfaction (US)

PPIs	Assessment Grades				
Service Fulfilment (SFU)					
Overall service reliability	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Responsiveness to special requests	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Accuracy of document & information	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Incidence of cargo damage	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Incidence of service delay	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Service Costs (SCU)					
Overall service costs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Cargo handling charges	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Cost of terminal ancillary services	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied

Table 5.9 Assessment grades of the PPIs under terminal supply chain integration (TSCI)

PPIs	Assessment Grades				
Intermodal Transport Systems (ITST)					
Sea side connectivity	Very Poor	Poor	Medium	Good	Very Good
Land side connectivity	Very Poor	Poor	Medium	Good	Very Good
Reliability of multimodal operations	Very Poor	Poor	Medium	Good	Very Good
Efficiency of multimodal operations	Very Poor	Poor	Medium	Good	Very Good
Value-Added Services (VAST)					
Facilities for adding value to cargos	Very Poor	Poor	Medium	Good	Very Good
Capacity to provide different value-added services	Very Poor	Poor	Medium	Good	Very Good
Service adaptation to customers	Very Poor	Poor	Medium	Good	Very Good
Tailored services to customers	Very Poor	Poor	Medium	Good	Very Good
Information/Communication Integration (ICIT)					
Integrated EDI for communication	Very Poor	Poor	Medium	Good	Very Good
Integrated IT to share data	Very Poor	Poor	Medium	Good	Very Good
Collaborate with channel members	Very Poor	Poor	Medium	Good	Very Good
Latest IT in the industry	Very Poor	Poor	Medium	Good	Very Good

Table 5.10 Assessment grades of the PPIs under sustainable growth (SG)

PPIs	Assessment Grades				
Safety and Security (SSS)					
Identifying restricted areas and access control	Very Poor	Poor	Medium	Good	Very Good
Formal safety and security training practices	Very Poor	Poor	Medium	Good	Very Good
Adequate monitoring and threat awareness	Very Poor	Poor	Medium	Good	Very Good
Safety and security officers and facilities	Very Poor	Poor	Medium	Good	Very Good
Environment (EVS)					
Carbon footprint	Very Poor	Poor	Medium	Good	Very Good
Total water consumption	Very Poor	Poor	Medium	Good	Very Good
Total energy consumption	Very Poor	Poor	Medium	Good	Very Good
Waste recycling	Very Poor	Poor	Medium	Good	Very Good
Environment management programs	Very Poor	Poor	Medium	Good	Very Good
Social Engagement (SES)					
Employment	Very Poor	Poor	Medium	Good	Very Good
Regional GDP	Very Poor	Poor	Medium	Good	Very Good
Disclose of information	Very Poor	Poor	Medium	Good	Very Good

5.3.1.1 Quantitative PPIs

A set of quantitative grades can be defined based on various sources such as publicly available data, internal sources of port/terminals and industrial best practices, etc. The defined assessment grades are verified by the panel of the experts aforementioned.

5.3.1.1.1 Output

- Percentage of growth in TEU throughput (cargo performance)

The percentage of change of container throughput volume in TEUs handled in a container port (terminal) over a certain period of time (annual base) can be used for both internal and external comparisons. In order to measure percentage of change in TEU throughput, this study analyses percentage of change of the top 50, top 20 and top 21-50 container ports (in terms of container throughput) for the last three years (Table 5.11). Based on this data, a set of quantitative grades with equivalent distribution {leq 0 % (minus growth), 5%, 10%, 15%, 20%, geq 25%} are defined.

Table 5.11 Percentage change of container throughputs in the top 50 container ports

	Percentage Change (top 50 ports)			Percentage Change (top 20 ports)			Percentage Change (top 21-50 ports)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2011-2012	-5.3%	6.2%	25.9%	-5.3%	4.7%	25.9%	-4.4%	7.1%	23.8%
2010-2011	-8.0%	8.9%	28.6%	0.3%	9.1%	22.1%	-8.0%	8.8%	28.6%
Average	-6.7%	7.6%	27.3%	-2.5%	6.9%	24.0%	-6.2%	8.0%	26.2%

Source: The journal of commerce, The JOC Top 50 world container ports each year; World shipping Council (www.worldshipping.org); Containerization International –Top 100 Ports each year.

- Percentage of growth in vessel call size (vessel performance)

The percentage of growth in total vessel call capacity over a certain period of time can be calculated as the number of vessel calls multiplied by the size of vessels. The size of vessel is generally measured with different units such as DWT (deadweight tonnage), GT (gross tonnage) and TEUs (twenty foot equivalent units for container vessel), etc. It is clear that using TEU for container port performance measurement is more desirable. However, many ports collect the data with DWT, while others collect them with GT for the purpose of calculating vessel charges and port service charges (i.e. vessel arrival charge, pilot/tug charge, etc.). Even though GT can be arguably converted to DWT, and vice-versa (Branch and Stopford, 2013), this is not a universal rule for applying to every vessel size. Thus, percentage of growth in total vessel call capacity is used to solve the non-uniform data problems. Based on the publicly available data from ports of various sizes, a set of quantitative grades for the vessel call capacity growth {leq 0 % (minus growth), 5%, 10%, 15%, geq 20%} are defined.

5.3.1.1.2 Productivity

Increased vessel sizes, throughput volumes and customers' needs have required higher operational productivity with higher service qualities from terminal operators. Beškovnik (2008) classified a container terminal consisting of five subsystems: berth, crane, yard, gate and labour. It is noteworthy that productivity in a modern container terminal can be achieved by a well-established operational plan under the given terminal capacity. For instance, the operation of the quay cranes is more dependent on the equipment operational plan between quay and yard areas rather than the quay cranes themselves. In light of this, terminal operators have always exerted all possible efforts to achieve their goals such as productivity improvement in an ever changing port environment. According to The Tioga Group (2010), productivity is a combined result of operational efficiency and resource utilization and can be increased either by increasing utilization or by increasing operational efficiency. Therefore productivity is not a simple indicator but a ratio (or percentage) of the combined two sub-indicators. For example, productivity is measured by units of output (i.e. throughputs) per units of input (i.e. port superstructure, equipment, labour).

- Ship load rate

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 sub-indicators which are total container throughput volume and an average vessel capacity which can be calculated as the total capacity of vessel divided by the total number of vessels. Based on the data used for the output PPIs above, the load rate can be easily calculated as the container throughput volume divided by the average vessel capacity. As discussed before, however, there is no uniform data of the vessel capacity in port systems but it is mostly either DWT or GT. Therefore, assessment grades for ship load rate are determined in terms of available sources. One is the calculation of a container throughput volume divided by an average vessel capacity, when the associated data for the selected alternative ports is available. Another is the percentage of growth in load rate. An example of a set of quantitative grades for the calculation of the load rate (TEU/average GT or DWT) {less than (equal to) 25, 40, 55, 70, 85, more than (equal to) 100 (TEUs/ton)} is defined. A set of assessment grades for the percentage of growth in load rate is defined as {leq 0 % (minus growth), 10%, 20%, 30%, geq 40%}.

- Berth utilization (TEUs/berth length)

According to previous studies, the berth productivity can be measured by both the number of berths (Tongzon, 2001) and the total length of berths (Tongzon and Ganesalingam, 1994, Cullinane *et al*., 2002, Cullinane *et al*., 2006). However, non-unified berth size which is variously expressed in terms of its capacity makes it difficult to apply to measuring berth productivity. For example, the container terminals in Busan port, Korea, have different sizes of berths including 50,000 dwt (which can accommodate a post-panamax vessel) with 300-340m as a main berth as well as the berth size with 20,000 dwt as a feeder berth. In addition, there are various units of the berth size even within a terminal. According to industrial practices, terminal operators measure berth productivity in terms of either the gross berth productivity (GBP) or the net berth productivity (NBP). These absolutely depend on both the number of cranes and the capability of cranes. If a large number of cranes (or the higher crane capacity) is used for loading and unloading operations, it naturally leads to a higher berth productivity. Both the GBP and NBP denote productivity per berth and are expressed by lifts (or movements) per hour. The only difference is the GBP is estimated as the total number of container throughputs divided by the gross berth time (the total number of hours vessel staying at berth) which includes all delays arisen from such events as machinery failure, break time and other time consumptions, etc., while the NBP is calculated as the total number of container throughputs divided by the net berth working time. The NBP, thus, is generally presented much higher than GBP. However, either is not often easily obtained from terminal operators. In light of this aspect, it is a rational approach to use the length of berth rather than the other berth productivity measurements in this study. This can be calculated as the total throughput volumes divided by the total berth length. According to the data collected from leading container terminals in North-East Asia, they mostly achieved the berth productivity with more than 1,000 TEU/m/year and some of them achieved more than 2,000 TEU/m/year in 2012. However, total TEU per berth length in North American and European ports demonstrates a lower achievement between 230 and 650 TEU/m/year (The Tioga Group, 2010), between 660 and 900 TEU/m/year in Canadian port (Tardif, 2010) and between 400 and 1,000 TEU/m/year (Rankine, 2003), respectively. Based on the data collected, the assessment grades of the berth utilization can be defined as {leq 300TEUs, 600TEUs, 900TEUs, 1200TEUs, 1500TEUs, geq 1800TEUs}.

- Berth occupancy rate

Berth occupancy is the ratio of time that a vessel is occupying a berth over a certain period time. This can be calculated as the total hours of vessels at berth divided by the total hours of the terminal operation. As recommended in the major ports development plan, berth occupancy level of between 60% and 80% would be optimal to avoid congestion (Rankine, 2003). In case of Dar es Salaam port in Tanzania, more than 70% is a sign of congestion with high berth occupancy, while low berth occupancy (less than 50 %) denotes underutilization of resources (Mwasenga, 2012). In data collected from the world's leading ports, the berth occupancy levels vary between 45% and 83%. It is noteworthy that the terminals with very high berth occupancy (i.e. generally more than 80%) denote either a low level of berth productivity or a low level of crane productivity. Therefore, this could lead to port congestion. Based on these data, the assessment grades of the berth occupancy can be defined as {leq 45%, 50%, 55%, 60%- 80%, geq 80%}.

- Crane efficiency (movement/h)

As the size of container vessels is becoming larger, efficiency of the container terminals is a critical challenge for ports today. With regard to this issue, the productivity of the quay cranes has been discussed in the front line. On top of that, the cranes have evolutionarily achieved their bigger size and higher speed with more accuracy for handling containers. There are various sizes of quay crane depending on their capability. Rankine (2003) demonstrated the physical limitations of crane productivity in terms of the type of quay crane. According to the data, the theoretical crane productivity based on its type can be classified as follows:

- Post-panamax quay cranes: 35-45 lifts per hour
- Panamax quay cranes: 20-30 lifts per hour
- Mobile quay cranes: 18-25 lifts per hour

Crane productivity can generally be measured in lifts per hour. In other words, crane productivity, utilization and efficiency, measuring the ability to handle the cargo from vessel to shore (or vice-versa) can be measured by both cranes' availability (crane numbers and hours) and cranes' capability (movement per hour). Container terminals generally have 2-3 quay cranes per berth and use 5-6 quay cranes for large vessels. A certain period of cranes' productivity is theoretically higher if fewer cranes serve the vessels, while more cranes with higher capacity contribute a faster vessel turnaround time. Thus, terminal operators have always considered the optimum number of cranes in order to provide a shorter vessel turnaround time for shipping lines when the cranes work for the vessel. On top of that, this can be also determined by types of crane (crane capability) that the terminal has. According to Rankine (2003), the productivity of the conventional single lift quay cranes is between 20 and 25 moves per crane per ship operating hour. According to Hanam Canada Corporation (2008), crane productivity of pacific coast container ports in Canada is 24 moves per hour. According to the data of crane lifts per hour of 10 container terminals in Busan port, it varies between 25 and 35 moves per hour in 2012. Shanghai Zhenhua Port Machinery Co, Ltd (ZPMC) reported that dual-spreader cranes at the port of Dubai had created a new world record: 104 TEU per hour (Goussiatiner, 2007). However, this result is not an average of crane productivity per annum per hour but a one-off record during the measuring point. In addition, the productivity per annum per hour may not reach the record since crane productivity generally depends on a number of factors such as vessel size, vessel stowage configuration, the TEU to containers ratio, average container weights, total container throughputs and containers handled in each task, etc. Based on these data, the assessment grade of the crane productivity can be defined as {leq 20 moves, 25 moves, 30 moves, 35 moves, 40 moves, geq 45 moves}.

- Container yard utilization (TEU/area of container yard)

There are various types of container handling operation in terms of equipment types in container yards (CY). Obviously container terminals located in restricted areas using RMG (rail-mounted gantry) or RTG (Rubber-tired gantry) operation generally show a high storage density and stacking height with a high utilization (e.g. Asian ports such as Hong Kong, Singapore, Busan, etc.). On the other hand, container terminals with large CY areas, e.g. most U.S. ports, using the straddle carrier operation show a low storage density and stacking height with a low CY utilization. The Table 5.12 shows different levels of density depending on the CY equipment types.

Table 5.12 Density levels depending on the equipment types

Type	Density
RO RO/ship's gear Wheeled combination Dedicated wheeled	Very low density
Wheeled equipment/top-pick Top-pick/ wheeled equipment	Low density
Straddle carrier/top-pick/wheeled RTG/Top-pick/wheeled	Mid density
Straddle carrier RTG	High density
Pure RMG	Very high density

Source: Author created based on The Tioga Group (2010)

On top of that, the yard equipment operation is determined by the physical yard capacity. The yard capacity is generally measured based on the terminal ground slots (TGS), taking into account the average dwell time (the days within which containers are stored in the terminal), peak factor (a factor of which the highest volume of container moves might be realized by the terminal), stacking height (average expected stack height by average number of containers in utilised stacks) and stacking density (how heavily is the container yard being utilized). For instance, based on Table 5.13, TGS, yard capacity and CY productivity can be calculated using Eq. (5.24)-(5.26) (Ministry of Oceans and Fisheries, 2001).

$$\text{TGS} = \frac{\text{Expected annual volume x Dwell Time(days) x Peak factor}}{\text{Stacking Density X Stacking Height X 365}} \tag{5.24}$$

$$\text{Yard capacity= TGS x dwell time x peak factor x operational factor x stacking height} \tag{5.25}$$

$$\text{CY productivity} = \frac{\text{Number of containers in CY}}{\text{CY Capacity}} \text{ x } 100 \tag{5.26}$$

- TGS: (900,000x3x1.3)/(0.8x3.5x365)= 3434
- Yard capacity= 3434 x 3 x 1.3 x 0.7 x 3.5

  = 32812[4]

Table 5.13 Factors for calculating CY capacity

Expected annual container volume (TEU)	900,000
Average dwell time (days)	3.0
Staking density factor	0.8
Peak factor	1.3
Annual working day	365
Staking Height	3.5
Operational factor	0.7

Source: Own Calculation. Based on the Ministry of Oceans and Fisheries (2001), Korean Port Development Plan.

However, these factors are not generally available and vary between ports depending on their operational types. Thus, consideration of this perspective is beyond the scope of this study. The area of a CY and the annual throughput is generally available and is readily applied to assess CY productivity levels. Therefore, CY productivity measurement in this study can be calculated as the number of container throughputs divided by the total area of the CY. According to Rankine (2003), the industry benchmarking of the CY productivity denotes

[4] When calculate the yard capacity, TEU factor (the ratio between the number of container (TEU + FEU) and the number of TEU) is generally taken into account. However, the result is obtained without taking into account the TEU factor because of data lacking.

20,000TEU/hectare/year ($2TEU/m^2/year$). Data from world leading ports varies from $2TEU/m^2/year$ to $10TEU/ m^2/year$. Based on these data, the assessment grade of the CY productivity can be defined as {leq 2 TEU/m^2, 4 TEU/m^2, 6 TEU/m^2, 8 TEU/m^2, geq 10 TEU/m^2}.

- Labour (TEU/employee)

A high degree of skill covering operating procedures, customer service, safety and security is required for all staff in order to achieve outstanding labour productivity from large investment in terminal equipment in container port. Labour productivity (or gang productivity) is usually measured by number of moves per man-hour. However, the man-hour is hardly available from terminal operators and varies between terminals. For instance, there are many influencing factors such as no night shifts in some terminals and various types of employee such as full time and part time. This situation makes it difficult to assume the standard annual labour of one person. Thus, labour productivity in this study is measured as the total throughput divided by the number of employees. In rational terms, it will take a low level of labour productivity to implement better staff training, to review better working practices and reorganize better staff utilisation. Drewry (1998) indicated figures of labour productivity for a medium sized terminal (handling about 210,000 TEU per year) as 900TEU/man and for a large terminal (handling about 600,000 TEU per year) as 1,100TEU/man. Data from world leading ports in Asia, they suggest different figures between 1,000TEU/man and 6,000TEU/man. Based on these data, the assessment grade of the labour productivity can be defined as {leq 1,000TEU/man, 2,000TEU/man, 3,000TEU/man, 4,000TEU/man, 5,000TEU/man, geq 6,000TEU/man}.

5.3.1.1.3 Lead-time

- Vessel turnaround time

Vessel turnaround time, also known as the duration of the ship's stay in port, is defined as total time spent by a ship from its entry at anchorage till its departure from anchorage. Constituents of the vessel turnaround time include two broad categories which are pre/post waiting time (i.e. waiting time after registering vessel arrival, berthing/unberthing time, sailing delay) and vessel time at berth (i.e. preparing time for loading/unloading service, clearing time for vessel leave, operational time) (Figure 5.4). Vessel turnaround time can substantially be reduced through a decrease in vessel time at berth rather than a decrease in waiting time. Vessel time at berth depends on the quantity of container, size and characteristic of a vessel, the type of quay and yard equipment and other resources used, etc. Therefore, modern container ports have invested huge capital and resource on acquisition of state-of-the-art systems and equipment to reduce vessel time at berth. On top of that, they have also introduced such strategies as the well-organized operational plan, transfer of containers to dryports in order to overcome limited area of container yard, clearance of documentation before vessel arrival, integration of information system, and acquisition of state-of-the-art quay and yard equipment, etc. These trends are identified and found by Ducruet and Merk (2013) who presented an overview of time efficiency in world container ports in 1996, 2006 and 2011. According to their study, it was found that there were gradual improvements in vessel turnaround time in most countries (ports) in 2011 compared to those in both 2006 and 1996. Average vessel turnaround time at the country level in 2011 includes: South Korea (0.68 days), China (0.96 days), Hong Kong (0.72 days), Taiwan (0.71 days), Singapore (1.16 days) and the United States (1.02 days). On the other hands, in the case of Dar es Salaam port in Tanzania, vessel turnaround time from 2001 to 2011 varied between 2.1 and 7.3 days (Mwasenga, 2012). Based on their result, the assessment grade of the vessel turnaround time can be defined as {geq 5 days, 4 days, 3days, 2days, leq 1day}.

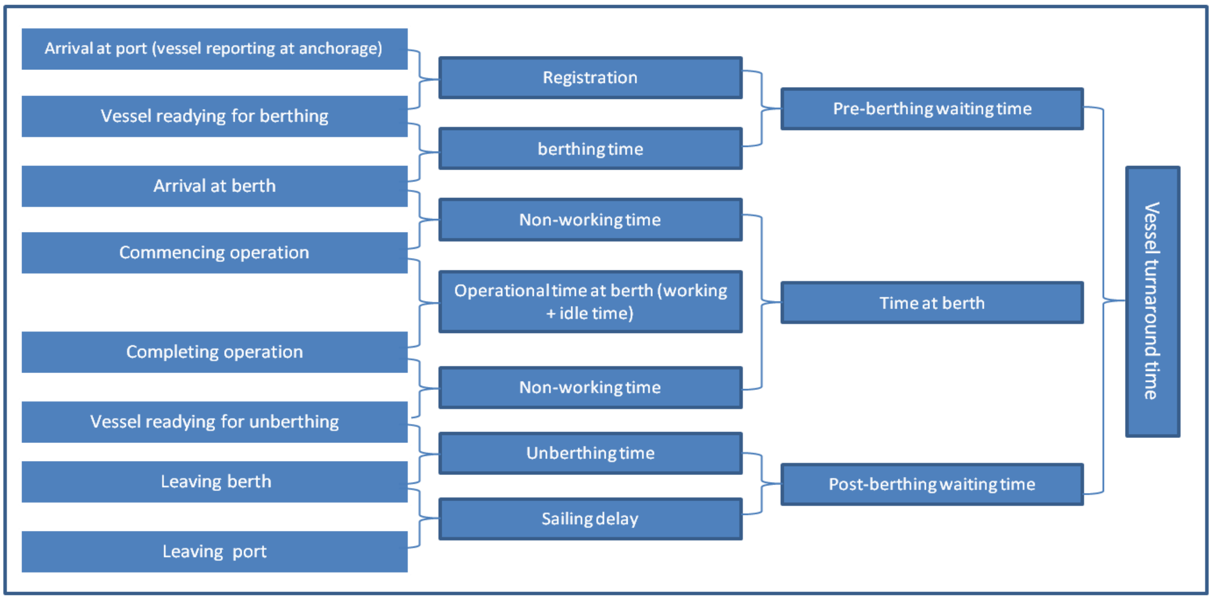

Figure 5.4 Break-down of ship's time in port
Source: Author created based on De Monie (1988).

- Vehicle turnaround time

Vehicle turnaround time is defined as total time spent by a vehicle from its arrival at the terminal gate and its departure from the terminal gate. It measures the efficiency of the gatehouse as well as yard procedures. The major determinants of the turnaround time, for example, depend on scanning operations, gates layout, terminal size, availability of equipment during delivery operations, etc. However, vehicles stuck in traffic outside of the terminal gate sometimes causes delay and even misses pre-assigned collection delivery slots. Practically accepted vehicle turnaround time is between 25 and 30 minutes, while in a dedicated container terminal for a single user, it can be reduced to 10-15 minutes for regular customers (Rankine, 2003). Average truck turnaround time of Canadian ports in 2009 recorded between 19 minutes and 23 minutes (Tardif, 2010). Dar es Salaam port in Tanzania, truck turnaround time from July 2010 to September 2011 was varying between 2.5 and 4 hours (Mwasenga, 2012). Interviews from terminal operators in world leading container ports emphasised a period of between 15 minutes and 20 minutes from entry to exit is considered good. Based on these data, the assessment grades of the vehicle turnaround time can be defined as {geq 40 mins, 35 mins, 30 mins, 25 mins, 20 mins, leq 15 mins}.

- Container dwell time

Container dwell time is the average time in days a container remains stacked at the terminal. It refers to identifying the efficiency of terminal clearance procedures because dwell time is influenced by either local characteristics and policy (i.e. free dwell service and storage price) or customs' procedure time. Import dwell time is generally longer than export's. However, in some cases, dwell time is not directly related to the mentioned service qualities. For instance, many port users often use the container yard for storage purposes because terminal operators normally provide free storage or cheap storage charges. In addition, the period of free storage provided by terminal operators is different depending on cargo characteristics and customers, import container, export container, internal transfer (within same terminal), inter-terminal transfer (between different terminals within the same port), full and empty container, on-dock service providers and off-dock service providers, etc. This situation distorts container dwell time data. Most container terminals offer 3 or 4 days free storage to importers (Beckett Rankine Partnership, 2003). Average container dwell time in Canadian ports was between 1.8 days and 3.2 days (Oliver, 2009). Average import container dwell times of the Dar es Salaam port in Tanzania since 2001, were between 11.5 days and 25.4 days (Mwasenga, 2012). According to real data from world leading container ports in far-east Asia, average container dwell time of container types per annum varies from 2 days to 10 days. Based on the international bench marking data, the assessment grades of the container dwell time can be defined as {geq 1 month, 3 weeks, 10 days, 7 days, 5 days, leq 3 days}.

5.3.1.1.4 Profitability

- Revenue growth

Revenue is the sum of money that a company actually gains during a certain period and is calculated as the price at which goods or services are sold multiplied by the number of units or amount sold. Revenue growth is one of most frequently used financial indicators to measure 'how fast a company expanded during the basic period compared to the year before'. Revenue growth is calculated in Eq. (5.27).

$$\text{Revenue growth} = \frac{\text{revenue for this year}}{\text{revenue for last year}} - 1 \tag{5.27}$$

In order to set a measurement grade of the revenue growth, this study uses the revenue growth (between 2008 and 2012) of four major global terminal operators (GTOs) such as PSA (Port of Singapore Authority), HPH (Hutchison Port Holdings), APM terminals and DP (Dubai Ports) world (Table 5.14). Based on the data, the assessment grade of the revenue growth can be defined as {leq 0 %, 2 %, 4 %, 6 %, 8 %, geq 10 %}.

Table 5.14 Revenue growth of four major GTOs

Growth on revenue	2008	2009	2010	2011	2012
PSA	-	-12.7%	6.3%	5.8%	4.3%
HPH	-	-15.4%	13.4%	11.4%	3.5%
APM	-	43.0%	5.2%	4.9%	10.5%
DP world	-	-14.1%	9.1%	-3.2%	4.8%

Source: Author's own calculation based on financial reports (2008-2012) of each company.

- EBIT (operating profit) margin

EBIT, earnings before interests and tax, is also referred to as 'operating profit', 'operating income' and 'operating earnings'. In other words, EBIT is to measure the profit from a company's core business operations which excludes any earning from the company's investment and the effect of interests and taxes. It is noteworthy that EBITDA (earnings before interests, tax, depreciation and amortisation) is generally calculated in advance in order to calculate EBIT which can be calculated as follows.

- EBIT = EBITDA - taxes and interests

  Operating profit margin = revenue – cost of sales- general and administrative expenses

$$\text{EBIT margin} = \frac{\text{EBIT}}{\text{revenue}} \text{ x } 100 \tag{5.28}$$

This indicator is particularly useful when comparing different terminal operators where each terminal operator may have varying capital structures or tax environments. EBIT margin is

EBIT as a percentage of revenue and is calculated as EBIT divided by revenue. In order to set a measurement grade of the EBIT margin, this work uses the EBIT margins of four major GTOs between 2008 and 2012 (Table 5.15). Based on the data, the assessment grade of the EBIT margin can be defined as {leq 0%, 10 %, 15 %, 20 %, 25 %, geq 30 %}.

Table 5.15 EBIT margins of four major GTOs

EBIT	2008	2009	2010	2011	2012
PSA	33.47%	31.40%	35.67%	34.26%	35.87%
HPH	-	-	25.22%	24.66%	23.65%
APM	10.03%	13.16%	21.43%	16.42%	19.15%
DP world	29.49%	23.79%	25.41%	29.48%	31.94%

Source: Author's own calculation based on financial reports of each company.

- Net profit margin

Net profit, referred to as net income for the year, is a good indicator for a company to measure the net profitability after deducting all costs. In the income statement, the indicator of a company's financial performance is calculated in the following process and Eq. (5.29).

- Revenue - cost of sales = gross profit
- Gross profit - general and administrative expenses = operating profit (EBIT)
- Operating profit + (other income-other expenses) = profit from operations
- Profit from operations + (finance income – finance costs) – income tax expense = profit for the year

$$\text{Net profit margin} = \frac{\text{net income}}{\text{revenue}} \text{ x } 100 \tag{5.29}$$

Net profit margin is net profit as a percentage of revenue and is calculated as net profit divided by revenue. In order to set a measurement grade of the net profit margin, this study uses the net profit margins of four major GTOs between 2008 and 2012 (Table 5.16). Based on the data, the assessment grade of the net profit margin can be defined as {leq 0 %, 5 %, 10 %, 15 %, 20 %, geq 25 %}.

Table 5.16 Net profit margins of four major GTOs

Net profit margin	2008	2009	2010	2011	2012
PSA	23.7%	25.1%	29.4%	26.8%	28.6%
HPH	-	-	-	-	-
APM	5.1%	11.7%	18.6%	13.8%	15.1%
DP world	18.9%	11.8%	14.6%	17.8%	20.4%

Source: Author's own calculation based on financial reports of each company.

5.3.1.1.5 Solvency and liquidity

- Solvency

Solvency denotes the ability of the company to cover its long-term liabilities and indicates the degree of financial risk that a company faces. However, it is noteworthy that it is impossible to suggest an optimum level of the solvency ratio which varies between types of industries. Commonly used solvency ratios in practice include debt to equity and debt (or equity) to assets, etc. Debt to equity ratio can be calculated as the following formula.

$$\text{Solvency} = \frac{\text{total debt}}{\text{owner's equity}} \tag{5.30}$$

From Table 5.17, the improved debt to equity ratios of major GTOs represent reduction of the degree of financial risk but do not mean achievement of financial efficiency or effectiveness. Based on the benchmarking result of the major GTOs' debt to equity ratios, the assessment grades of the debt to equity can be developed as {geq 2, 1.8, 1.6. 1.4, 1.2, leq 1}.

Table 5.17 Debt to equity ratios of the major GTOs

Solvency	2008	2009	2010	2011	2012
PSA	147.2%	136.5%	114.1%	91.7%	79.6%
HPH	169.6%	147.8%	146.5%	95.5%	109.1%
APM	128.3%				
DP world	116.1%	135.9%	127.9%	128.1%	88.3%
Average	140.3%	140.1%	129.5%	105.1%	92.3%

Source: Author's own calculation based on financial reports (2008-2012) of each company.

Debt (equity) to assets ratio can be calculated by dividing the amount of debt by the amount of total assets. In practice, debt to assets ratio of less than 0.5 is generally deemed to be healthy while current ratio more than 0.5 is generally deemed to be unhealthy.

$$\text{Solvency} = \frac{\text{total debt (or owner's equity)}}{\text{total assets}} \tag{5.31}$$

Based on the selected GTOs' debt to assets ratios, the assessment grade of this PPI can be defined as {geq 0.5, leq 0.5}.

Table 5.18 Debt to assets ratios of the major GTOs

Solvency	2008	2009	2010	2011	2012
PSA	59.6%	57.7%	53.3%	47.8%	44.3%
HPH	62.9%	59.7%	59.4%	48.8%	52.2%
APM	56.2%	0.0%	0.0%		
DP world	53.7%	57.6%	56.1%	56.2%	46.9%
Average	58.1%	43.7%	42.2%	50.9%	47.8%

Source: Author's own calculation based on financial reports (2008-2012) of each company.

- Current ratio (liquidity)

We sometimes find the case that even where a company is profitable, at the same time it may encounter cash flow problems. That is a vital reason why liquidity should be managed. Current ratio, also known as the similar concept of net working capital ratio, is a useful indicator to measure a company's liquidity. The current ratio denotes the ability of the company to cover its short term liabilities and is calculated as the amount of current assets divided by the amount of current liabilities. As with the solvency ratio, an optimum level of the current ratio also varies between the types of industry. In practice, a current ratio of approximately between 1 and 2 is generally deemed to be prudent while current ratio less than 1 is generally deemed to be imprudent. However, it is noteworthy that a high current ratio is not always a good liquidity condition for the company because it may indicate that the company has too much inventory or the company is not investing their excess cash.

$$\text{Current ratio} = \frac{\text{current assets}}{\text{current liabilities}} \tag{5.32}$$

In order to set a measurement grade of the current ratio, based on the best practice and the selected GTOs' current ratios, the assessment grade of this PPI can be defined as {leq 1, between 1 and 2, geq 2}.

Table 5.19 Current ratios of the major GTOs

Liquidity	2008	2009	2010	2011	2012
PSA	56.3%	105.8%	115.5%	220.8%	237.0%
HPH	-	-	-	-	-
APM	-	-	-	-	-
DP world	140.4%	256.5%	303.9%	118.7%	145.1%
Average	98.3%	181.1%	209.7%	169.7%	191.1%

Source: Author's own calculation based on financial reports (2008-2012) of each company.

5.3.2 Measurement of each PPI at the bottom level

The MADM problems are normally modelled by an extended $m \times n$ decision matrix as shown in Table 5.20, where there are m alternatives (i.e. ports) a_i ($i = 1, 2, \dots, m$) which have n attributes (i.e. PPIs) x_j ($j = 1, 2, \dots, n$). In addition, x_{mn} is a numerical value of a quantitative attribute x_n at an alternative a_m and x'_{mn} is a subjective judgement for evaluation of a qualitative attribute x'_n at an alternative a'_m. Each element can be assessed using a belief structure (i.e. degrees of belief, DoB) (Yang and Sen, 1994, Yang, 2001). The belief structure is represented by an expectation that was originally developed for modelling a subjective assessment with uncertainty using a single set of assessment grades (i.e. linguistic terms) for all criteria (Yang and Singh, 1994, Yang and Sen, 1994). Its usage was upgraded for both objective and subjective assessments using a different number of numerical and linguistic assessment grades (Yang, 2001). Therefore, the measurement can be presented by degrees of belief belonging to either linguistic terms (for the qualitative PPIs) or numerical values (for the quantitative PPIs).

Table 5.20 Extended decision matrix

Alternatives (a_i)	Quantitative PPIs (x_j)					Alternatives (a'_i)	Qualitative PPIs (x'_j)				
	x_1	….	x_j	….	x_n		x'_1	….	x'_j	….	x'_n
a_1	x_{11}	….	x_{1j}	….	x_{1n}	a'_1	x'_{11}	….	x'_{1j}	….	x'_{1n}
….	….	….	….	….	….	….	….	….		….	….
a_i	x_{i1}	….	x_{ij}	….	x_{in}	a'_i	x'_1		x'_{ij}	….	x'_{in}
....	….	….	….	….	….	….	….	….	….	….	….
a_m	x_{m1}	….	x_{mj}	….	x_{mn}	a'_m	x'_{m1}	….	x'_{mj}	….	x'_{mn}

5.3.2.1 Measurement of the qualitative PPIs

As aforementioned, the degrees of belief associated with linguistic terms for qualitative PPIs are straightforwardly obtained by assessors' judgements. This study offers assessors judgement flexibility by assessing on either one grade or even more, instead of assessing only on one grade to avoid uncertainties in subjective judgement. On top of that this study permits incomplete judgements (i.e. the sum of DoB is less than 1) when assessors are not able to conduct a precise judgement due to inadequacy of information, which can be assigned to an unknown scale. In this regard, this study could minimise the missing data problems, which is hard to find in other methodologies.

The following set of evaluation grades may be defined for evaluation of the qualitative PPIs (x'_j) in Table 5.20.

$$H = \{H_1, \dots\dots\dots., H_j, \dots\dots\dots., H_n\} \tag{5.33}$$

where H_j is an evaluation grade for x'_j and n is the number of the evaluation grades. Without loss of generality, H_1 and H_n represent the worst and the best grades respectively and a large value H_{j+1} is supposed to be preferred to a small value H_j. This can be demonstrated as follows:

$$H = \{(H_1, \beta_1), \dots, (H_j, \beta_j), \dots, (H_n, \beta_n)\} \tag{5.34}$$

where $\beta_j \geq 0$ $(j = 1 \dots n), \sum_{j=1}^{n} \beta_j \leq 1$ and $\beta_j$denotes degrees of belief.

Then, if there are k assessors who evaluate the qualitative PPI with DoB (β_j) on linguistic terms (H_j, either one or even more), the judgements can be aggregated using Eq. (5.35).

$$H^{aggregation} = \frac{\sum_{j=1}^{n} B_j^l}{k},\ l=1 \ldots k,\ \sum_{j=1}^{n} B_j^l \leq 1 \tag{5.35}$$

The measurement of belief degrees with respect to linguistic terms for "commitment and loyalty of the employees (CL)" is provided as an example. A set of the fuzzy linguistic terms {very low, low, medium, high, very high} was identified in Table 5.6. Thus, the evaluation grades for CL can be demonstrated in terms of Eqs. (5.33)-(5.34) as follows:

$$CL = \{very\ low\ (H_1), low\ (H_2), medium (H_3), high\ (H_4), very\ high\ (H_5)\}$$

If there are four assessors who evaluate the CL to high, high, very high and medium, respectively, the assessments can be expressed as follows:

Expert 1: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 1), (very\ high, 0)\}$

Expert 2: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 1), (very\ high, 0)\}$

Expert 3: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 1)\}$

Expert 4: $CL = \{(very\ low, 0), (low, 0), (medium, 1), (high, 0), (very\ high, 0)\}$

Then using Eq. (5.35), the following CL assessment sets and aggregated DoB can be obtained by dividing each DoB by 4 experts.

Expert 1: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0.25), (very\ high, 0)\}$

Expert 2: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0.25), (very\ high, 0)\}$

Expert 3: $CL = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 0.25)\}$

Expert 4: $CL = \{(very\ low, 0), (low, 0), (medium, 0.25), (high, 0), (very\ high, 0))$

$$CL^{aggre} = \{(very\ low, 0+0+0+0), (low, 0+0+0+0), (medium, 0+0+0+0.25), (high, 0.25+0.25+0+0), (very\ high, 0+0+0.25+0)\}$$

$$CL^{aggregation} = \{(very\ low, 0), (low, 0), (medium, 0.25), (high, 0.5), (very\ high, 0.25)\}$$

5.3.2.2 Measurement of the quantitative PPIs

Location measurement techniques have been introduced to produce the belief degrees with respect to quantitative PPIs (Yang *et al*., 2009a, Yeo *et al*., 2014). There are four types of location measures such as linear, bilinear, non-linear and judgemental. In the linear condition, in general, values are monotonically increased or monotonically decreased (Yang *et al*., 2009a). The former means more is better than less (Eq. (5.36)) while in the latter case where less is better than more (Eq. (5.37)), respectively. Locations for both cases are measured using following equations.

$$L_a = \frac{V_a - V_{min}}{V_{mas} - V_{min}} \tag{5.36}$$

where L_a stands for the location of one state, V_a is its state value, V_{mas} is the value of the state with maximal value and V_{min} is the value of the state with the minimal value.

$$L_a = \frac{V_{max} - V_a}{V_{mas} - V_{min}} \tag{5.37}$$

where L_a stands for the location of one state, V_a is its state value, V_{mas} is the value of the state with maximal value and V_{min} is the value of the state with minimal value.

In the bilinear condition, neither maximal value nor minimal value is preferable but optimal value where some mid-point is preferable to anything else (Yang *et al.*, 2009a). If more is better than less case, then the location can be calculated using following equation.

$$L_a = \frac{V_a - V_{min}}{U_{mas} - V_{min}} \tag{5.38}$$

where U_{mas}denotes the value of the state with the highest preference and other symbols denote the same meaning as the ones in Eq. (5.37).

In addition, if less is better than more, then the location can be calculated using following equation.

$$L_a = \frac{V_{max} - V_a}{V_{mas} - U_{max}} \tag{5.39}$$

where all symbols denotes the same meaning as the ones in Eq. (5.38).

On the other hand, in the non-linear condition, a location can be measured with a simplified method and may have various forms depending on the relation of the states of PPIs. Finally, the judgemental case is preferred to be measured using fuzzy numbers based on linguistic terms (Yang *et al.*, 2009a).

Depending on the quantitative PPIs' conditions (linear, bilinear, non-linear and judgemental), different location measurement techniques can be used. PPIs in the lowest level are quantitative which can be measured using precise numbers. The following is an example of linear condition for "throughput growth". A set of quantitative grades {leq $0\%, 5\%, 10\%, 15\%, 20\%, geq$ 25%} was already defined in Table 5.5. The assessment grades can be demonstrated based on Eqs. (5.33)-(5.34) as follows.

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), geq\ 25\%(H_6)\}$$

If any quantitative number $h_{j,i}$ (with an evaluation grade H_j) is evaluated between $h_{j-1,i}$ (with an evaluation grade H_{j-1}) and $h_{j+1,i}$ (with an evaluation grade H_{j+1}), the DoB can be transformed using following equation based on location measurement technique with liner condition.

$$If\ h_{j-1,i} < h_{j,i} < h_{j+1,i}\ then\ B_{j+1,i} = \frac{h_{j,i}-h_{j-1,i}}{h_{j+1,i}-h_{j-1,i}}, B_{j-1,i} = 1 - h_{j+1,i} \quad (5.40)$$

where $B_{j+1,i}$ represents the DoB associated quantitative number with the grade $H_{j+1}$and $B_{j-1,i}$ represents the DoB associated quantitative number with the grade H_{j-1}.

If throughput growth, for example, is 2%, this value can be transformed as DoB in terms of Eq. (5.40).

$$h_{j-1,i} = \ leq\ 0\%(H_1), \qquad h_{j,i} = 2\%, \qquad h_{j+1,i} = 5\%(H_2)$$

Thus, $B_{j+1,i} = \frac{2-0}{5-0} = 0.4$ DoB with $5\%(H_2)$ and $B_{j-1,i} = 1 - 0.4 = 0.6$ DoB with $leq\ 0\%(H_4)$. Therefore, the throughput growth (TG) set is assessed as follows.

$$H^{TG} = \{(leq\ 0\%, 0.6), (5\%, 0.4), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$$

5.3.3 Mapping process –transform the evaluation from the lowest level PPIs to top level PPI.

PPIs for port performance measurement include different numbers and linguistic terms of assessment grades in the lower-level PPIs and the associated upper-level PPI. The defined grades, thus, need to be interpreted and transformed into a unified format for assessment of the associated upper level PPIs (Yeo *et al.*, 2014). This can be done in terms of fuzzy IF-THEN rule base belief structure. Yang (2001) developed the rule based utility techniques that can be easily applied for transforming qualitative and quantitative data, hence the techniques have already been proven by many scholars (Yang *et al.*, 2009a, Yang *et al.*, 2009b, Yeo *et al.*, 2014). The core of this technique is a fuzzy mapping technique to transform fuzzy inputs to fuzzy outputs. As shown in Figure 5.5, I^i ($\sum_{i=1}^{n} I^i \leq 1$) indicates the fuzzy input associated with a lower-level PPI and O^j ($O^j = \sum_{i=1}^{n} I^i \beta_i^j$) represents the fuzzy output transformed from I^i. B_i^j ($\sum_{j=1}^{n} \beta_i^j = 1$) denotes the DoB assigned by experts' judgements for presenting the relationship between assessment grades of different levels. For example, the upper level PPI "output (OPC)" can be expressed using linguistic terms as "very low (OPC1)", "low (OPC2)", "medium (OPC3)", "high (OPC4)" and "very high (OPC5)". The numerical grades used to assess the lowest level PPI "throughput growth (TG)" can be expressed "less than 0% (TG1)", "5% (TG2)", "10% (TG3), "15% (TG4)", "20% (TG5)" and more than 25% (TG6). The decision makers have assigned the fuzzy rules for mapping from throughput growth to output (Table

5.21). It is noteworthy that the throughput growth of "less than 0%" means that the output is said to be equivalent to a grade "very low" using fuzzy rules. Based on R^5 and R^6, 2% throughput growth can be transformed into (30% OPC2 ($O^2 = 0.4 \times 0.75$) and 10% OPC1 ($O^1 = 0.4 \times 0.25$)) and (60% OPC1 ($O^1 = 0.6 \times 1$)) respectively. It can be equally described as 70% OPC1 and 30% OPC2 (Figure 5.5). This mapping process can be conducted from the lowest level PPIs to the top level goal in the same manner.

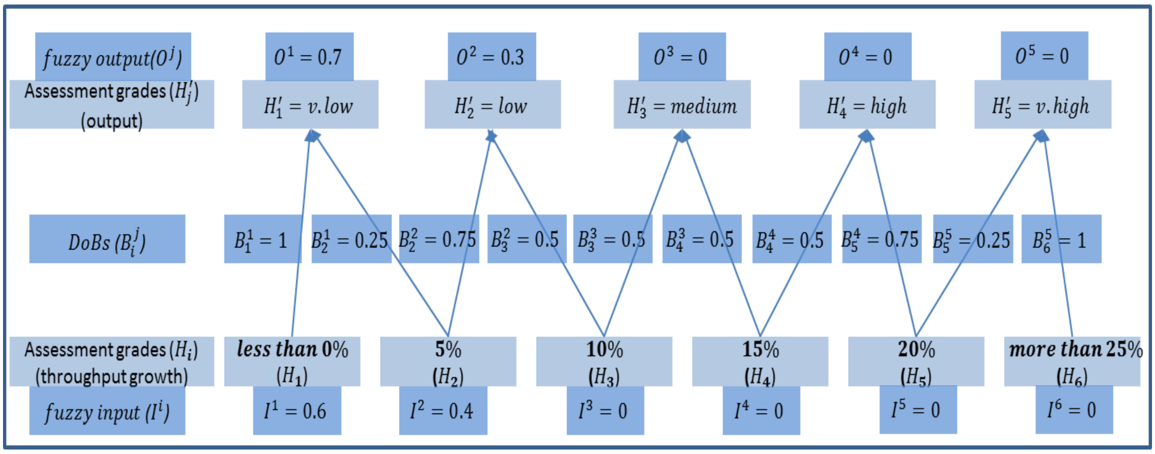

Figure 5.5 Fuzzy mapping process (from throughput growth to output)

Table 5.21 Fuzzy rule base belief structure (output)

<u>Throughput growth to output</u>	R^1: *IF terminal operator's "throughput growth (TG)" is "more than 25% (TG6)", then "output (OPC)" is "very high (OPC5)" with 100%* DoB. *This can be simplified and presented by symbols as* R^1: *If "TG" is "TG6", then "OPC" is "100% OPC5"* *Similarly,* R^2: *If "TG" is "TG5", then "OPC" is "25% OPC5" and "75% OPC4"* R^3: *If "TG" is "TG4", then "OPC" is "50% OPC4" and "50% OPC3"* R^4: *If "TG" is "TG3", then "OPC" is "50% OPC3" and "50% OPC2"* R^5: *If "TG" is "TG2", then "OPC" is "75% OPC2" and "25% OPC1"* R^6: *If "TG" is "TG1", then "OPC" is "100% OPC1"*

5.3.4 Weighting assignment using analytic hierarchy process

Weights play an important role in the context of the ER framework. Local weights of PPIs at the same level can be obtained through either a simple rating method or pair-wise comparisons (Yang and Xu, 2002). The AHP (Analytic Hierarchy Process), introduced by Saaty (1980), has been popularly used to assign the relative importance of each criterion (i.e. PPI) (Pillay and Wang, 2003, Riahi *et al*., 2012, John *et al*., 2014). This methodology employs a unidirectional hierarchical relationship of the linear top-down form of hierarchy from goal to criteria to alternatives. This method regards each criterion as independent in nature in a hierarchy and can identify a unidirectional relationship with a linear chain among decision levels (Saaty, 1990). Hence, the AHP method is considered as the most convenient tool for solving complicated problems.

The characteristics and calculations of the AHP were described in 5.2.2. For further information, please refer to 5.2.2.

5.3.5 Synthesis of the PPIs using evidential reasoning algorithm and utility techniques

The transformed results from the lowest level PPIs to the top level goal and their relative weights can be synthesised by the ER algorithm and utility theory. The calculations of the ER algorithm and utility techniques were described in 5.2.3. For further information, please refer to 5.2.3. The synthesised results can be simply obtained by IDS (intelligent decision system) (Yang and Xu, 2000). The Windows based tool, IDS, facilitates the process of decision making from collecting information to building up a model, defining alternatives and criteria and different assessments (Yeo *et al*., 2014). On top of that, 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 (Xu and Yang, 2005). This software has widely been used in a variety of applications, such as motorcycle assessment (Yang and Xu, 2002), organizational self-assessment (Yang *et al*., 2001), risk analysis of a liquefied natural gas carrier (Nwaoha *et al*., 2011), vessel selection (Yang *et al*., 2009b), crew reliability (Riahi *et al*., 2012) and port choice (Yeo *et al*., 2014). The IDS via ER and utility technique is especially useful when dealing with MADM problems of the following features (Xu and Yang, 2005).

- Mixture of quantitative and qualitative information
- Mixture of deterministic and random information
- Incomplete (missing) information
- Vague (fuzzy) information
- Large number (hundreds) of criteria in a hierarchy
- Large number of alternatives

5.4 AN EMPIRICAL STUDY ON COMTAINER TERMINAL PERFORMANCE MEASUREMENT

The hybrid model is applied to measure and analyse the performance of the dedicated 12 container terminals in Korea to validate the proposed framework. According to Talley (2006), the objectives of ports/terminals can be varied in terms of governance types. The private ports maximise their profits or market share, while the public ports or subsidised ports more focus on maximising throughput volumes but sometimes allow a zero-profit or operating deficit. Highly increased in Public-Private Partnerships (PPP) in the port industry since the 1990s, the landlord ports are one of the most predominant governance types in pursuing the maximisation of the port profits or market shares. In terms of the taxonomy developed by Baird (1995, 1997), the port governance (i.e. the administrative and ownership structures) of the case container terminals in Korea is located somewhere between the PRIVATE and the PRIVATE/public model. Regardless of the degree of private participation (i.e. financial involvement), the objectives of the terminals are to maximise their profits and market shares. The roles of the government (including port authorities) are not only to develop port infrastructure such as breakwater, connecting roads and railways to port but also to control and supervise the terminals' operations.

Korea has played an important role in the maritime industry as an economy that handled the fourth largest global container throughput of approximately 23 million TEUs in 2013. The 12 container terminals handled more than 80% of total container throughput in 2013 with approximately 18.7 million TEUs. Considering the role of the 12 container terminals in Korean economy as well as data availability from the different port stakeholders, the 12 container terminals are selected as real cases to validate the proposed framework. Table 5.22 denots the characteristics of container terminals in three major ports in South Korea.

5.4.1 Data collection

PPIs include various types of numeric and subjective data to reflect the complexity of port/terminal business environments. The quantitative data (i.e. CA and FS) were collected directly from terminal operating companies and information systems/databases managed by port authorities, government and credit rating agencies.

Table 5.22 Container terminals in Korea

Port	Terminal	Operator	Capacity of berth	Annual hadling capacity (teu)	Berth length (m)	Opening year	Note
Busan North	Jasungdae	Korea Hutchison	4,000TEUx4 / 700TEUx1	1,700,000	1,447	1978	
	Shinsundae	CJ Korea Express	4,000TEUx5	2,000,000	1,500	1991	
	Gamman	SBTC, BGCT	4,000TEUx4	1,560,000	1,400	1998	
	Singamman	Dongbu Busan	4,000TEUx2 / 400TEUx1	780,000	826	2002	
	Uam	Uam Co., Ltd	2,000TEUx1 / 400TEUx2	300,000	500	1996	Closed in 2016
	Gamcheon	HanJin		660,000	600	1998	Closed in 2009
Busan New	1-1	PNIT	4,000TEUx6	1,380,000	1,200	2006	
	1-1, 2	PNC	4,000TEUx3	2,730,000	2,000	2009	
	2-1	HJNC	4,000TEUx2 / 2,000TEUx2	1,600,000	1,100	2009	
	2-2	HPNT	4,000TEUx2 / 2,000TEUx2	1,600,000	1,150	2010	
	2-3	BNCT	4,000TEUx4	1,920,000	1,400	2011	
Gwangyang	1		4,000TEUx2	1,600,000	1,400	1998	Transferred to general berth in 2013
	2-1	HSGC	2,000TEUx2 / 4,000TEUx2	1,140,000	1,150	2002	
	2-2	KIT	2,000TEUx2 / 4,000TEUx2	1,140,000	1,150	2004	
	3-1	Korea Express	4,000TEUx4	1,600,000	1,400	2007	
Incheon	SICT	SICT	1,500TEUx2	240,000	407	2009	
	E1CT	E1CT	2,000TEUx1	140,000	259	2009	
	Korea Express	Korea Express	400TEUx2	100,000	225	2009	
	HJS	HJS	10,000 ton x1/20,000 ton x1 /50,000 ton x1/40,000 ton x1	240,000	625	1996	Multipurpose berth

Source: Ministry of Land, Transport and Maritime Affairs (2013)

The qualitative PPIs were collected using questionnaires from three groups of terminal operators (TO), users (i.e. shipping lines, third-party logistics providers and freight forwarders, PU) and administrators (i.e. port authority and government, AD) to assess their own associated PPIs to measure each port performance. The survey was conducted through an online survey tool as well as distributed by emails. The detailed responses of the survey are listed in Table 5.23.

Table 5.23 Response details

Terminal	Stakeholder	Total distributed	Email received	Online received	Usable response	Judgement on:
T1	TO	25	0	12 (11)	11	SA, TSCI, SSS, EVS
	PU	200	38 (31)	20(12)	43	US, TSCI
	AD	40	0	9 (6)	6	SG
T2	TO	25	0	9 (8)	8	SA, TSCI, SSS, EVS
	PU	200	38 (30)	20(12)	42	US, TSCI
	AD	40	0	9 (6)	6	SG
T3	TO	25	2 (2)	12 (10)	12	SA, TSCI, SSS, EVS
	PU	200	38 (30)	20(12)	42	US, TSCI
	AD	40	0	9 (6)	6	SG
T4	TO	25	1 (1)	6 (6)	7	SA, TSCI, SSS, EVS
	PU	200	38 (30)	20(12)	42	US, TSCI
	AD	40	0	9 (6)	6	SG
T5	TO	25	4 (4)	13 (10)	14	SA, TSCI, SSS, EVS
	PU	200	38 (30)	20(12)	42	US, TSCI
	AD	40	0	9 (6)	6	SG
T6	TO	25	0	7 (7)	7	SA, TSCI, SSS, EVS
	PU	200	38 (30)	20 (12)	42	US, TSCI
	AD	40	0	9 (6)	6	SG
T7	TO	25	14 (14)	0	14	SA, TSCI, SSS, EVS
	PU	200	24 (24)	6 (4)	28	US, TSCI
	AD	40	0	10 (10)	10	SG
T8	TO	25	15 (15)	0	15	SA, TSCI, SSS, EVS
	PU	200	25 (25)	6 (4)	29	US, TSCI
	AD	40	0	10 (10)	10	SG
T9	TO	25	11 (11)	0	11	SA, TSCI, SSS, EVS
	PU	200	24 (24)	6 (4)	28	US, TSCI
	AD	40	0	10 (10)	10	SG
T10	TO	25	0	14 (14)	14	SA, TSCI, SSS, EVS
	PU	200	16 (16)	13 (12)	28	US, TSCI
	AD	40	0	6 (6)	6	SG
T11	TO	25	0	11 (11)	11	SA, TSCI, SSS, EVS
	PU	200	16 (16)	13 (12)	28	US, TSCI
	AD	40	0	6 (6)	6	SG
T12	TO	25	0	14 (14)	14	SA, TSCI, SSS, EVS
	PU	200	16 (16)	13 (12)	28	US, TSCI
	AD	40	0	6 (6)	6	SG
Sum	TO	375	47 (47)	98 (91)	138	SA, TSCI, SSS, EVS
	PU*	800	349 (302)	177 (120)	422	US, TSCI
	AD**	120	0 (0)	84 (84)	84	SG

Note: *The questionnaire for port users were distributed to the port users who have an experience using a terminal' service in each port so that they can judge on their associated PPIs performance of one to three terminal(s) in Busan North, Busan New, Gwang Yang and Incheon Port, respectively.

**The questionnaire for port administrators were distributed to the port administrators who are in charge of administrating each port so that they can judge on PPIs performance of three terminals in Busan, Gwang Yang and Incheon Ports.

5.4.1.1 Terminal operators

The questionnaire survey to dedicated container terminals was conducted in order to collect the qualitative data of the SA, TSCI, SSS, EVS. The dedicated container terminal in Korea means that any types of cargo except for container box cannot be handled in the dedicated container terminal in terms of the Harbour Transport Business Act. There are 9 dedicated container terminals in Busan Port, 3 terminals in Gwangyang Port and 4 terminals in Incheon Port. 138 questionnaires were collected from TOs, indicating similar response rates (20%-30%) in terms of the work experience. On top of that, 75% of responses came from managers' level including assistant manager, manager, deputy general manager, department manager while 6% were collected from top management level.

Table 5.24 The profile of terminal operators

The profile of terminal operator	Frequency (138)	Percentage
Experience		
Less than 5	30	22%
5-10	41	30%
10-15	39	28%
Over 15	28	20%
Position		
Staff	25	18%
Assistant manager	32	23%
Manager	30	22%
Deputy general manager	25	18%
Department manager	17	12%
Managing director	7	5%
CEO	1	1%

5.4.1.2 Port users

This study divided the port users into shipping lines and logistics service providers (i.e. third-party logistics providers, freight forwarders, ship and cargo agents, etc.). The lists of shipping lines were obtained from the Korea Ship-owners' Association (KSA) and database systems in each port authority. The samples were chosen in terms of their ports of call in Busan North Port, Gwangyang Port, Incheon Port, Busan New Port based on the database systems of each port authority and terminal operator. On top of that, the lists of logistics services providers were obtained from the Korea International Freight Forwarders Association (KIFFA) and the Korea Integrated Logistics Association (KILA). 422 samples were collected from PUs, indicating various response rates (12%-39%) in terms of the work experience. On top of that, 78% of responses came from managers' level including assistant manager, manager, deputy general manager, department manager while 6% were collected from top management level.

Table 5.25 The profile of port users

The profile of port users	Frequency (422)	Percentage
Ship lines	175	41%
Logistics service providers	247	59%
Experience		
Less than 5	166	39%
5-10	145	34%
10-15	51	12%
Over 15	60	14%
Position		
Staff	67	16%
Assistant manager	195	46%
Manager	70	17%
Deputy general manager	30	7%
Department manager	33	8%
Managing director	21	5%
CEO	6	1%

5.4.1.3 Port administrators

Port regulators/administrators such as port authority and government were invited to assess the sustainable growth (SG) dimension. 22 questionnaires were collected from PUs, indicating almost 50% collected from over 15 years' experience. On top of that, 90% of responses came from managers' level including assistant manager, manager, deputy general manager, department manager while 9% were collected from top management level.

Table 5.26 The profile of port administrators

The profile of port users	Frequency (22)	Percentage
Port authority	11	50%
Ministry of oceans and fisheries	11	50%
Experience		
Less than 5	4	18%
5-10	4	18%
10-15	4	18%
Over 15	10	45%
Position		
Staff (assistant official)	0	0%
Assistant manager (junior official)	6	27%
Manager (chief official)	4	18%
Deputy general manager (secretary official)	7	32%
Department manager (deputy commissioner)	3	14%
Managing director (chief commissioner)	2	9%
CEO (chief administrator)	0	0%

5.4.2 Evaluate each port/terminal based on the lowest level PPIs.

In this section, the calculation process with respect to each PPI is demonstrated. In order to avoid duplication, one container terminal (T6) is denoted as an example case. However, the obtained results of other alternative terminals are presented in Appendix I. For further information, please refer to Appendix I.

5.4.2.1 Quantitative PPIs (T6)

Based on given information and previous discussion, different location measurement techniques can be used to transform degrees of belief (DoB) for quantitative PPIs.

Throughput volume growth in T6

The quantitative assessment grades of the throughput growth is already defined as *{leq 0%, 5%, 10%, 15%, 20%, geq 0%}* in section 5.3.1.

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), geq\ 25\%(H_6)$$

The data of the throughput growth between 2012 and 2013 in T6 is demonstrated in Table 5.27.

Table 5.27 Throughput growth (2012-2013)

Terminal	2012	2013	Growth ('12-'13)
T6	1,988,675	2,391,890	20.28%

The throughput growth in T6 is 20.28%, this value can be transformed to DoB using Eq. (5.40).

$$h_{j-1,i} = 20\%(H_5), \qquad h_{j,i} = 20.28\%, \qquad h_{j+1,i} = geq\ 25\%(H_6)$$

Thus, $B_{j+1,i} = \frac{20.28-20}{25-20} = 0.056$ DoB with $geq\ 25\%(H_6)$ and $B_{j-1,i} = 1 - 0.056 = 0.944$ DoB with $20\%(H_5)$. Therefore, the throughput growth (TG) set in T6 is assessed as follows:

$$H^{TG} = \{(leq\ 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.944), (geq\ 25\%, 0.056)\}$$

Other quantitative PPIs to transform DoB for terminal 6 are also presented in Appendix I.

The transformed DoB sets of the quantitative PPIs for T6 are summarised in Table 5.28. They are to be used for mapping process in the next step.

Table 5.28 DoB sets of quantitative PPIs (T6)

PPIs	Degrees of Belief
Throughput volume growth	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.944), (geq\ 25\%, 0.056)\}$
Vessel call size growth	$H^{V\ capacity} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0.392), (geq\ 20\%, 0.608)\}$
Ship load rate	$H^{loadrate} = \{(\text{leq } 25\text{TEU}, 0), (40\text{TEU}, 0.343), (55\text{TEU}, 0.657), (70\text{TEU}, 0), (85\text{TEU}, 0), (\text{geq } 100\text{TEU}, 0)\}$
Berth utilization	$H^{berth\ U} = \{(\text{leq } 300\text{TEU}, 0), (600\text{TEU}, 0), (900\text{TEU}, 0), (1200\text{TEU}, 0), (1500\text{TEU}, 0), (\text{geq } 1800\text{TEU}, 1)\}$
Berth occupancy	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (geq\ 80\%, 0)\}$
Crane efficiency	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.8), (35moves, 0.2), (40moves, 0), (geq\ 45moves, 0)\}$
Yard utilization	$H^{yard} = \{(leq\ 2TEU, 0), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 1)\}$
Labour utilization	$H^{labour} = \{(\text{leq } 1000\text{TEU}, 0), (2000\text{TEU}, 0), (3000\text{TEU}, 0), (4000\text{TEU}, 0), (5000\text{TEU}, 0.856), (\text{geq } 6000\text{TEU}, 0.144)\}$
Vessel turnaround time	$H^{vessel\ T} = \{(\text{geq } 5\text{days}, 0), (4\text{days}, 0), (3\text{days}, 0), (2\text{days}, 0), (\text{leq } 1\text{day}, 1)\}$
Truck turnaround time	$H^{truck\ T} = \{(\text{geq } 40\text{mins}, 0), (35\text{mins}, 0), (30\text{mins}, 0), (25\text{mins}, 0), (20\text{mins}, 0.34), (\text{leq } 15\text{mins}, 0.66)\}$
Container dwell time	$H^{dwell} = \{(\text{geq } 4\text{weeks}, 0), (3\text{weeks}, 0), (10\text{days}, 0), (7\text{days}, 0), (5\text{days}, 0.35), (\text{leq } 3\text{days}, 0.65)\}$
Revenue growth	$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 1)\}$
Operating profit margin	$H^{operating\ M} = \{(\text{leq } 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.056), (\text{geq } 30\%, 0.944)\}$
Net profit margin	$H^{net\ M} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0.364), (15\%, 0.636), (20\%, 0), (\text{geq } 25\%, 0)\}$
Current ratio	$H^{CR} = \{(leq\ 1,1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
Debt to total asset	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
Debt to equity	$H^{DE} = \{(geq\ 2,1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$

5.4.2.2 Qualitative PPIs (T6)

As aforementioned, the DoB with respect to linguistic terms for qualitative PPIs are straightforwardly obtained by assessors' judgements. 7 assessors from T6 evaluated on the SA, TSCI, SSS and EVS. 42-43 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T6 took part in assessing the US and TSCI and 6 assessors from port authority and government participated in the judgements on SG.

Table 5.29 Response details for T6

	Terminal operator	User		Administrator	
	T6	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	17 (13)	21 (17)	0	0
Online received	7 (7)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(7)	(18)	(24)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

<u>Supporting Activities</u>

Based on Eq. (5.34), the judgement results by a number of assessors can be represented as follows (Table 5.30). Total 7 assessors from T6 took part in the judgements on supporting activities. Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35). The results are presented in Table 5.31.

Table 5.30 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	0	5	2	7
Capability	0	1	2	4	0	7
Training and education opportunity	0	1	3	2	1	7
Commitment and Loyalty	0	0	3	4	0	7
Organisation Capital (OCS)						
Culture	0	1	1	5	0	7
Leadership	0	0	3	3	1	7
Alignment	0	1	2	3	1	7
Teamwork	0	0	3	2	2	7
Information Capital (ICS)						
IT systems	1	0	1	4	1	7
Databases	0	1	2	3	1	7
Networks	0	0	2	5	0	7

Table 5.31 Degrees of belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.00	0.71	0.29	1.00
Capability	0.00	0.14	0.29	0.57	0.00	1.00
Training and education opportunity	0.00	0.14	0.43	0.29	0.14	1.00
Commitment and Loyalty	0.00	0.00	0.43	0.57	0.00	1.00
Organisation Capital (OCS)						
Culture	0.00	0.14	0.14	0.72	0.00	1.00
Leadership	0.00	0.00	0.43	0.43	0.14	1.00
Alignment	0.00	0.14	0.29	0.43	0.14	1.00
Teamwork	0.00	0.00	0.43	0.29	0.29	1.00
Information Capital (ICS)						
IT systems	0.14	0.00	0.14	0.57	0.14	1.00
Databases	0.00	0.14	0.29	0.43	0.14	1.00
Networks	0.00	0.00	0.29	0.71	0.00	1.00

Users' Satisfaction

Total 42-43 assessors from port users took part in the judgements on users' satisfaction (see Table 5.32). Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35) (see Table 5.33).

Table 5.32 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	8	11	18	6	43
Responsiveness to special requests	3	4	18	13	4	42*
Accuracy of document & information	1	2	13	18	9	43
Incidence of cargo damage	0	5	9	20	9	43
Incidence of service delay	3	3	17	16	4	43
Service Costs (SCU)						
Overall service costs	4	7	15	15	2	43
Cargo handling charges	3	8	18	12	2	43
Cost of terminal ancillary services	3	12	16	10	2	43

Note: *1 assessor from freight forwarder has no confidence to provide the associated question.

Table 5.33 Degrees of belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.19	0.26	0.42	0.14	1.00
Responsiveness to special requests	0.07	0.10	0.43	0.31	0.10	1.00
Accuracy of document & information	0.02	0.05	0.30	0.42	0.21	1.00
Incidence of cargo damage	0.00	0.12	0.21	0.47	0.21	1.00
Incidence of service delay	0.07	0.07	0.40	0.37	0.09	1.00
Service Costs (SCU)						
Overall service costs	0.09	0.16	0.35	0.35	0.05	1.00
Cargo handling charges	0.07	0.19	0.42	0.28	0.05	1.00
Cost of terminal ancillary services	0.07	0.28	0.37	0.23	0.05	1.00

Terminal Supply Chain Integration

Total 48 assessors from T6 and port users took part in the judgements on terminal supply chain integration (see Table 5.34). Then, the measurement can be presented by DoB belonging to linguistic terms based Eq. (5.35) (see Table 5.35).

Table 5.34 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	1	4	12	21	10	48
Land side connectivity	1	5	13	22	7	48
Reliability for multimodal operations	2	2	15	19	10	48
Efficiency of multimodal operations	2	4	13	19	10	48
Value-Added Services (VAST)						
Facilities for adding value to cargos	3	5	14	22	4	48
Capacity to provide different services	0	5	15	22	6	48
Service adaptation to customers	4	8	9	21	6	48
Tailored services to customers	4	4	13	22	5	48
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	1	16	22	9	48
Integrated IT to share data	0	3	15	22	8	48
Collaborate with channel members	0	4	17	21	6	48
Latest IT in the industry	0	6	14	21	7	48

Table 5.35 Degrees of belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.02	0.08	0.25	0.44	0.21	1.00
Land side connectivity	0.02	0.10	0.27	0.46	0.15	1.00
Reliability for multimodal operations	0.04	0.04	0.31	0.40	0.21	1.00
Efficiency of multimodal operations	0.04	0.08	0.27	0.40	0.21	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargos	0.06	0.10	0.29	0.46	0.08	1.00
Capacity to provide different services	0.00	0.10	0.31	0.46	0.13	1.00
Service adaptation to customers	0.08	0.17	0.19	0.44	0.13	1.00
Tailored services to customers	0.08	0.08	0.27	0.46	0.10	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.02	0.33	0.46	0.19	1.00
Integrated IT to share data	0.00	0.06	0.31	0.46	0.17	1.00
Collaborate with channel members	0.00	0.08	0.35	0.44	0.13	1.00
Latest IT in the industry	0.00	0.13	0.29	0.44	0.15	1.00

Sustainable Growth

Total 6-13 assessors from T6 (7 assessors) and port administration (6 assessors) took part in the judgements on sustainable growth (see Table 5.36). Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35) (see Table 5.37).

Table 5.36 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	0	3	10	13
Formal safety and security training practices	0	0	0	4	9	13
Adequate monitoring and threat awareness	0	0	0	2	11	13
Safety and security officers and facilities	0	0	0	2	11	13
Environment (EVS)						
Carbon footprint	0	3	4	3	3	13
Total water consumption	0	0	2	5	6	13
Total energy consumption	0	0	0	6	7	13
Waste recycling	0	1	4	4	4	13
Environment management programs	0	1	6	2	4	13
Social Engagement (SES)						
Employment	0	0	4	1	1	6
Regional GDP	0	0	1	3	2	6
Disclose of information	0	2	3	1	0	6

Table 5.37 Degrees of belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.00	0.23	0.77	1.00
Formal safety and security training practices	0.00	0.00	0.00	0.31	0.69	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.00	0.15	0.85	1.00
Safety and security officers and facilities	0.00	0.00	0.00	0.15	0.85	1.00
Environment (EVS)						
Carbon footprint	0.00	0.23	0.31	0.23	0.23	1.00
Total water consumption	0.00	0.00	0.15	0.38	0.46	1.00
Total energy consumption	0.00	0.00	0.00	0.46	0.54	1.00
Waste recycling	0.00	0.08	0.31	0.31	0.31	1.00
Environment management programs	0.00	0.08	0.46	0.15	0.31	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.67	0.17	0.17	1.00
Regional GDP	0.00	0.00	0.17	0.50	0.33	1.00
Disclose of information	0.00	0.33	0.50	0.17	0.00	1.00

5.4.3 Mapping process –transform the evaluation from the lowest level PPIs to top level PPI.

In this section, the mapping process from the transformed DoB sets of the quantitative PPIs to three principal-PPIs (i.e. output, productivity and lead-time) is demonstrated. Meanwhile, the mapping process from the all bottom level PPIs to their associated upper level principal-PPIs is presented in Appendix II. For further information, please refer to Appendix II.

5.4.3.1 Mapping PPIs to output (principal-PPI)

Throughput growth to output in T6

In the previous section, DoB sets of the throughput growth in each terminal was obtained based on given information. The numerical grades used to assess "throughput growth (TG)" are "leq 0% (TG1)", "5% (TG2)", "10% (TG3), "15% (TG4)", "20% (TG5)" and geq 25% (TG6) (see Table 5.5). The linguistic terms of the principle-PPI, "output (OPC)", are "very low (OPC1)", "low (OPC2)", "medium (OPC3)", "high (OPC4)" and "very high (OPC5)" (see Table 5.4).

In terms of the fuzzy rule base belief structure in Table 5.38, mapping from throughput growth to output can be conducted. According to Table 5.28, the throughput growth set in T6 is assessed as follows:

$$H^{TG} = \{(leq\ 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.944), (geq\ 25\%, 0.056)\}$$

Based on $R^1$and R^2, it can be transformed into 70.8% OPC4 ($O^4 = 0.944 \times 0.75$) and 29.2% OPC5 ($O^5 = (0.944 \times 0.25) + (0.056 \times 1)$) respectively. The TG output set in T6 is assessed as follows:

$$H^{TG\ OPC} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0.708), (very\ high, 0.292)\}$$

Table 5.38 Fuzzy rule base belief structure

Throughput growth (TG) to output (OPC)	R^1: *IF terminal operator's "throughput growth (TG)" is "more than 25% (TG6)", then "output (OPC)" is "very high (OPC5)" with 100% DoB.* *This can be simplified and presented by symbols as* R^1: *If "TG" is "TG6", then "OPC" is "100% OPC5"* *Similarly,* R^2: *If "TG" is "TG5", then "OPC" is "25% OPC5"and "75% OPC4"* R^3: *If "TG" is "TG4", then "OPC" is "50% OPC4" and "50% OPC3"* R^4: *If "TG" is "TG3", then "OPC" is "50% OPC3" and "50% OPC2"* R^5: *If "TG" is "TG2", then "OPC" is "75% OPC2"and "25% OPC1"* R^6: *If "TG" is "TG1", then "OPC" is "100% OPC1"*

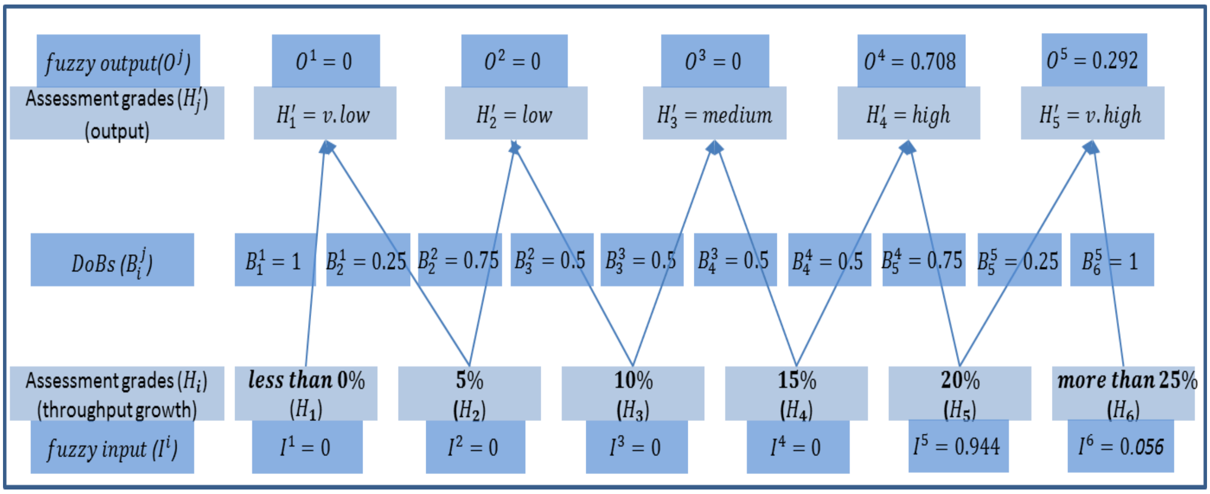

Figure 5.6 Fuzzy mapping process (from throughput growth to output)

Vessel capacity growth to output in T6

The numerical grades "less than 0% (VC1)", "5% (VC2)", "10% (VC3), "15% (VC4)" and "more than 20% (VC5)" for "vessel capacity growth (VC)" can be mapped using the following fuzzy rule.

Table 5.39 Fuzzy rule base belief structure

Vessel capacity (VC) to output (OPC)	R^1: *If "VC" is "VC5", then "OPC" is "100% OPC5"* R^2: *If "VC" is "VC4", then "OPC" is "25% OPC5"and "75% OPC4"* R^3: *If "VC" is "VC3", then "OPC" is "25% OPC4", "50% OPC3"and "25% OPC2"* R^4: *If "VC" is "VC2", then "OPC" is "75% OPC2"and "25% OPC1"* R^5: *If "VC" is "VC1", then "OPC" is "100% OPC1"*

According to Table 5.28, the vessel capacity growth set in T6 is assessed as follows:

$$H^{V\ capacity} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0.392), (geq\ 20\%, 0.608)\}$$

Based on $R^1$and R^2, it can be transformed into 29.4% OPC4 ($O^4 = 0.392 \times 0.75$) and 70.6% OPC5 ($O^5 = (0.392 \times 0.25) + (0.608 \times 1)$) respectively. The VC output set in T6 is assessed as follows:

$$H^{VC\ OPC} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0.294), (very\ high, 0.706)\}$$

5.4.3.2 Mapping to productivity

<u>Ship load rate to productivity in T6</u>

The numerical grades used to assess the "ship load rate (LR)" are "leq 25TEU (LR1)", "40TEU (LR2)", "55TEU (LR3), "70TEU (LR4)", "85TEU (LR5)" and geq 100TEU (LR6) (see Table 5.5). The linguistic terms of principle-PPI, "productivity (PDC)", are "very low (PDC1)", "low (PDC2)", "medium (PDC3)", "high (PDC4)" and "very high (PDC5)" (see Table 5.4). The mapping from ship load rate to productivity can be conducted using the following fuzzy rule.

Table 5.40 Fuzzy rule base belief structure

<u>Ship load rate (LR) to productivity (PDC)</u>	R^1: *If "LR" is "LR6", then "PDC" is "100% PDC5"*
	R^2: *If "LR" is "LR5", then "PDC" is "25% PDC5"and "75% PDC4"*
	R^3: *If "LR" is "LR4", then "PDC" is "50% PDC4" and "50% PDC3"*
	R^4: *If "LR" is "LR3", then "PDC" is "50% PDC3" and "50% PDC2"*
	R^5: *If "LR" is "LR2", then "PDC" is "75% PDC2"and "25% PDC1"*
	R^6: *If "LR" is "LR1", then "PDC" is "100% PDC1"*

According to Table 5.28, the ship load rate set in T6 is assessed as follows:

$$H^{LR} = \{(leq\ 25TEU, 0), (40TEU, 0.343), (55TEU, 0.657), (70TEU, 0), (85TEU, 0), (geq\ 100TEU, 0)\}$$

Based on R^4 and R^5, it can be transformed into <u>8.6% PDC1</u> ($O^1 = 0.343 \times 0.25$) and <u>58.6% PDC2</u> ($O^2 = (0.343 \times 0.75) + (0.657 \times 0.5)$ and <u>32.9% PDC3</u> ($O^3 = 0.657 \times 0.5$), respectively. The LR productivity set in T6 is assessed as follows:

$$H^{LR\ PDC} = \{(very\ low, 0.086), (low, 0.586), (medium, 0.329), (high, 0), (very\ high, 0)\}$$

<u>Berth utilisation to productivity in T6</u>

The numerical grades used to assess the "berth utilization (BU)" are "leq 300TEU (BU1)", "600TEU (BU2)", "900TEU (BU3), "1200TEU (BU4)", "1500TEU (BU5)" and "geq

1800TEU (BU6)" (see Table 5.5). The mapping from berth utilisation to productivity can be conducted using the following fuzzy rule.

Table 5.41 Fuzzy rule base belief structure

Berth utilisation (BU) to productivity (PDC)	R^1: *If "BU" is "BU6", then "PDC" is "100% PDC5"* R^2: *If "BU" is "BU5", then "PDC" is "25% PDC5"and "75% PDC4"* R^3: *If "BU" is "BU4", then "PDC" is "50% PDC4" and "50% PDC3"* R^4: *If "BU" is "BU3", then "PDC" is "50% PDC3" and "50% PDC2"* R^5: *If "BU" is "BU2", then "PDC" is "75% PDC2"and "25% PDC1"* R^6: *If "BU" is "BU1", then "PDC" is "100% PDC1"*

According to Table 5.28, the berth utilization set in T6 is assessed as follows:

$$H^{BU} = \{(less\ than\ 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0), (more\ than\ 1800TEU, 1)\}$$

Based on R^1, it can be transformed into 100% PDC5 ($O^5 = 1 \times 1$). The BU productivity set in T6 is assessed as follows:

$$H^{BU\ PDC} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 1)\}$$

Berth occupancy rate to productivity in T6

The numerical grades used to assess the "berth occupancy rate (BO)" are "less than 45% (BO1)", "50% (BO2)", "55% (BO3), "geq 80% (BO4)" and "60-80% (BO5)"[5] (see Table 5.5). The mapping from berth occupancy rate to productivity can be conducted using the following fuzzy rule.

Table 5.42 Fuzzy rule base belief structure

Berth occupancy rate (BO) to productivity (PDC)	R^1: *If "BO" is "BO5", then "PDC" is "100% PDC5"* R^2: *If "BO" is "BO4", then "PDC" is "25% PDC5"and "75% PDC4"* R^3: *If "BO" is "BO3", then "PDC" is "25% PDC4", "50% PDC3" and "25% PDC2".* R^4: *If "BO" is "BO2", then "PDC" is "75% PDC2"and "25% PDC1"* R^5: *If "BO" is "BO1", then "PDC" is "100% PDC1"*

According to Table 5.28, the berth occupancy rate set in T6 is assessed as follows:

$$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (geq\ 80\%, 0)\}$$

[5] It is noteworthy that the terminals with a very high berth occupancy ratio (i.e. generally more than 80%) denote either a low level of berth productivity or a low level of crane productivity. According to the interview survey with terminal operators, in addition, this situation (more than 80%) is considered as a sign of port congestion, thus, they always keep the berth occupancy rate optimum level between 60% and 80%. Hence, the assessment grades for berth occupancy rate are developed through ranking survey on the defined grades beforehand. The ranking of the berth occupancy rate is 1) 60%- 80% 2) more than 80% (temporary case is only allowable), 3) 55%, 4) 50% and 5) less than 45%.

Based on R^1, it can be transformed into 100% PDC5 ($O^5 = 1 \times 1$). The BO productivity set in T6 is assessed as follows:

$$H^{BO\ PDC} = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 1)\}$$

Crane efficiency to productivity in T6

The numerical grades used to assess the "crane efficiency (CE)" are "leq 20van (CE1)", "25van (CE2)", "30van (CE3), "35van (CE4)", "40van (CE5)" and "geq 45van (CE6)" (see Table 5.5). The mapping from crane efficiency to productivity can be conducted using the following fuzzy rule.

Table 5.43 Fuzzy rule base belief structure

Crane efficiency (CE) to productivity (PDC)	R^1: *If "CE" is "CE6", then "PDC" is "100% PDC5"* R^2: *If "CE" is "CE5", then "PDC" is "25% PDC5"and "75% PDC4"* R^3: *If "CE" is "CE4", then "PDC" is "50% PDC4" and "50% PDC3"* R^4: *If "CE" is "CE3", then "PDC" is "50% PDC3" and "50% PDC2"* R^5: *If "CE" is "CE2", then "PDC" is "75% PDC2"and "25% PDC1"* R^6: *If "CE" is "CE1", then "PDC" is "100% PDC1"*

According to Table 5.28, the crane efficiency set in T6 is assessed as follows:

$$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.8), (35moves, 0.2), (40moves, 0), (geq\ 45mvoes, 0)\}$$

Based on R^3 and R^4, it can be directly transformed into 40% PDC 2 ($O^2 = 0.8 \times 0.5$) and 50% PDC3 ($O^3 = (0.8 \times 0.5) + (0.2 \times 0.5)$ and 10% PDC4 ($O^4 = 0.2 \times 0.5$), respectively. The CE productivity set in T6 is assessed as follows:

$$H^{CE\ PDC} = \{(very\ low, 0), (low, 0.4), (medium, 0.5), (high, 0.1), (very\ high, 0)\}$$

Yard utilisation to productivity in T6

The numerical grades used to assess the "yard utilisation (YU)" are "leq 2TEU (YU1)", "4TEU (YU2)", "6TEU (YU3), "8TEU (YU4)" and "geq 10TEU (YU5)" (see Table 5.5). The mapping from yard utilisation to productivity can be conducted using the following fuzzy rule.

Table 5.44 Fuzzy rule base belief structure

Yard utilisation (YU) to productivity (PDC)	R^1: *If "YU" is "YU5", then "PDC" is "100% PDC5"* R^2: *If "YU" is "YU4", then "PDC" is "25% PDC5"and "75% PDC4"* R^3: *If "YU" is "YU3", then "PDC" is "25% PDC4", "50% PDC3" and "25% PDC2".* R^4: *If "YU" is "YU2", then "PDC" is "75% PDC2"and "25% PDC1"* R^5: *If "YU" is "YU1", then "PDC" is "100% PDC1"*

According to Table 5.28, the yard utilisation set in T6 is assessed as follows:

$$H^{yard} = \{(leq\ 2TEU, 0), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 1)\}$$

Based on R^1, it can be directly transformed into 100% PDC 5 ($O^5 = 1 \times 1$). The YU productivity set in T6 is assessed as follows:

$$H^{YU\ PDC} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 1)\}$$

Labour utilisation to productivity in T6

The numerical grades used to assess the "labour utilisation (LU)" are "leq 1000TEU (LU1)", "2000TEU (LU2)", "3000TEU (LU3), "4000TEU (LU4)", "5000TEU (LU5)" and "geq 6000TEU (LU6)" (see Table 5.5). The mapping from labour utilisation to productivity can be conducted using the following fuzzy rule.

Table 5.45 Fuzzy rule base belief structure

Labour utilisation (LU) to productivity (PDC)	R^1: *If "LU" is "LU6", then "PDC" is "100% PDC5"* R^2: *If "LU" is "LU5", then "PDC" is "25% PDC5"and "75% PDC4"* R^3: *If "LU" is "LU4", then "PDC" is "50% PDC4" and "50% PDC3"* R^4: *If "LU" is "LU3", then "PDC" is "50% PDC3" and "50% PDC2"* R^5: *If "LU" is "LU2", then "PDC" is "75% PDC2"and "25% PDC1"* R^6: *If "LU" is "LU1", then "PDC" is "100% PDC1"*

According to Table 5.28, the labour utilisation set in T6 is assessed as follows:

$$H^{labour} = \{(leq\ 1000TEU, 0), (2000TEU, 0), (3000TEU, 0), (4000TEU, 0), (5000TEU, 0.856), (geq\ 6000TEU, 0.144)\}$$

Based on $R^1$and R^2, it can be transformed into 64.2% PDC4 ($O^4 = 0.856 \times 0.75$) and 35.8% PDC5 ($O^5 = (0.856 \times 0.25) + (0.144 \times 1)$) respectively. The LU productivity set in T6 is assessed as follows:

$$H^{LU\ PDC} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0.642), (very\ high, 0.358)\}$$

5.4.3.3 Mapping to lead-time

Vessel turnaround to lead-time in T6

The numerical grades used to assess the "vessel turnaround (VT)" are "geq 5 days (VT1)", "4days (VT2)", "3days (VT3), "2days (VT4)" and "leq 1days (VT5)" (see Table 5.5). The linguistic terms of principle-PPI, "lead-time (LTC)", are "very poor (LTC1)", "poor (LTC2)", "medium (LTC3)", "good (LTC4)" and "very good (LTC5)" (see Table 5.4). The mapping from vessel turnaround to lead-time can be conducted using the following fuzzy rule.

Table 5.46 Fuzzy rule base belief structure

Vessel turnaround (VT) to lead-time (LTC)	R^1: *If "VT" is "VT5", then "LTC" is "100% LTC5"* R^2: *If "VT" is "VT4", then "LTC" is "25% LTC5"and "75% LTC4"* R^3: *If "VT" is "VT3", then "LTC" is "25% LTC4", "50% LTC3" and "25% LTC2".* R^4: *If "VT" is "VT2", then "LTC" is "75% LTC2"and "25% LTC1"* R^5: *If "VT" is "VT1", then "LTC" is "100% LTC1"*

According to Table 5.28, the vessel turnaround set in T6 is assessed as follows:

$$H^{vessel\ T} = \{(\text{more than 5days}, 0), (\text{4days}, 0), (\text{3days}, 0), (\text{2days}, 0), (\text{less than 1day}, 1)\}$$

Based on R^1, it can be directly transformed into 100% LTC 5 ($O^5 = 1 \times 1$). The VT productivity set in T6 is assessed as follows:

$$H^{VT\ LTC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0), (very\ good, 1)\}$$

Truck turnaround to lead-time in T6

The numerical grades used to assess the "truck turnaround (TT)" are "geq 40 minutes (TT1)", "35minutes (TT2)", "30minutes (TT3), "25minutes (TT4)", "20minutes (TT5)" and "leq 15minutes (TT6)" (see Table 5.5). The mapping from truck turnaround to lead-time can be conducted using the following fuzzy rule. According to Table 5.28, the truck turnaround set in T6 is assessed as follows:

$$H^{truck\ T} = \{(geq\ 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.34), (leq\ 15mins, 0.66)\}$$

Based on $R^1$and R^2, it can be transformed into 25.5% LTC4 ($O^4 = 0.34 \times 0.75$) and 74.5% LTC5 ($O^5 = (0.34 \times 0.25) + (0.66 \times 1)$) respectively. The TT productivity set in T6 is assessed as follows.

$$H^{TT\ LTC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.255), (very\ good, 0.745)\}$$

Table 5.47 Fuzzy rule base belief structure

Vessel turnaround (VT) to lead-time (LTC)	R^1: *If "TT" is "TT6", then "LTC" is "100% LTC5"* R^2: *If "TT" is "TT5", then "LTC" is "25% LTC5"and "75% LTC4"* R^3: *If "TT" is "TT4", then "LTC" is "50% LTC4" and "50% LTC3"* R^4: *If "TT" is "TT3", then "LTC" is "50% LTC3" and "50% LTC2"* R^5: *If "TT" is "TT2", then "LTC" is "75% LTC2"and "25% LTC1"* R^6: *If "TT" is "TT1", then "LTC" is "100% LTC1"*

Container dwell time to lead-time in T6

The numerical grades used to assess the "container dwell time (CD)" are "geq 4 weeks (CD1)", "3 weeks (CD2)", "10 days (CD3), "7 days (CD4)", "5 days (CD5)" and "leq 3 days (CD6)" (see Table 5.5). The mapping from container dwell time to lead-time can be conducted using the following fuzzy rule.

Table 5.48 Fuzzy rule base belief structure

Container dwell time (CD) to lead-time (LTC)	R^1: *If "CD" is "CD6", then "LTC" is "100% LTC5"* R^2: *If "CD" is "CD5", then "LTC" is "25% LTC5"and "75% LTC4"* R^3: *If "CD" is "CD4", then "LTC" is "50% LTC4" and "50% LTC3"* R^4: *If "CD" is "CD3", then "LTC" is "50% LTC3" and "50% LTC2"* R^5: *If "CD" is "CD2", then "LTC" is "75% LTC2"and "25% LTC1"* R^6: *If "CD" is "CD1", then "LTC" is "100% LTC1"*

According to Table 5.28, the container dwell time set in T6 is assessed as follows.

$$H^{dwell} = \{(geq\ 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.35), (leq\ 3days, 0.65)\}$$

Based on $R^1$and R^2, it can be transformed into 26.3% LTC4 ($O^4 = 0.35 \times 0.75$) and 73.8% LTC5 ($O^5 = (0.35 \times 0.25) + (0.65 \times 1)$) respectively. The CD productivity set in T6 is assessed as follows.

$$H^{CD\ LTC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.263), (very\ good, 0.738)\}$$

5.4.4 Weighting assignment using analytic hierarchy process

The judgements of five among ten evaluators[6] have verified with the CR of 0.10 or less by using Eq. (5.11). 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 and Çifçi, 2012) are used to derive the weights of the criteria. The geometric means judged by five evaluators on the six dimensions (i.e. core activities, support activities, financial strength, users satisfaction, terminal supply chain integration and sustainable growth) at the second level are obtained using Eq. (5.9) as shown in Table 5.49. Then the weights in the pairwise comparison matrix are obtained by using Eq. (5.10) as 0.31, 0.13, 0.15, 0.23, 0.12 and 0.07 respectively (Table 5.50). Core activities are considered to be the most important dimension and followed by user satisfaction, financial strength, support activities, terminal supply chain integration and sustainable growth. Based on Eq. (5.11) and Table 5.51, λ_{max} can be obtained as follows:

$$\frac{\boldsymbol{e_{ji}}}{\boldsymbol{w_i}} = \frac{1.89}{0.31} = 6.09,\ \frac{0.78}{0.13} = 6.07,\ \frac{0.92}{0.15} = 6.09,\ \frac{1.38}{0.23} = 6.11,\ \frac{0.7}{0.12} = 6.07, \frac{0.42}{0.07} = 6.07, \lambda_{max} = \frac{36.45}{6} = 6.075, CI = \frac{6.075-6}{5} = 0.015, RI = 1.24,\ CR = \frac{0.015}{1.24} = 0.012.$$

[6] The 5 experts (1 terminal operator, 1 liner, 1 forwarder, 1 academia, 1 port authority) among 10 experts in the previous survey (in chapter 3) responded in this survey.

Similarly, the weights of the third level and the bottom level criteria can be obtained. It is noteworthy that the weights obtained 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 (=0.31 (the local weight of core activities) × 0.257 (the local weight of output) × 0.696 (the local weight of throughput)). Consequently, the local weights of all criteria and the normalised weights of the bottom level criteria are shown in Table 5.52.

Derived from the results of AHP, overall service reliability (SFU1) is the most important PPI, which has a relative importance value of 0.059, followed by crane productivity (PDC4, 0.056), throughput growth (OPC1, 0.056), vessel turnaround (LTC1, 0.041), net profit margin (PFF3, 0.035), overall service cost (SCU1, 0.034), EBIT margin (PFF2, 0.032), revenue growth (PFF1, 0.031), incidence of cargo damage (SFU6, 0.031) and intermodal transport systems (ITST, 0.029), as shown the top 10 highest scores in Table 5.52

In the contrast, total water consumption (0.002), waste recycling (0.002) and carbon footprint (0.002) under environment (EVS) are the least important PPIs. The top 10 rank PPIs in the AHP results include three PPIs under core activities (CA), three PPIs under financial strength (FP) and three PPIs under users' satisfaction (US).

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, 0.31; FS, 0.15 and US, 0.23) influence more on the global weights of their associated bottom level PPIs than other three dimensions do, despite no significant weight difference between PPIs in the same cluster.

Table 5.49 The geometric means of 6 dimensions judged by 5 experts

	CA	SA	FP	US	TSCI	SG
CA	1	2.86	2.30	1.25	2.70	3.87
SA	0.35	1	0.72	0.43	1.15	2.86
FP	0.44	1.38	1	0.76	1.20	2.11
US	0.80	2.35	1.32	1	1.89	2.61
TSCI	0.37	0.87	0.83	0.53	1	1.64
SG	0.26	0.35	0.47	0.38	0.61	1
SUM	3.22	8.81	6.65	4.34	8.55	14.09

Table 5.50 Local weights of 6 dimensions

	CA	SA	FP	US	TSCI	SG	Weights
CA	0.31	0.32	0.35	0.29	0.32	0.27	0.31
SA	0.11	0.11	0.11	0.10	0.13	0.20	0.13
FP	0.14	0.16	0.15	0.17	0.14	0.15	0.15
US	0.25	0.27	0.20	0.23	0.22	0.18	0.23
TSCI	0.12	0.10	0.13	0.12	0.12	0.12	0.12
SG	0.08	0.04	0.07	0.09	0.07	0.07	0.07

Table 5.51 Calculation of $\boldsymbol{e_{ji}} \times \boldsymbol{w_i}$

	CA	SA	FP	US	TSCI	SG		Weights		Priority
CA	1	2.86	2.30	1.25	2.70	3.87		0.31		1.89
SA	0.35	1	0.72	0.43	1.15	2.86		0.13		0.78
FP	0.44	1.38	1	0.76	1.20	2.11	×	0.15		0.92
US	0.80	2.35	1.32	1	1.89	2.61		0.23	=	1.38
TSCI	0.37	0.87	0.83	0.53	1	1.64		0.12		0.70
SG	0.26	0.35	0.47	0.38	0.61	1		0.07		0.42

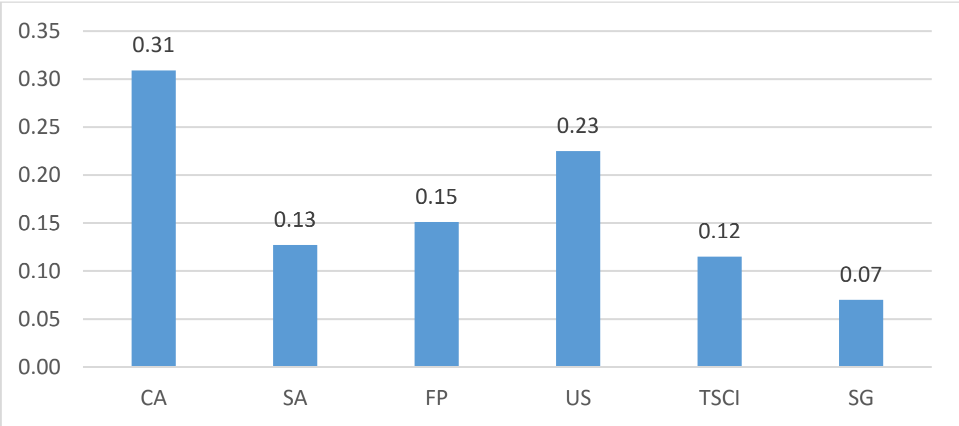

Figure 5.7 Relative weights of 6 dimensions

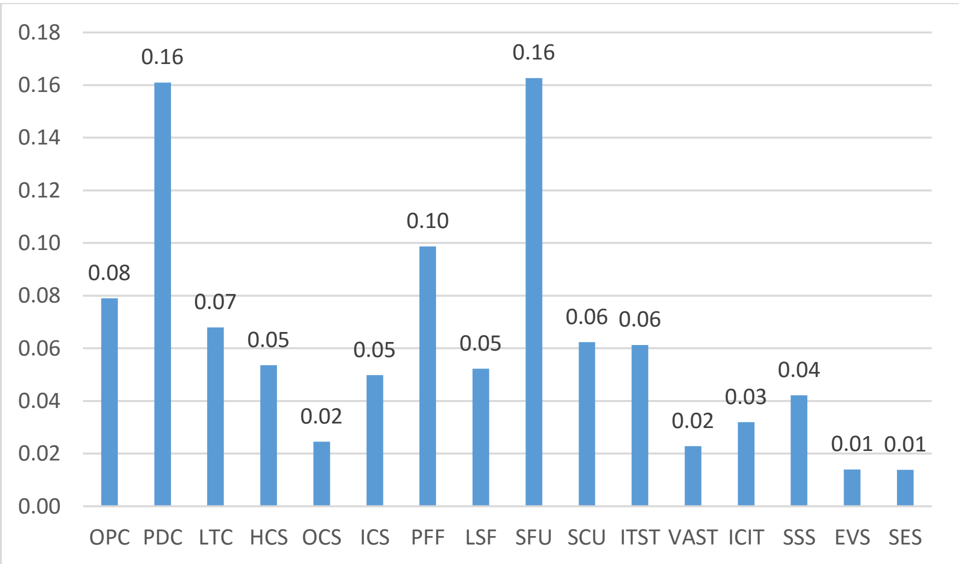

Figure 5.8 Normalised relative weights of 16 principal PPIs

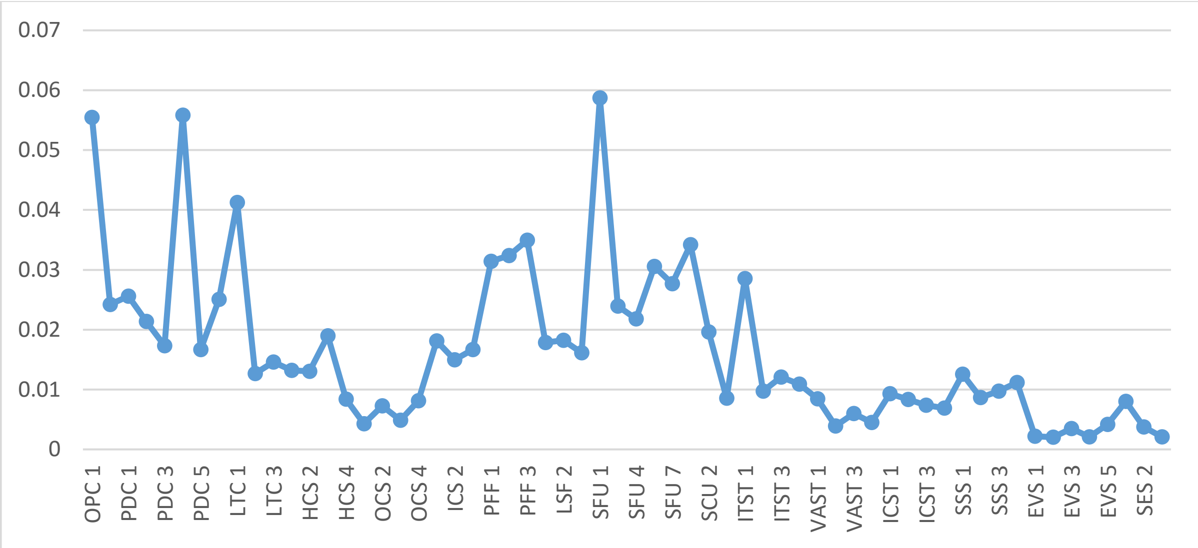

Figure 5.9 Global weights of 60 PPIs (independent)

Table 5.52 PPIs' relative weights

	LW (local weights)	NW (normalised weights)
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
Support 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 of 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 cargos (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

5.4.5 Synthesis of the DoB and weights of PPIs using the evidential reasoning algorithm

In this section, aggregation of the bottom level PPIs (i.e. throughput growth and vessel call size growth) under principal-PPI (i.e. output) is demonstrated as an example case, then the transformed results from the lowest level PPIs to the top level goal and their relative weights can be synthesised by IDS incorporating the ER algorithm Eqs. (5.11)-(5.21) and utility technique Eqs. (5.22)-(5.23) in a hierarchical decision structure. The Windows-based tool, IDS, facilitates the process of making decisions from collecting information to building up a model, defining alternatives and criteria and different assessments. On top of that, 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.

5.4.5.1 Aggregation of bottom level PPIs

Output in T6

Based on the transformed results from mapping process and relative weights (see Table 5.53), throughput growth and vessel call size growth are aggregated to output, which is presented as follows:

Based on Eqs. (5.11)-(5.15) and Table 5.53, $m_1^1 = w_1\beta_1^1 = 0, m_2^1 = w_1\beta_2^1 = 0, m_3^1 = w_1\beta_3^1 = 0, m_4^1 = w_1\beta_4^1 = 0.696 \times 0.708 = 0.49276, m_5^1 = w_1\beta_5^1 = 0.696 \times 0.292 = 0.20303, \bar{m}_D^1 = 1 - w_1 = 1 - 0.696 = 0.304, \tilde{m}_D^1 = w_1\left(1 - \sum_{j=1}^5 \beta_j^1\right) = 0.696(1-1) = 0.$

$m_1^2 = w_2\beta_1^2 = 0, m_2^2 = w_2\beta_2^2 = 0, m_3^2 = w_2\beta_3^2 = 0, m_4^2 = w_2\beta_4^2 = 0.304 \times 0.294 = 0.08938, m_5^2 = w_2\beta_5^2 = 0.304 \times 0.706 = 0.21462\ , \bar{m}_D^2 = 1 - w_2 = 1 - 0.304 = 0.696, \tilde{m}_D^2 = w_2\left(1 - \sum_{j=1}^5 \beta_j^2\right) = 0.304(1-1) = 0.$

Based on Eq. (5.19), $K_{c(2)} = \left[1 - \sum_{j=1}^5 \sum_{\substack{t=1 \\ j \neq t}}^5 m_j^{c(1)} m_t^2\right]^{-1} = [1 - (0 + 0 + 0 + 0.10576\ (= 0.49276 \times 0.21462) + 0.01816\ (= 0.20323 \times 0.08938)]^{-1} = 1.14145.$

Based on Eqs. (5.16)-5.18) $m_1^{c(2)} = K_{c(2)}\left(m_1^{c(1)} m_1^2 + m_1^{c(1)} m_D^2 + m_D^{c(1)} m_1^2\right) = 0,$

$$m_2^{c(2)} = K_{c(2)}\left(m_2^{c(1)} m_2^2 + m_2^{c(1)} m_D^2 + m_D^{c(1)} m_2^2\right) = 0,$$

$$m_3^{c(2)} = K_{c(2)}\left(m_3^{c(1)} m_3^2 + m_3^{c(1)} m_D^2 + m_D^{c(1)} m_3^2\right) = 0,$$

$$m_4^{c(2)} = K_{c(2)}\left(m_4^{c(1)}m_4^2 + m_4^{c(1)}m_D^2 + m_D^{c(1)}m_4^2\right)$$
$$= 1.14145(0.49276 \times 0.08938 + 0.49276 \times 0.696 + 0.08938 \times 0.304)$$
$$= 0.47276,$$

$$m_5^{c(2)} = K_{c(2)}\left(m_5^{c(1)}m_5^2 + m_5^{c(1)}m_D^2 + m_D^{c(1)}m_5^2\right)$$
$$= 1.14145(0.20323 \times 0.21462 + 0.20323 \times 0.696 + 0.21462 \times 0.304)$$
$$= 0.28572,$$

$$\tilde{m}_D^{c(2)} = K_{c(2)}\left(\tilde{m}_D^{c(1)}\tilde{m}_D^2 + \tilde{m}_D^{c(1)}\bar{m}_D^2 + \bar{m}_D^{c(1)}\tilde{m}_D^2\right) = 0,$$

$$\bar{m}_D^{c(2)} = K_{c(2)}\left(\bar{m}_D^{c(1)}\bar{m}_D^2\right) = 1.14145(0.304 \times 0.696) = 0.24151.$$

Based on Eq. (5.20), $\{D_j\}: \beta_j = \frac{m_j^{c(L)}}{1-\bar{m}_D^{c(L)}} = 0,\ j = 1, 2, 3,$

$$\{D_j\}: \beta_4 = \frac{m_4^{c(2)}}{1 - \bar{m}_D^{c(2)}} = \frac{0.47276}{1 - 0.24151} = 0.62330,$$

$$\{D_j\}: \beta_5 = \frac{m_5^{c(2)}}{1 - \bar{m}_D^{c(2)}} = \frac{0.28572}{1 - 0.24151} = 0.37669.$$

Table 5.53 Mapping results and relative weights and aggregation (Output)

Output	Very Low	Low	Medium	High	Very High	Weight
Throughput growth	0	0	0	0.708	0.292	0.696
Vessel call size growth	0	0	0	0.294	0.706	0.304
Aggregation results	0	0	0	0.62330	0.37669	

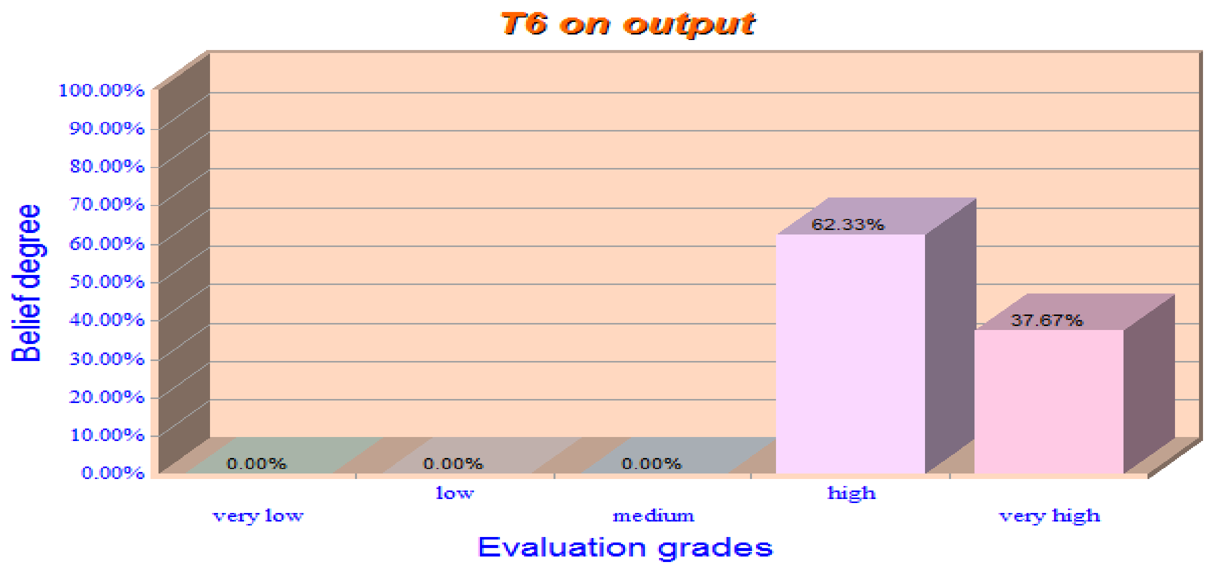

Figure 5.10 Mapping result of output in T6

Similarly, the aggregations of the bottom level PPIs can be obtained. By help of the IDS software, the bottom level PPIs of the productivity and lead-time are aggregated as follows:

<u>Productivity in T6</u>

Table 5.54 Aggregation of bottom level PPIs (productivity)

Productivity	Very Low	Low	Medium	High	Very High	Weight
Ship load rate	0.086	0.586	0.329	0	0	0.158
Berth utilization	0	0	0	0	1	0.132
Berth occupancy	0	0	0	0	1	0.107
Crane efficiency	0	0.4	0.5	0.1	0	0.345
Yard utilization	0	0	0	0	1	0.103
Labour utilization	0	0	0	0.642	0.358	0.155
Aggregation results	0.0114	0.24372	0.24193	0.12523	0.37769	

<u>Lead-time in T6</u>

Table 5.55 Aggregation of bottom level PPIs (lead-time)

Lead-time	Very Poor	Poor	Medium	Good	Very Good	Weight
Vessel turnaround time	0	0	0	0	1	0.602
Truck turnaround time	0	0	0	0.255	0.745	0.185
Container dwell time	0	0	0	0.263	0.738	0.213
Aggregation results	0	0	0	0.05007	0.94992	

The aggregations of all bottom level PPIs for T6 are demonstrated in Appendix III. For further information, please refer to Appendix III.

5.4.5.2 Mapping from principal-PPIs to 6 dimensions

The dimension "core activities (CA)" can be expressed using linguistic terms "very poor (CA1)", "poor (CA2)", "medium (CA3)", "good (CA4)" and "very good (CA5)" (see Table 5.3). In terms of the fuzzy rule base belief structure in Table 5.56, mapping process from output (and productivities and lead-time) to core activities can be conducted.

Table 5.56 Fuzzy rule base belief structure

<u>Output (OPC) to core activities (CA)</u>	R^1: *If "OPC" is "OPC5", then "CA" is "100% CA5"* R^2: *If "OPC" is "OPC4", then "CA" is "25% CA5" and "75% CA4"* R^3: *If "OPC" is "OPC3", then "CA" is "25% CA4", "50% CA3" and "25% CA2"* R^4: *If "OPC" is "OPC2", then "CA" is "75% CA2" and "25% CA1"* R^5: *If "OPC" is "OPC1", then "CA" is "100% CA1"*

Table 5.55 Continued

Output (OPC) to core activities (CA)	R^1: *If "OPC" is "OPC5", then "CA" is "100% CA5"* R^2: *If "OPC" is "OPC4", then "CA" is "25% CA5"and "75% CA4"* R^3: *If "OPC" is "OPC3", then "CA" is "25% CA4", "50% CA3"and "25% CA2"* R^4: *If "OPC" is "OPC2", then "CA" is "75% CA2"and "25% CA1"* R^5: *If "OPC" is "OPC1", then "CA" is "100% CA1"*
Productivities (PDC) to core activities (CA)	R^6: *If "PDC" is "PDC5", then "CA" is "100% CA5"* R^7: *If "PDC" is "PDC4", then "CA" is "25% CA5"and "75% CA4"* R^8: *If "PDC" is "PDC3", then "CA" is "25% CA4", "50% CA3"and "25% CA2"* R^9: *If "PDC" is "PDC2", then "CA" is "75% CA2"and "25% CA1"* R^{10}: *If "PDC" is "PDC1", then "CA" is "100% CA1"*
Lead-time (LTC) to core activities (CA)	R^{11}: *If "LTC" is "LTC5", then "CA" is "100% CA5"* R^{12}: *If "LTC" is "LTC4", then "CA" is "25% CA5"and "75% CA4"* R^{13}: *If "LTC" is "LTC3", then "CA" is "25% CA4", "50% CA3"and "25% CA2"* R^{14}: *If "LTC" is "LTC2", then "CA" is "75% CA2"and "25% CA1"* R^{15}: *If "LTC" is "LTC1", then "CA" is "100% CA1"*

Output to Core activities in T6

According to Table 5.53, the output set in T6 is assessed as follows:

$$H^{OPC} = \{(very\ low, 0), (low, 0), (medium, 0), (high, 0.62), (very\ high, 0.38)\}$$

Based on $R^1$and R^2, it can be transformed into 46.7% CA4 ($O^4 = 0.62 \times 0.75$) and 53.3% CA5 ($O^5 = (0.62 \times 0.25) + (0.38 \times 1)$) respectively. The OPC core activities set in T6 is assessed as follows:

$$H^{OPC\ CA} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.467), (very\ good, 0.533)\}$$

Productivity to Core activities in T6

According to Table 5.54, the productivities set in T6 is assessed as follows:

$$H^{PDC} = \{(\text{very low}, 0.01), (low, 0.24), (medium, 0.24), (high, 0.13), (very\ high, 0.38)\}$$

Based on R^6, R^7, R^8, $R^9$and R^{10}, it can be transformed into 7% CA1 ($O^1 = (0.01 \times 1) + (0.24 \times 0.25)$), 24% CA2 ($O^2 = 0.24 \times 0.75) + (0.24 \times 0.25)$), 12% CA3 ($O^3 = 0.24 \times 0.5$) , 15.75% CA4 ($O^4 = (0.24 \times 0.25) + (0.13 \times 0.75\ )$) and 41.25% CA5 ($O^5 = (0.13 \times 0.25) + (0.38 \times 1)$) respectively. The PDC core activities set in T6 is assessed as follows:

$$H^{PDC\ CA} = \{(\text{very poor}, 0.07), (poor, 0.24), (medium, 0.12), (good, 0.158), (very\ good, 0.413)\}$$

Lead-time to Core activities in T6

According to Table 5.55, the lead-time set in T6 is assessed as follows:

$$H^{LTC} = \{(very\ poor, 0), (poor, 0), (medium, 0), (good, 0.05), (very\ good, 0.95)\}$$

Based on $R^{11}$and R^{12}, it can be transformed into 3.8% CA4 ($O^4 = 0.05 \times 0.75$) and 96.2% CA5 ($O^5 = (0.05 \times 0.25) + (0.95 \times 1)$) respectively. The LTC core activities set in T6 is assessed as follows:

$$H^{LTC\ CA} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.038), (very\ good, 0.962)\}$$

5.4.5.3 *Aggregation of principal-PPIs*

Core activities in T6

By help of the IDS software, the principal PPIs (output, productivities and lead-time) are aggregated to core activities as follows:

Table 5.57 Aggregation of principal-PPIs (core activities)

Core activities	Very Poor	Poor	Medium	Good	Very Good	Weight
Output	0	0	0	0.467	0.533	0.257
Productivity	0.07	0.24	0.12	0.158	0.413	0.522
Lead-time	0	0	0	0.038	0.962	0.221
Aggregation results	0.0389	0.13089	0.06508	0.1833	0.58179	

6 dimensions in T6

The aggregation results of other dimensions using IDS software are obtained as follows. Mapping results from principal-PPIs to 6 dimensions and aggregation of the principal-PPIs are demonstrated in Appendix IV. For further information, please refer to Appendix IV.

Table 5.58 Aggregation of principal-PPIs (6 dimensions)

Aggregation results	Very Poor	Poor	Medium	Good	Very Good
Core Activities	0.0389	0.13089	0.06508	0.18330	0.58179
Support Activities	0.05187	0.10161	0.05723	0.41682	0.37244
Financial Strength	0.13907	0.14111	0.08373	0.22279	0.41328
Users' Satisfaction	0.10017	0.16557	0.07047	0.34144	0.32233
Terminal Supply Chain Integration	0.06468	0.11421	0.05794	0.35510	0.40805
Sustainable Growth	0.00929	0.03140	0.02052	0.12392	0.81483

5.4.5.4 *Mapping from 6 dimensions to goal*

The top level goal "port performance (PP)" can be expressed using linguistic terms "very poor (PP1)", "poor (PP2)", "medium (PP3)", "good (PP4)" and "very good (PP5)" (see Table

5.3). In terms of the fuzzy rule base belief structure in Table 5.59, mapping process from 6 dimensions to goal can be conducted.

Table 5.59 Fuzzy rule base belief structure

Core activities (CA) to port performance (PP)	R^1: *If "CA" is "CA5", then "PP" is "100% PP5"* R^2: *If "CA" is "CA4", then "PP" is "25% PP5"and "75% PP4"* R^3: *If "CA" is "CA3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^4: *If "CA" is "CA2", then "PP" is "75% PP2"and "25% PP1"* R^5: *If "CA" is "CA1", then "PP" is "100% PP1"*
Supporting activities (SA) to port performance (PP)	R^6: *If "SA" is "SA5", then "PP" is "100% PP5"* R^7: *If "SA" is "SA4", then "PP" is "25% PP5"and "75% PP4"* R^8: *If "SA" is "SA3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^9: *If "SA" is "SA2", then "PP" is "75% PP2"and "25% PP1"* R^{10}: *If "SA" is "SA1", then "PP" is "100% PP1"*
Financial strength (FS) to port performance (PP)	R^{11}: *If "FS" is "FS5", then "PP" is "100% PP5"* R^{12}: *If "FS" is "FS4", then "PP" is "25% PP5"and "75% PP4"* R^{13}: *If "FS" is "FS3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^{14}: *If "FS" is "FS2", then "PP" is "75% PP2"and "25% PP1"* R^{15}: *If "FS" is "FS1", then "PP" is "100% PP1"*
Users' satisfaction (US) to port performance (PP)	R^{16}: *If "US" is "US5", then "PP" is "100% PP5"* R^{17}: *If "US" is "US4", then "PP" is "25% PP5"and "75% PP4"* R^{18}: *If "US" is "US3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^{19}: *If "US" is "US2", then "PP" is "75% PP2"and "25% PP1"* R^{20}: *If "US" is "US1", then "PP" is "100% PP1"*
Terminal supply chain integration (TSCI) to port performance (PP)	R^{21}: *If "TSCI" is "TSCI5", then "PP" is "100% PP5"* R^{22}: *If "TSCI" is "TSCI4", then "PP" is "25% PP5"and "75% PP4"* R^{23}: *If "TSCI" is "TSCI3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^{24}: *If "TSCI" is "TSCI2", then "PP" is "75% PP2"and "25% PP1"* R^{25}: *If "TSCI" is "TSCI1", then "PP" is "100% PP1"*
Sustainable growth (SG) to port performance (PP)	R^{26}: *If "SG" is "SG5", then "PP" is "100% PP5"* R^{27}: *If "SG" is "SG4", then "PP" is "25% PP5"and "75% PP4"* R^{28}: *If "SG" is "SG3", then "PP" is "25% PP4", "50% PP3"and "25% PP2"* R^{29}: *If "SG" is "SG2", then "PP" is "75% PP2"and "25% PP1"* R^{30}: *If "SG" is "SG1", then "PP" is "100% PP1"*

Core activities to goal in T6

According to Table 5.58, the core activities set in T6 is assessed as follows:

$$H^{CA} = \{(\text{very poor}, 0.04), (poor, 0.13), (medium, 0.07), (good, 0.18), (very\ good, 0.58)\}$$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into <u>7.3% PP1</u> ($O^1 = (0.04 \times 1) + (0.13 \times 0.25)$), <u>11.5% PP2</u> ($O^2 = 0.13 \times 0.75) + (0.07 \times 0.25)$), <u>3.5% PP3</u> ($O^3 = 0.07 \times 0.5$), <u>15.3% PP4</u> ($O^4 = (0.07 \times 0.25) + (0.18 \times 0.75)$) and <u>62.5% PP5</u> ($O^5 = (0.18 \times 0.25) + (0.58 \times 1)$) respectively. The CA goal (port performance) set in T6 is assessed as follows:

$$H^{CA\ PP} = \{(\text{very poor}, 0.073), (poor, 0.115), (medium, 0.035), (good, 0.153), (very\ good, 0.625)\}$$

Supporting activities to goal in T6

According to Table 5.58, the supporting activities set in T6 is assessed as follows:

$$H^{SA} = \{(\text{very poor}, 0.05), (poor, 0.10), (medium, 0.06), (good, 0.42), (very\ good, 0.37)\}$$

Based on R^6, R^7, R^8, $R^9$and R^{10}, it can be transformed into 7.5% PP1 ($O^1 = (0.05 \times 1) + (0.1 \times 0.25)$), 9% PP2 ($O^2 = 0.1 \times 0.75) + (0.06 \times 0.25)$), 3% PP3 ($O^3 = 0.06 \times 0.5$), 33% PP4 ($O^4 = (0.06 \times 0.25) + (0.42 \times 0.75)$) and 47.5% PP5 ($O^5 = (0.42 \times 0.25) + (0.37 \times 1)$) respectively. The SA goal (port performance) set in T6 is assessed as follows:

$$H^{SA\ PP} = \{(\text{very poor}, 0.075), (poor, 0.09), (medium, 0.03), (good, 0.33), (very\ good, 0.475)\}$$

Financial strength to goal in T6

According to Table 5.58, the financial strength set in T6 is assessed as follows:

$$H^{FS} = \{(\text{very poor}, 0.14), (poor, 0.14), (medium, 0.08), (good, 0.22), (very\ good, 0.41)\}$$

Based on R^{11}, R^{12}, R^{13}, R^{14} and R^{15}, it can be transformed into 17.5% PP1 ($O^1 = (0.14 \times 1) + (0.14 \times 0.25)$), 12.5% PP2 ($O^2 = 0.14 \times 0.75) + (0.08 \times 0.25)$), 4% PP3 ($O^3 = 0.08 \times 0.5$), 18.5% PP4 ($O^4 = (0.08 \times 0.25) + (0.22 \times 0.75)$) and 46.5% PP5 ($O^5 = (0.22 \times 0.25) + (0.41 \times 1)$) respectively. The FS goal (port performance) set in T6 is assessed as follows:

$$H^{FS\ PP} = \{(\text{very poor}, 0.175), (poor, 0.125), (medium, 0.04), (good, 0.185), (very\ good, 0.465)\}$$

Users' satisfaction to goal in T6

According to Table 5.58, the users' satisfaction set in T6 is assessed as follows:

$$H^{US} = \{(\text{very poor}, 0.1), (poor, 0.17), (medium, 0.07), (good, 0.34), (very\ good, 0.32)\}$$

Based on R^{16}, R^{17}, R^{18}, $R^{19}$and R^{20}, it can be transformed into 14.3% PP1 ($O^1 = (0.1 \times 1) + (0.17 \times 0.25)$), 14.5% PP2 ($O^2 = 0.17 \times 0.75) + (0.07 \times 0.25)$), 3.5% PP3 ($O^3 = 0.07 \times 0.5$), 27.3% PP4 ($O^4 = (0.07 \times 0.25) + (0.34 \times 0.75)$) and 40.5% PP5 ($O^5 = (0.34 \times 0.25) + (0.32 \times 1)$) respectively. The US goal (port performance) set in T6 is assessed as follows:

$$H^{US\ PP} = \{(\text{very poor}, 0.143), (poor, 0.145), (medium, 0.035), (good, 0.273), (very\ good, 0.405)\}$$

Terminal supply chain integration to goal in T6

According to Table 5.58, the terminal supply chain integration set in T6 is assessed as follows.

$$H^{TSCI} = \{(\text{very poor}, 0.06), (poor, 0.11), (medium, 0.06), (good, 0.36), (very\ good, 0.41)\}$$

Based on R^{21}, R^{22}, R^{23}, $R^{24}$and R^{25}, it can be transformed into 8.8% PP1 ($O^1 = (0.06 \times 1) + (0.11 \times 0.25)$), 9.8% PP2 ($O^2 = 0.11 \times 0.75) + (0.06 \times 0.25)$), 3% PP3 ($O^3 = 0.06 \times 0.5$), 28.5% PP4 ($O^4 = (0.06 \times 0.25) + (0.36 \times 0.75)$) and 50% PP5 ($O^5 = (0.36 \times 0.25) + (0.41 \times 1)$) respectively. The TSCI goal (port performance) set in T6 is assessed as follows:

$$H^{TSCI\ PP} = \{(\text{very poor}, 0.088), (poor, 0.098), (medium, 0.03), (good, 0.285), (very\ good, 0.5)\}$$

Sustainable growth to goal in T6

According to Table 5.58, the sustainable growth set in T6 is assessed as follows:

$$H^{SG} = \{(\text{very poor}, 0.01), (poor, 0.03), (medium, 0.02), (good, 0.12), (very\ good, 0.81)\}$$

Based on R^{26}, R^{27}, R^{28}, $R^{29}$and R^{30}, it can be transformed into 1.8% PP1 ($O^1 = (0.01 \times 1) + (0.03 \times 0.25)$), 2.8% PP2 ($O^2 = 0.03 \times 0.75) + (0.02 \times 0.25)$), 1% PP3 ($O^3 = 0.02 \times 0.5$), 10.3% PP4 ($O^4 = (0.02 \times 0.25) + (0.13 \times 0.75)$) and 84.3% PP5 ($O^5 = (0.13 \times 0.25) + (0.81 \times 1)$) respectively. The SG goal (port performance) set in T6 is assessed as follows:

$$H^{SG\ PP} = \{(\text{very poor}, 0.018), (poor, 0.028), (medium, 0.01), (good, 0.103), (very\ good, 0.843)\}$$

5.4.5.5 Aggregation of 6 dimensions

Goal (port performance) in T6

By help of the IDS software, the 6 dimensions are aggregated as follows.

Table 5.60 Aggregation of 6 dimensions (goal)

Goal (port performance)	Very Poor	Poor	Medium	Good	Very Good	Weight
Core Activities	0.073	0.115	0.035	0.153	0.625	0.31
Support Activities	0.075	0.09	0.03	0.33	0.475	0.128
Financial Strength	0.175	0.125	0.04	0.185	0.465	0.151
Users' Satisfaction	0.143	0.145	0.035	0.273	0.405	0.225
Terminal Supply Chain Integration	0.088	0.098	0.03	0.285	0.5	0.116
Sustainable Growth	0.018	0.028	0.01	0.103	0.843	0.07
Aggregation results	0.08940	0.09992	0.02748	0.20129	0.58188	

5.4.5.6 Calculation of port performance using utility techniques

As shown in Table 5.60, it is not straightforward to use the overall aggregated results obtained using ER to rank each candidate port/terminal. Thus, utility techniques can be used in order to obtain a single crisp value for the top-level goal of T6 from the aggregated values. Based on Table 5.60, the fuzzy set for the T6's performance can be expressed as follows.

$$H^{PP} = \{(\text{very poor}, 0.089), (poor, 0.1), (medium, 0.028), (good, 0.201), (very\ good, 0.582)\}$$

The fuzzy set for the goal is expressed by five linguistic terms, indicating the lowest preference is given to 'very poor' and the highest preference is given to 'very good'. Thus, the preference value is designated from one (i.e. the lowest preference) to five (i.e. the highest preference). Based on Eqs. (5.22)-(5.23) and the fuzzy set H^{PP}, the performance of T6 can be calculated as shown in Table 5.61. The overall performance of T6 is evaluated with 0.77156.

Table 5.61 Calculation of port performance

	Very Poor	Poor	Medium	Good	Very Good
Preference value	1	2	3	4	5
U_j	$\frac{1-1}{5-1}=0$	$\frac{2-1}{5-1}=0.25$	$\frac{3-1}{5-1}=0.5$	$\frac{4-1}{5-1}=0.75$	$\frac{5-1}{5-1}=1$
β_j	0.08940	0.09992	0.02748	0.20129	0.58188
$\beta_j U_j$	0	0.02498	0.01374	0.150968	0.58188
R_C	$R_C = \sum_{j=1}^{5} \beta_j U_j = 0.77156$				

The transformed results from the lowest level PPIs to the top level goal and their interdependent weights for 12 alternative container terminals are synthesised by IDS incorporating the ER algorithm and utility technique. As shown in Table 5.62-Table 5.64, the performance scores of each container terminal can be easily compared and decision makers can straightforwardly identify their strengths and weaknesses. Table 5.62 shows the overall performance score of each container terminal in terms of performance ranking index. The difference is significant between the leading performer group (i.e. T6, T4, T12, T5 and T9) and the poor performer group (i.e. T7, T2 and T8). Table 5.63 demonstrates the performance scores of the sixteen principal-PPIs. T6, T4, T5 and T7 show the highest performance on 3 principal-PPIs followed by T11 with 2 principal-PPIs. Interestingly, even though T7 shows the highest performance on crucial principal-PPIs such as SFU, SCU and LSF, the terminal is assessed to be the least competitive terminal with the lowest performance especially in terms of OPC, PDC and PFF. The results can lead to the performance scores of the six dimensions (see Table 5.64 and Figure 5.12). Most terminals outperform on qualitative dimensions such as SG, SA and TSCI but are less competitive on quantitative dimensions such as CA and FS. These benchmarking results provide an important contribution for decision makers to enhance their terminal performance based on any necessary comparisons. Furthermore, it can be used for a longitudinal study to investigate the improvement of terminals within different timeframes.

Table 5.62 Performance score of each container terminal

	Performance	Ranking index	Ranking
T 1	VP 0.28; P 0.9; M 0.03; G 0.21; VG 0.38	0.58	9
T 2	VP 0.29; P 0.17; M 0.04; G 0.20; VG 0.31	0.52	11
T 3	VP 0.23; P 0.14; M 0.04; G 0.23; VG 0.37; UK 0.0004	0.59	7
T 4	VP 0.16; P 0.08; M 0.03; G 0.22; VG 0.52	0.71	2
T 5	VP 0.18; P 0.1; M 0.04; G 0.25; VG 0.44	0.67	4
T 6	VP 0.09; P 0.1; M 0.03; G 0.20; VG 0.58	0.77	1
T 7	VP 0.37; P 0.11; M 0.03; G 0.16; VG 0.32; UK 0.02	0.48	12
T 8	VP 0.27; P 0.15; M 0.03; G 0.18; VG 0.34; UK 0.02	0.54	10
T 9	VP 0.14; P 0.12; M 0.04; G 0.24; VG 0.4; UK 0.06	0.66	5
T 10	VP 0.24; P 0.14; M 0.04; G 0.19; VG 0.37; UK 0.02	0.58	8
T 11	VP 0.18; P 0.17; M 0.05; G 0.23; VG 0.36; UK 0.02	0.61	6
T 12	VP 0.17; P 0.09; M 0.03; G 0.19; VG 0.50; UK 0.02	0.69	3

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.

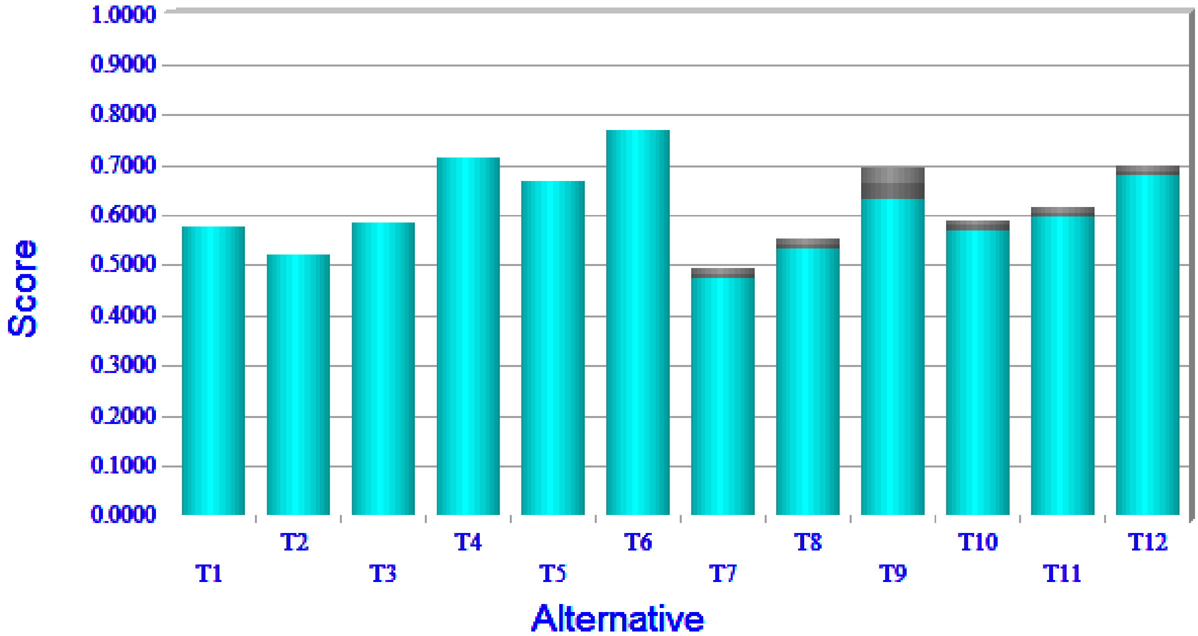

Figure 5.11 Performance ranking

Table 5.63 Performance score on 16 principal-PPIs

	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T12	Ranking
OPC	0.0000	0.1240	0.0943	0.0087	0.0002	0.9123	0.1521	0.2832	0.4901	0.0000	0.3021	1.0000	T12>T6>T9>T11
PDC	0.5320	0.5175	0.5820	0.6274	0.6190	0.6406	0.2804	0.2070	0.3529	0.3284	0.3325	0.4346	T6>T4>T5>T3
LTC	0.9856	0.9806	0.9731	0.9942	0.9947	0.9930	0.9378	0.9561	0.9458	0.9011	0.8793	0.9529	T5>T4>T6>T1
HCS	0.6771	0.5155	0.7543	0.7789	0.6981	0.7360	0.3508	0.7327	0.8287	0.7716	0.8520	0.7801	T11>T9>T12>T4
OCS	0.7301	0.4714	0.8592	0.8137	0.7288	0.7447	0.4905	0.7531	0.8186	0.7815	0.7686	0.7451	T3>T9>T4>T10
ICS	0.7791	0.5872	0.7804	0.6051	0.6435	0.7504	0.3750	0.7091	0.8876	0.6533	0.8084	0.8062	T9>T11>T12>T3
PFF	0.0000	0.0000	0.0395	0.6652	0.5741	0.8211	0.0000	0.2768	0.5615	0.7078	0.3969	0.2829	T6>T10>T4>T5
LSF	0.3535	0.3995	0.8873	0.8873	0.3364	0.1296	0.9583	0.1296	0.5000	0.4859	0.9583	0.8873	T7=T11>T3=T4=T12
SFU	0.7480	0.6566	0.5990	0.7180	0.7304	0.6803	0.7877	0.7616	0.7130	0.6398	0.6756	0.6393	T7>T8>T1>T5
SCU	0.6459	0.6024	0.5546	0.5934	0.5857	0.5422	0.6476	0.6217	0.5984	0.5852	0.5852	0.6171	T7>T1>T8>T12
ITST	0.7124	0.6604	0.6585	0.7444	0.7438	0.7415	0.6338	0.6993	0.7283	0.6422	0.7070	0.7171	T4>T5>T6>T9
VAST	0.6428	0.5746	0.5970	0.6748	0.7424	0.6728	0.6525	0.6817	0.7048	0.5752	0.5594	0.6477	T5>T9>T8>T4
ICIT	0.7294	0.6498	0.6731	0.7439	0.7515	0.7416	0.6500	0.6874	0.7258	0.6784	0.7055	0.7138	T5>T4>T6>T1
SSS	0.9255	0.7825	0.8650	0.9861	0.8909	0.9837	0.8387	0.9178	0.9454	0.8857	0.8752	0.8770	T4>T6>T9>T1
EVS	0.6851	0.5832	0.6732	0.7882	0.7091	0.7950	0.3058	0.5664	0.5022	0.5081	0.4650	0.5509	T6>T4>T5>T1
SES	0.7869	0.6235	0.5685	0.9003	0.7594	0.6777	0.3447	0.5080	0.5378	0.6064	0.4319	0.3576	T4>T1>T5>T6

Table 5.64 Performance score on 6 dimensions

6 DMS	CA	SA	FS	US	TSCI	SG
T 1	0.4947	0.7421	0.0698	**0.7409**	0.7200	**0.8865**
T 2	0.5153	0.5420	0.0736	0.6541	0.6548	0.7453
T 3	0.5562	**0.7958**	0.2249	0.5962	0.6636	0.8126
T 4	**0.5690**	0.7295	**0.7467**	0.7073	**0.7487**	**0.9591**
T 5	**0.5679**	0.6942	0.5078	**0.7169**	**0.7608**	**0.8615**
T 6	**0.7878**	0.7588	**0.6626**	0.6660	**0.7470**	**0.9317**
T 7	0.3511	0.3732	0.2096	**0.7756**	0.6471	0.7047
T 8	0.3475	0.7387	0.2097	**0.7492**	0.7076	0.8290
T 9	0.4940	**0.8606**	**0.5520**	0.7030	**0.7378**	0.8451
T 10	0.3398	0.7443	**0.6658**	0.6373	0.6514	0.8103
T 11	0.4148	**0.8364**	0.5311	0.6673	0.6970	0.7715
T 12	**0.6765**	**0.8046**	0.4554	0.6424	0.7192	0.7748
Average	0.50955	0.71835	0.40908	0.68802	0.70458	0.82768
Ranking	T6>T12>T4>T5	T9>T11>T12>T3	T4>T10>T6>T9	T7>T8>T1>T5	T5>T4>T6>T9	T4>T6>T5>T1

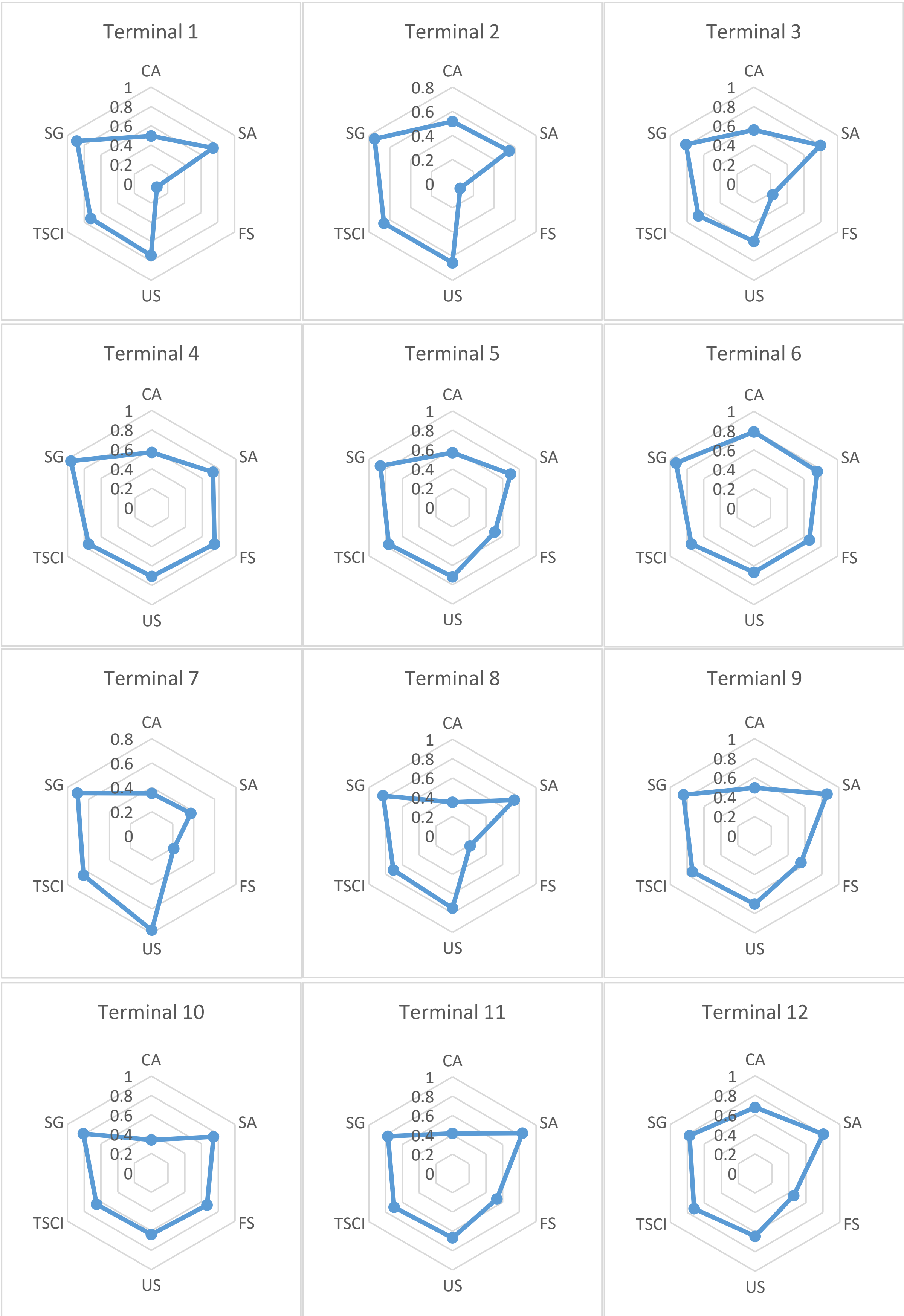

Figure 5.12 Performance score on 6 dimensions

5.4.6 Sensitivity analysis

Sensitivity analysis is used to test the results and to validate the feasibility and robustness of the proposed models. The sensitivity analysis in this study is conducted through analysing how sensitive the outputs (e.g. performance score of each container terminal) are to minor change in inputs (e.g. DoB or weights). This study adopts three axioms that used by Yang *et al*. (2009c) and Riahi *et al*. (2012). If the model is robust and its inference reasoning is logical, the sensitivity analysis must satisfy the following axioms (Yang *et al*., 2009c).

Axiom 1. A slight increment/decrement in the degrees of belief associated with any assessment grades of the bottom level PPIs will certainly result in the effect of a relative increment/decrement in the model output (i.e. the performance score of the terminals).

Axiom 2. Given the same variation of belief degree distributions of the bottom level PPIs, its influence magnitude to the model output will keep consistency with their weight distributions.

Axiom 3. The total influence magnitudes of N number of PPIs at the bottom level to the model output will be always greater than the one from the K number of PPIs ($K < N$) when the same variation of the belief degree associated with the highest-evaluation assessment grade of each of such N and K PPIs is decreased, and simultaneously the belief degree associated with the lowest-assessment grade of each of such N and K PPIs is increased.

To test the axioms 1 and 2, the degrees of belief (β_j) associated with the highest-evaluation assessment grades (H_j) of all PPIs at the bottom level are decreased by 0.1 and 0.2 one by one, and simultaneously the degrees of belief associated with the lowest assessment grades of corresponding PPIs are increased by 0.1 and 0.2 one by one. For example, if the belief degree of ‘throughput growth’ belonging to ‘20%’ decreases by 0.1 and, simultaneously, the belief degree of it belonging to ‘leq 0%’ increases by 0.1. However, if the belief degree attached to ‘20%’ is less then 0.1 (i.e. 0.08), then the remaining belief degree (i.e. 0.02=0.1-0.08) can be taken from the one attached to ‘15%’. The example of decrement of the PPI at the bottom level by 0.1 and 0.2 is shown in Table 5.65. The effect of ‘throughput growth’ by 0.1 in T6 decreases the model output (i.e. overall performance) from 0.7716 to 0.7663, while the effect of ‘throuhput growth’ by 0.2 decreases the model output from 0.7716 to 0.7615. Similar analysis has been conducted to investigate the influence of the other PPIs at the bottom level, which is depicted in Figure 5.13. The effects of belief degrees (i.e. either 0.1 or 0.2) associated with the bottom level PPIs indicate that the model outputs are sensitive to them. In addition, it is clear that the influence magnitudes of the belief degree changes of the PPIs to the model outputs are significantly different (i.e. the difference between 0.1 and 0.2), and the changes closely follow the weight distributions of the PPIs in Table 5.52. For example, as the 'overall service reliability' is the most crucial PPI (0.059) among the 60 PPIs, the model output is more sensitive to the 'overall service reliability' than the other PPIs. The results obtained in Figure 5.13 are in line with axioms 1 and 2.

Table 5.65 Decrement of the PPIs by 0.1 and 0.2

PPIs	Degrees of Belief	Performance
Throughput volume growth	{(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0), (20%, 0.944), (*geq* 25%, 0.056)}	0.7716
Vessel call size growth	{(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0.392), (*geq* 20%, 0.608)}	
Ship load rate	{(leq 25TEU, 0), (40TEU, 0.343), (55TEU, 0.657), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	
…………	………………………………………	
	The decrement of the PPIs by 0.1	
Throughput volume growth	{(leq 0%, 0.1), (5%, 0), (10%, 0), (15%, 0), (20%, 0.9), (*geq* 25%, 0)}	0.7663
Vessel call size growth	{(leq 0%, 0.1), (5%, 0), (10%, 0), (15%, 0.392), (*geq* 20%, 0.508)}	0.7704
Ship load rate	{(leq 25TEU, 0.1), (40TEU, 0.343), (55TEU, 0.557), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	0.7710
…………..	………………………………	
	The decrement of the PPIs by 0.2	
Throughput volume growth	{(leq 0%, 0.2), (5%, 0), (10%, 0), (15%, 0), (20%, 0.8), (*geq* 25%, 0)}	0.7615
Vessel call size growth	{(leq 0%, 0.2), (5%, 0), (10%, 0), (15%, 0.392), (*geq* 20%, 0.408)}	0.7692
Ship load rate	{(leq 25TEU, 0.2), (40TEU, 0.343), (55TEU, 0.457), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	0.7705
……………	………………………	

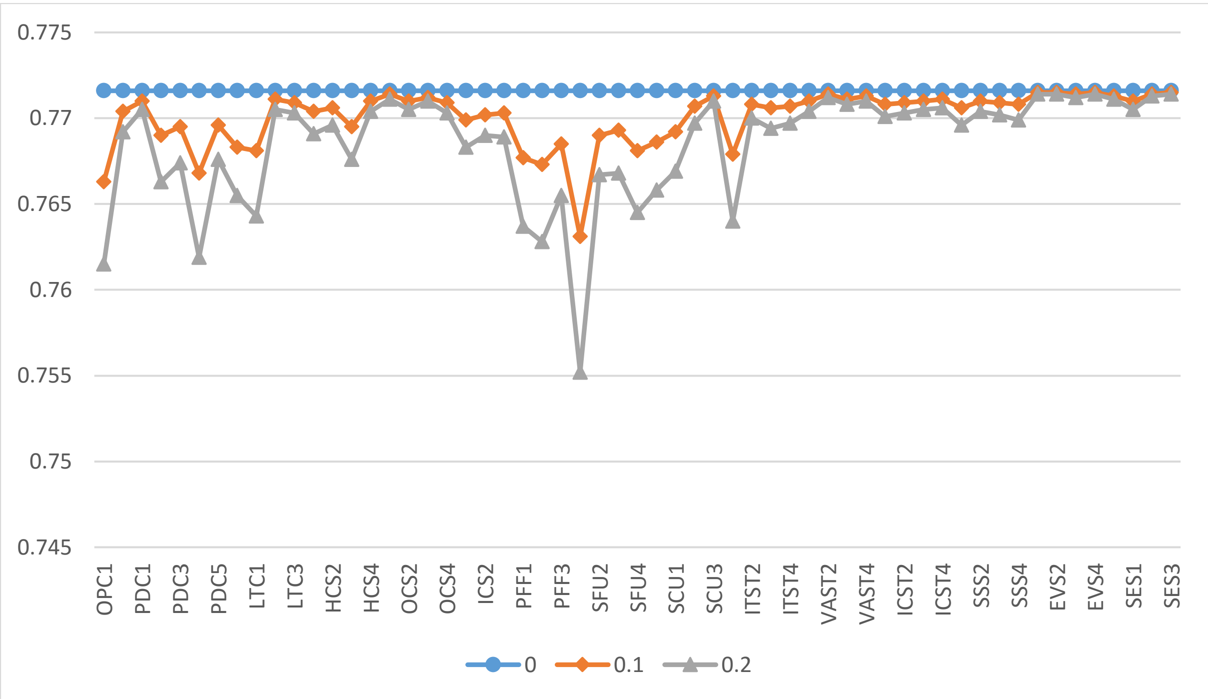

Figure 5.13 Sensitivitiy analysis of Terminal 6

To test the axiom 3, the degrees of belief associated with the highest-evaluation assessment grades of all PPIs at the bottom level (i.e. 60 PPIs) are decreased by 0.2, the performance score of Terminal 6 is evaluated as 0.5538. By selection of 32 PPIs (i.e. odd-numbered PPIs within the same cluster) from the 60 PPIs, the degrees of belief associated with the highest-evaluation assessment grades of the 32 PPIs are decreased by 0.2, and then the performance score of Terminal 6 is evaluated as 0.6458. The total influence magnitudes of the 60 PPIs (i.e. N number of PPIs) to the model output (i.e. 0.6458) is greater than the one (i.e. 0.5538) from the 32 PPIs (i.e. K number of PPIs), the result obtained keep harmony with axiom 3.

5.5 CONCLUSION

Previous studies on port performance, port selection and port competitiveness mainly focus on sea-side operations only. Moreover, existing studies typically lack a structured approach to performance measurement in a multi-stakeholder environment. In this regard, this chapter introduced a new framework based on the combination of the AHP and FER techniques to incorporate multiple objectives of key stakeholders. The synthesis of the evaluations of quantitative and qualitative PPIs with their weights was conducted through an IDS decision support tool. The hybrid method was applied to 12 dedicated container terminals in Korea to demonstrate its relevance in an empirical setting.

The result suggests that terminal 6 shows the best results, followed by terminal 4, terminal 12 and terminal 5 (Table 5.62). Terminal 7 is assessed to be the least competitive terminal with the lowest performance especially in terms of output, productivity and profitability. Terminal 6 outperforms the other terminals in terms of productivity, profitability and environment but is less competitive at the level of two principal-PPIs such as liquidity & solvency and service costs. On the other hand, terminal 4 has its strengths in terms of intermodal transport systems, safety & security and social engagement but is especially less competitive on output. Terminal 12 is assessed to be the most competitive with output, accordingly in core activities. Terminal 5 show the highest performance on lead-time, value-added services and information & communication integration, accordingly in terminal supply chain integration. Based on the results (Table 5.62-Table 5.64), it is possible to provide the strengths and weaknesses of the 12 container terminals. Accordingly, decision makers in the terminal operating companies can identify the particular areas for improvement to enhance their competitiveness.

Derived from the results of relative weights among the six dimensions (Table 5.50), core activities constitute the most important dimension, which has a relative importance value of 0.31, followed by users' satisfaction (value of 0.23) and financial strength (value of 0.14). In contrast, sustainable growth is the least important dimension (value of 0.07).

Amongst 16 principal-PPIs, service fulfilment (0.16), productivity (0.16) and profitability (0.1) and output (0.08) are found to be the most important whilst environment (0.1) and social engagement (0.1) is the least important principal-PPI (Figure 5.8). A plausible explanation would be that in the context of the container port industry, container throughput, berth-yard operation, mode turnaround time and labour productivity, service reliability, customer satisfaction are important criteria for port performance measurement. However, being cost and price competitive is crucial but not sufficient for port performance measurement (0.06). This finding is 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 and hinterland connectivity (Yeo *et al*., 2008). Terminal operating companies 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 to sustain themselves in a highly competitive environment.

The results yielded by the hybrid approach present the ranking of the terminals in terms of their overall performance with respect to multiple PPIs as well as a PPI's ranking with a single performance value. This feature enables us to identify the strengths and weaknesses of the ports and offers insights to the terminal operating companies to find optimal strategies to improve their performance.

Nevertheless, further studies for identifying interdependencies among the PPIs and result validity are to be conducted. Given complex port/terminal activities and operations, decision makers may require an essential understanding of the interdependency among the PPIs and develop appropriate solutions to improve port/terminal performance. Based on the research findings, further empirical study to benchmark port performance in different regions/areas and for different timeframes can be carried out to identify the best practices/solutions of the leading performers in view of an improvement of weaker PPIs.

CHAPTER 6 A HYBRID APPROACH TO THE MODELLING OF PORT PERFORMANCE MEASUREMENT: PPIs INTERDEPENDENCY MODEL

This chapter aims to propose a new conceptual PPI measurement model using a hybrid approach of a FER method, a DEMATEL and an ANP technique. First, a combined method of the DEMATEL and ANP is applied to address interdependency among the PPIs. Then, the FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs. An analysis of four major container ports in Korea is conducted to validate the proposed framework. The empirical results indicate that the hybrid approach attempting to use quantitative modelling for dealing with the uncertainties and interdependency problems can be successfully fulfilled. The hybrid model represents an effective performance measurement tool and offers a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner.

6.1 INTRODUCTION

The measurement of port and terminal performance may require an essential understanding of the cause-effect relationship among the influencing factors and criteria. A number of port performance indicators (PPIs) may interact with and feedback themselves (inner dependency) or each other (outer dependency). However previous studies, including the work in chapter 5 have done little on the analysis of interdependencies among the factors (i.e. PPIs).

Chapter 5 took into account two disciplines: MCDM and uncertainty. The PPIs were treated as having an independent nature by using AHP for PPIs' weights in the FER model. The AHP incorporating FER model is not capable of analysing the interdependencies among the PPIs. This chapter takes into account one more discipline of the interdependencies among the PPIs, capable of delivering more accurate results in a situation, where PPIs show high relationship.

This chapter aims at proposing a new conceptual PPI measurement model using a hybrid approach of a FER method (Yang and Xu, 2002), a DEMATEL tool (Gabus and Fontela, 1973) and an ANP technique (Saaty, 1996). A combined method of the DEMATEL and ANP is applied to address interdependency among the PPIs in a complimentary way. The DEMATEL is first used to identify whether there are interdependent relationships among the PPIs while the ANP is applied to determine the intensity of the relationships among the PPIs. Furthermore, the FER is applied to deal with uncertainties presented in the evaluations of the selected PPIs and to synthesise the evaluations of quantitative and qualitative PPIs with their weights. The hybrid approach, in attempting to use quantitative modelling for dealing with the uncertainties and interdependency problems, can fulfil the aforementioned research gap.

In the next section, the research methodology is presented and previous studies that used the methodology are reviewed. In section 6.3, there is an empirical investigation of 4 Korean container ports' performance measurement. Finally, the paper concludes with a discussion of results and recommendation for further research in section 6.4.

6.2 A HYBRID METHODOLOGY FOR PORT PERFORMANCE MEASUREMENT

The DEMATEL is first used to identify whether there are interdependent relationships among the PPIs, while the ANP is applied to determine the intensity of the relationships among the PPIs. Furthermore, the FER is applied for dealing with uncertainties presented in the evaluations of the selected PPIs. The proposed framework for port performance measurement using a hybrid approach of FER, and DEMATEL and ANP consists of following steps in Figure 6.1.

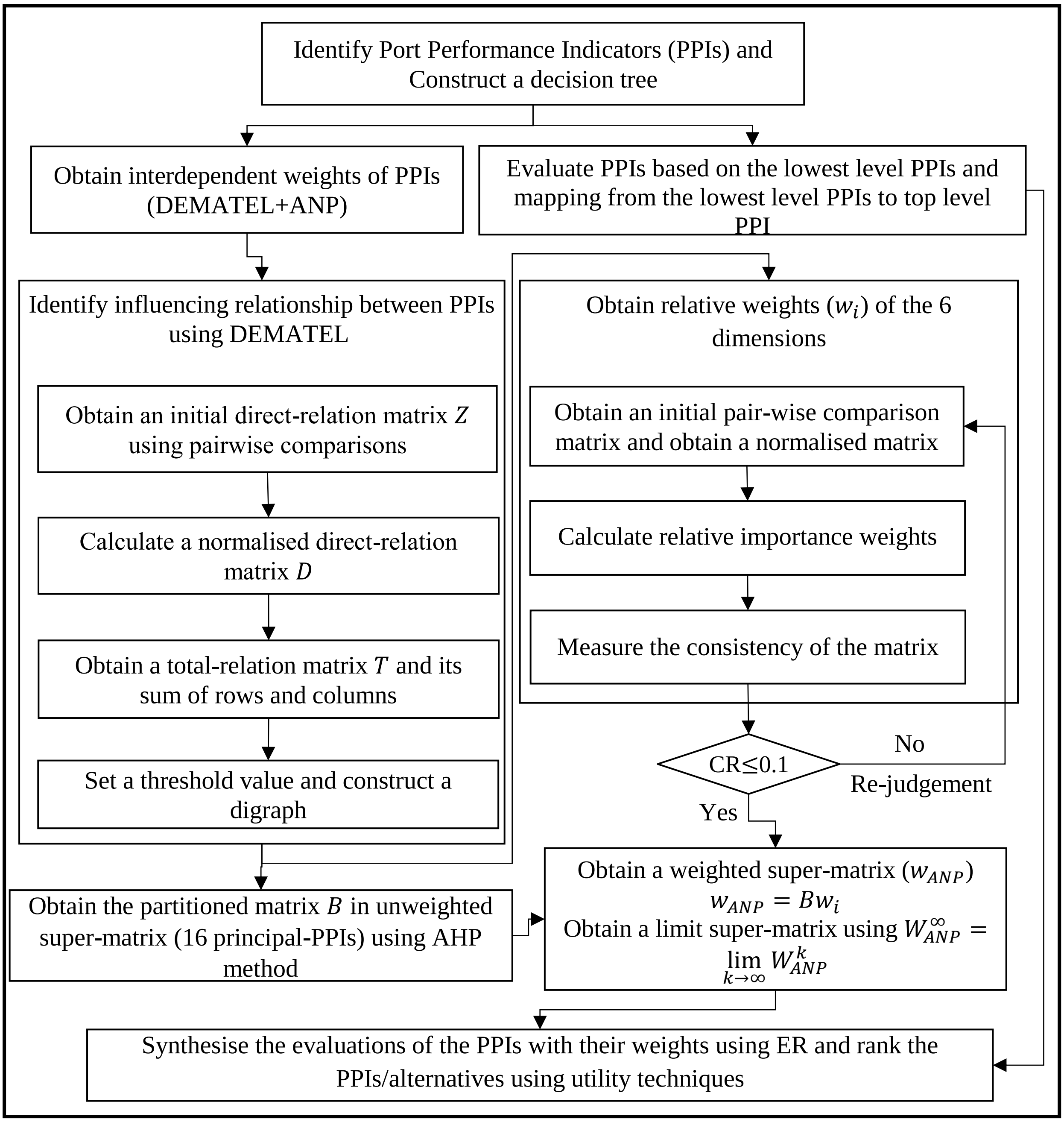

Figure 6.1 Proposed framework for port performance measurement

6.2.1 Hierarchies and networks

Many decision problems need to be explained using a network instead of a hierarchy structure because they involve various interplays and interdependencies within a cluster and between clusters at the same level or different levels (Saaty, 1996, Saaty, 2004). Given this complexity, decision makers may require an essential understanding of the cause-effect relationship between the criteria (Lin and Wu, 2004). A network structure is a special case of a hierarchy which allows for feedback between clusters. As shown in Figure 6.2, both a linear hierarchy and a non-linear network allow for inner dependency 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 and Vargas, 2013). The former is called an inner dependency and the latter is called an outer dependency, respectively. In this chapter, the dependencies between the dimensions/principal-PPIs/PPIs are identified by the DEMATEL approach, and then the ANP technique is applied to determine interdependent weights of the dimensions/principal-PPIs/PPIs.

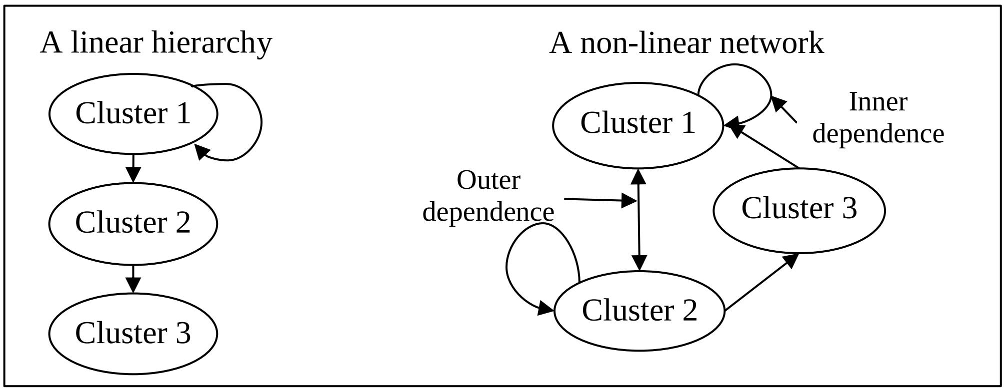

Figure 6.2 Structural difference between a hierarchy and a network model

6.2.2 The use of DEMATEL to identify the interdependencies among the PPIs

The DEMATEL 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 and Lee, 2007). The method is a structural modelling approach, which can divide the criteria in separate cause and effect groups. Based on the directed graph, known as *digraph*, it is possible to demonstrate the directed relationships and interdependency of the criteria (Liou *et al*., 2007, Büyüközkan and Çifçi, 2012).

The DEMATEL supposes a set of n basic PPIs as $S = \{x_1\, x_2\, \ldots x_i\, \ldots x_{n-1}\, x_n\}$, in which x_i is ith indicator of basic PPIs ($i = 1 \ldots$ or n) and S represents an 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. (6.1), 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 k expert.

$$Z = [z_{ij}]_{n\times n} = \frac{1}{m}\sum_{k=1}^{m} x_{ij}^k, \quad i, j = 1 \ldots n$$

$$Z = \begin{matrix} \\ x_1 \\ x_2 \\ \cdots \\ x_n \end{matrix} \begin{matrix} \begin{matrix} x_1 & x_2 & \ldots & x_n \end{matrix} \\ \begin{bmatrix} 0 & z_{12} & \cdots & z_{1n} \\ z_{21} & 0 & \cdots & z_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{1n} & \ldots & 0 \end{bmatrix} \end{matrix} \tag{6.1}$$

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 $0 \le d_{ij} \le 1$, can be obtained through following Eq. (6.2). In order to obtain a coefficient s, maximum value of the sums of each row and column is used.

$$D = s \cdot Z \quad or \quad [d_{ij}]_{n\times n} = s \cdot [z_{ij}]_{n\times n}, \qquad s > 0$$

$$s = min[\frac{1}{max1 \le i \le n\ \sum_{j=1}^{n} z_{ij}}, \frac{1}{max1 \le i \le n\ \sum_{i=1}^{n} z_{ij}}]\ \ i, j = 1, 2, \ldots, n \tag{6.2}$$

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. (6.3), in which I is denoted as the identity matrix. In Eq. (6.4), R_i and C_j denote the sums of rows and columns in the matrix T 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.

$$T = \lim_{m=\infty}(D^1 + D^2 + \cdots + D^m) = \sum_{m=1}^{\infty} D^i = D(I - D)^{-1} \quad (6.3)$$

$$R_i = \sum_{j=1}^{n} t_{ij}\ ,\ C_j = \sum_{i=1}^{n} t_{ij} \qquad (\mathrm{i}, j = 1, 2, \ldots\ldots, n)$$
$$pr_i^+ = R_i + C_i \ \ pr_i^- = R_i - C_i \quad (6.4)$$

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. 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.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N} \quad (6.5)$$

6.2.3 The use of ANP to determine PPIs' interdependent weights

After identifying interdependent relationships between 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 feedback among criteria/alternatives (Saaty, 1996). In the ANP technique, the relative weights (or priorities, ratings, preferences, etc.) are obtained using pairwise comparisons and evaluations. Unlike the AHP, the ANP allows interaction and feedback both between clusters (outer dependence) and within cluster (inner dependency) (Saaty, 2004). The former is interaction between the elements in the different clusters whilst the latter is the influence between elements in the same cluster. Feedback in a network structure is a better form to capture the complex interactions between the clusters/elements in decision problems (Saaty, 2004). Hence, the ANP approach, based on a network structure representing feedback approach within a decision network hierarchy, is capable of obtaining the interdependent weights of the dimensions/principal-PPIs/PPIs for this study.

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 and Vargas, 2013). According to (Saaty, 2012), there are three types of super-matrix:

Unweighted super matrix

The unweighted super matrix includes the local weights obtained from pairwise comparisons. The formation of the super matrix is shown in Eq. (6.6). The weight (W_{11}) can be obtained by pairwise comparisons between the elements (e_{11} e_{12} ... e_{1n_1}) on the left matrix and the elements (e_{11} e_{12} ... e_{1n_1}) at the top the matrix with respect to their associated upper criterion (C_1).

$$W = \begin{array}{c} \\ C_1 \\ \\ C_2 \\ \vdots \\ C_N \end{array} \begin{array}{c} \\ e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \\ e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \\ e_{N1} \\ e_{N2} \\ \vdots \\ e_{NnN} \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_N \\ e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{2n_2} & & e_{N1}e_{N2}\cdots e_{Nn_N} \end{array}}{\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \cdots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}} \quad (6.6)$$

where the *i*, *j* block of the weight matrix (W_{NN}) is given by

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

For instance, the super-matrix (unweighted super-matrix) of the non-linear network structure in Figure 6.2 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 dependency and feedback within the cluster 1 and cluster 2, respectively. Zero represents no feedback relationship between clusters.

The weights (w_{ij}) of the clusters and elements at each level can be obtained using pair-wise comparisons (i.e. AHP). The characteristics and calculations of the AHP were described in chapter 5. For further information, please refer to 5.2.2.

Weighted super matrix

The weighted (normalised) super-matrix is obtained by multiplying all the local weights in the unweighted super matrix by their associated cluster weights using Eq. (6.7).

$$w_{ANP} = Bw_i \tag{6.7}$$

where B is partitioned matrix (local weights) in unweighted super matrix and w_i denotes their associated cluster weights.

In this chapter, the matrix (B) and w_i can be derived based on the digraph of the DEMATEL. Based on the interdependency among the PPIs on the digraph, the effects of the interdependency between the PPIs are obtained through pairwise comparisons as well. Surveys are carried out in the form of a question such as "which PPI influences on PPI 1 more: PPI 2 or PPI 3? And how much more?". By repeating this process, a number of comparison matrices can be formed, which can identify the relative impacts of criteria interdependent relationships. The calculation procedure is the same as the one in AHP. The weights derived from pairwise comparisons are entered as the elements of columns of the interdependency matrix B. Then, a weighted super-matrix can be normalised by setting all columns' sums to unity. The sum of the probabilities of all states can be equal to one.

Limit super matrix

Last, a limited super matrix can be obtained by raising the weighted super-matrix to limiting powers using $W_{ANP}^{\infty} = \lim_{k\to\infty} W_{ANP}^{k}$ until the column of numbers is the same for every column. The values in column represents the global weights.

6.2.4 Fuzzy evidential reasoning to port performance measurement

The evaluations of quantitative and qualitative PPIs with their weights can be synthesised by the ER algorithm and utility theory. The calculations of the ER algorithm and utility techniques were described in chapter 5. For further information, please refer to 5.2.3.

6.2.5 Applications of the DEMATEL and ANP

An integrated method of the DEMATEL and ANP has been proven to be a successful tool for measuring dependency and feedback among elements in the complex decision problems in various applications such as airline safety measurement (Liou *et al*., 2007), service quality Shieh *et al*. (2010), supply chain performance (Najmi and Makui, 2010) and green suppliers selection (Büyüközkan and Çifçi, 2012).

Liou *et al*. (2007) investigated Taiwanese airline safety applying the DEMATEL along with ANP to suggest a new safety measurement model. The DEMATEL was used to identify the cause and effect relationship between safety factors and to draw their relation structure for the safety measurement. The ANP was used to compare dependency and feedback among criteria and alternatives.

Wu (2012) proposed an integrated method of the ANP and DEMATEL to introduce an effective solution to evaluate and choose knowledge management strategies for companies.

Najmi and Makui (2010) used a combined method of the AHP and DEMATEL to detect critical factors affecting supply chain performance. The DEMATEL was used to investigate interdependency among the factors and the AHP was used to extract relative weights of factors in different levels.

Chang *et al*. (2011) identified the principal factors for the IT industry in Taiwan to introduce RFID (Radio Frequency Identification) and investigated the cause and effect relationship between the factors using the AHP and DEMATEL.

Herat *et al*. (2012) applied the DEMATEL and ANP approach to select improvement projects in the Iranian healthcare sector. They classified nine areas of the healthcare organization excellence model into the cause and the effect groups using the DEMATEL. Based on these results, using the ANP, they proposed a ranking of the projects that should urgently be improved.

Wu and Tsai (2012) evaluated the criteria in the auto spare parts industry in Taiwan using the AHP and DEMATEL. For this, they used the AHP for investigating critical criteria to address a short-term improvement strategy for suppliers' performance. On the other hand, based on the diagraph derived from the DEMATEL, they suggested a long-term improvement opportunity for the auto spare parts industry.

Yüksel (2012) proposed a technical framework of the PESTEL (Political, Economic, Socio-cultural, Technological, Environment and Legal) analysis applying the AHP, ANP and DEMATEL. Using the AHP, he modelled a structure of the PESTEL criteria and sub-criteria as well as allocating their relative importance through pairwise comparisons. On the contrary, DEMATEL was used to determine interdependency among the PESTEL criteria. Lastly, global weights of the sub-criteria were obtained using the ANP.

The hybrid method has not yet been applied to port performance measurement under the interdependent situation. This study uses the integrated method for modelling PPIs interdependency for the following reasons. Firstly, it has been successfully applied in complex decision problems. Secondly, it can deal with both quantitative and qualitative PPIs for weighting and interdependency. Thirdly, it allows for group decision-making. Lastly, a relatively small sample size can be used for analysis.

6.3 PORT PERFORMANCE MEASUREMENT IN KOREAN MAJOR CONTAINER PORTS

The hybrid model is applied to measure and analyse the performance of the 4 major container ports in Korea from different port stakeholders' perspectives. The case is chosen and analysed at a port level instead of a terminal level because of 1) demonstrating the capability of the developed tools/methods in dealing with various port performance issues, and 2) PPIs show high interdependency when being used to carry out evaluation at a port level.

6.3.1 Identifying PPIs, setting assessment grades to each PPI and collecting data.

PPIs which were most crucially needed for measuring port performance were identified in chapter 3. For further information, please refer to section 3.3. On top of that, the assessment grades are allocated to all PPIs in chapter 5. For further information, please refer to section 5.3.1. The quantitative data (i.e. CA and FS) were collected directly from terminal operating companies and information systems/databases managed by port authorities, government and credit rating agencies. The qualitative PPIs were collected using questionnaires from three groups of terminal operators (TO), users (i.e. shipping lines, third-party logistics providers and freight forwarders, PU) and administrators (i.e. port authority and government, AD) to assess their own associated PPIs to measure each port performance. The survey was conducted through an online survey tool as well as distributed by emails. The detailed responses of the survey are listed in Table 6.1.

Table 6.1 Response details

	Busan North			Gwangyang			Incheon			Busan New		
	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
Total received	2 (2)	38 (31)	0	40 (40)	26 (26)	10	0	15 (11)	0	4 (4)	38 (31)	0
Online received	30 (29)	20 (12)	9 (6)	0	5 (3)	0	41 (39)	26 (17)	11 (6)	26 (24)	20 (12)	9 (6)
Usable response	(31)	(43(2))[1]	(6)	(40)	(29 (8))	(10)	(39)	(28)	(6)	(28)	(43(2))	(6)
Used for analysis	(31)	(127)[2]	(18)	(40)	(85)	(30)	(39)	(84)	(18)	(28)	(213)	(18)
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: [1]The data were collected based on container terminal level, hence it denotes the maximum sample size of 43 and the minimum of 42 in each terminal.
[2]The sample size of the PU and AD for the analysis is more than the number of 'usable response': Busan North (3 dedicated container terminals), Gwangyang (3 dedicated container terminals), Incheon (3 dedicated container terminals) and Busan New (5 dedicated container terminals). In principle, any types of cargo except for container box cannot be handled in the dedicated container terminal based on the Harbour Transport Business Act in South Korea.

6.3.2 Evaluate each port/terminal based on the lowest level PPIs.

In this section, the calculation process for one representative port (Busan New Port) with respect to each PPI will be demonstrated. However, the obtained results of other ports will be presented. It is noteworthy that the quantitative data used for each port represents an average or sum value of dedicated container terminals: Busan North Port (5 container terminals[7]), Gwangyang Port (3 container terminals), Incheon Port (3 container terminals) and Busan New port (5 container terminals).

6.3.2.1 Throughput volume growth

Based on information and previous discussion, different location measurement techniques can be used for quantitative PPIs. The quantitative assessment grades of the throughput growth is already defined as *{leq 0%, 5%, 10%, 15%, 20%, geq 0%}* (see Table 5.5).

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), geq\ 25\%(H_6)$$

The data of the throughput growth between 2012 and 2013 in 4 alternative container ports is demonstrated in Table 6.2.

Table 6.2 Throughput growth (2012-2013)

Ports	2012	2013	Growth ('12-'13)
Busan North	6,999,903	6,124,253	-12.51%
Gwangyang	2,148,222	2,284,438	6.34%
Incheon	1,120,037	1,232,935	10.08%
Busan New	9,391,528	10,913,634	16.21%

<u>Throughput growth in Busan New Port</u>

The throughput growth in Busan New Port is 16%, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 15\%(H_4), \qquad h_{j,i} = 16.21\%, \qquad h_{j+1,i} = 20\%(H_5)$$

Thus, $B_{j+1,i} = \frac{16.21-15}{20-15} = 0.242$ DoB with $20\%(H_5)$ and $B_{j-1,i} = 1 - 0.242 = 0.758$ DoB with $15\%(H_4)$. Therefore, the throughput growth set in Busan New Port is assessed as follows:

$$H^{TG} = \{(leq\ 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0.758), (20\%, 0.242), (geq\ 25\%, 0)\}$$

In a similar way, the throughput growth sets of other ports are obtained and they are presented as follows (Table 6.3).

[7] UTC (Uam Terminal Co., Ltd) and CJ BECT (Busan East Container Terminal co., Ltd) were integrated in 2014.

Table 6.3 Throughput growth sets

Port	Throughput growth set
Busan North	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
Gwangyang	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0.732), (10\%, 0.268), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
Incheon	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0.16), (15\%, 0.84), (20\%, 0), (geq\ 25\%, 0)\}$
Busan New	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0.758), (20\%, 0.242), (geq\ 25\%, 0)\}$

Other quantitative PPIs to transform DoB for Busan New Port are presented in Appendix V. The transformed DoB sets of the quantitative PPIs for other ports are also summarised in Appendix V.

6.3.2.2 Qualitative PPIs (Busan New Port)

28 assessors from terminal operators in Busan New Port evaluated on the SA, TSCI, SSS and EVS. 213 samples from shipping lines and freight forwarders who have experience in using the terminal services provided by terminal operators in Busan New Port were used for the assessments of the US and TSCI and 30 samples from port authority and government were used for the judgements on SG.

<u>Supporting Activities</u>

Based on Eq. (5.34), the judgement results by a number of assessors can be represented as follows (see Table 6.4). A total of 28 assessors from terminal operators took part in the judgements on supporting activities. Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35) (see Table 6.5).

Table 6.4 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	3	20	5	28
Capability	0	2	10	16	0	28
Training and education opportunity	0	5	10	12	1	28
Commitment and Loyalty	0	0	12	13	3	28
Organisation Capital (OCS)						
Culture	0	1	8	18	1	28
Leadership	0	0	10	12	6	28
Alignment	0	1	12	14	1	28
Teamwork	0	2	9	13	4	28
Information Capital (ICS)						
IT systems	1	2	6	17	2	28
Databases	0	4	9	14	1	28
Networks	0	1	15	11	1	28

Table 6.5 Degrees of belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.11	0.71	0.18	1.00
Capability	0.00	0.07	0.36	0.57	0.00	1.00
Training and education opportunity	0.00	0.18	0.36	0.43	0.04	1.00
Commitment and Loyalty	0.00	0.00	0.43	0.46	0.11	1.00
Organisation Capital (OCS)						
Culture	0.00	0.04	0.29	0.64	0.04	1.00
Leadership	0.00	0.00	0.36	0.43	0.21	1.00
Alignment	0.00	0.04	0.43	0.50	0.04	1.00
Teamwork	0.00	0.07	0.32	0.46	0.14	1.00
Information Capital (ICS)						
IT systems	0.04	0.07	0.21	0.61	0.07	1.00
Databases	0.00	0.14	0.32	0.50	0.04	1.00
Networks	0.00	0.04	0.54	0.39	0.04	1.00

Users' Satisfaction

A total of 210-213 samples from port users were used for the judgements on users' satisfaction (see Table 6.6). Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35) (see Table 6.7).

Table 6.6 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	2	20	67	83	40	212
Responsiveness to special requests	11	12	99	61	27	210
Accuracy of document & information	2	11	62	99	39	213
Incidence of cargo damage	3	18	49	96	47	213
Incidence of service delay	6	10	89	88	20	213
Service Costs (SCU)						
Overall service costs	12	34	79	72	16	213
Cargo handling charges	12	38	90	59	14	213
Cost of terminal ancillary services	13	56	73	60	11	213

Table 6.7 Degrees of belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.01	0.09	0.32	0.39	0.19	1.00
Responsiveness to special requests	0.05	0.06	0.47	0.29	0.13	1.00
Accuracy of document & information	0.01	0.05	0.29	0.46	0.18	1.00
Incidence of cargo damage	0.01	0.08	0.23	0.45	0.22	1.00
Incidence of service delay	0.03	0.05	0.42	0.41	0.09	1.00
Service Costs (SCU)						
Overall service costs	0.06	0.16	0.37	0.34	0.08	1.00
Cargo handling charges	0.06	0.18	0.42	0.28	0.07	1.00
Cost of terminal ancillary services	0.06	0.26	0.34	0.28	0.05	1.00

Terminal Supply Chain Integration

A total of 234-235 samples from terminal operators and port users were used for the judgements on terminal supply chain integration (see Table 6.8). Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35) (see Table 6.9).

Table 6.8 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	6	19	62	112	36	235
Land side connectivity	5	24	63	114	29	235
Reliability of multimodal operations	5	14	69	105	42	235
Efficiency of multimodal operations	7	10	80	103	35	235
Value-Added Services (VAST)						
Facilities for adding value to cargos	14	21	78	105	17	235
Capacity to provide different services	2	17	71	104	41	235
Service adaptation to customers	6	29	60	102	37	234
Tailored services to customers	9	19	72	109	26	235
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	8	78	102	46	235
Integrated IT to share data	0	17	71	108	39	235
Collaborate with channel members	0	15	82	110	28	235
Latest IT in the industry	0	22	69	106	38	235

Table 6.9 Degrees of belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.03	0.08	0.26	0.48	0.15	1.00
Land side connectivity	0.02	0.10	0.27	0.49	0.12	1.00
Reliability of multimodal operations	0.02	0.06	0.29	0.45	0.18	1.00
Efficiency of multimodal operations	0.03	0.04	0.34	0.44	0.15	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargos	0.06	0.09	0.33	0.45	0.07	1.00
Capacity to provide different services	0.01	0.07	0.30	0.44	0.17	1.00
Service adaptation to customers	0.03	0.12	0.26	0.44	0.16	1.00
Tailored services to customers	0.04	0.08	0.31	0.46	0.11	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.03	0.33	0.43	0.20	1.00
Integrated IT to share data	0.00	0.07	0.30	0.46	0.17	1.00
Collaborate with channel members	0.00	0.06	0.35	0.47	0.12	1.00
Latest IT in the industry	0.00	0.09	0.29	0.45	0.16	1.00

Sustainable Growth

A total of 30-61 samples from terminal operators and port administrators were used for the judgements on sustainable growth (see Table 6.10). Then, the measurement can be presented by DoB belonged to linguistic terms based on Eq. (5.35) (see Table 6.11).

Table 6.10 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	2	20	39	61
Formal safety and security training practices	0	1	2	26	32	61
Adequate monitoring and threat awareness	0	1	2	17	41	61
Safety and security officers and facilities	0	0	1	13	47	61
Environment (EVS)						
Carbon footprint	1	9	20	18	13	61
Total water consumption	0	2	10	28	21	61
Total energy consumption	0	0	2	37	22	61
Waste recycling	0	3	20	23	15	61
Environment management programs	0	7	31	9	14	61
Social Engagement (SES)						
Employment	0	0	15	9	6	30
Regional GDP	0	0	6	14	10	30
Disclose of information	0	5	20	5	0	30

Table 6.11 Degrees of beliefs on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.03	0.33	0.64	1.00
Formal safety and security training practices	0.00	0.02	0.03	0.43	0.52	1.00
Adequate monitoring and threat awareness	0.00	0.02	0.03	0.28	0.67	1.00
Safety and security officers and facilities	0.00	0.00	0.02	0.21	0.77	1.00
Environment (EVS)						
Carbon footprint	0.02	0.15	0.33	0.30	0.21	1.00
Total water consumption	0.00	0.03	0.16	0.46	0.34	1.00
Total energy consumption	0.00	0.00	0.03	0.61	0.36	1.00
Waste recycling	0.00	0.05	0.33	0.38	0.25	1.00
Environment management programs	0.00	0.11	0.51	0.15	0.23	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.50	0.30	0.20	1.00
Regional GDP	0.00	0.00	0.20	0.47	0.33	1.00
Disclose of information	0.00	0.17	0.67	0.17	0.00	1.00

The evaluations of the qualitative PPIs for other container ports are demonstrated in Appendix V. For further information, please refer to Appendix V.

6.3.3 Mapping process –Transform the evaluation from the lowest level PPIs to top level PPI.

In this section, the mapping process from the transformed degrees of belief (DoB) sets of the bottom level PPIs to their associated upper level principal-PPIs is demonstrated. The same fuzzy rules base belief structures in Table 5.38 - Table 5.48 are used for the mapping process. However, this chapter only demonstrates the results of mapping process in order to avoid duplication of the ones in Chapter 5. For further information, please refer to Chapter 5.

6.3.3.1 Mapping to output

Throughput growth to output

Table 6.12 Mapping results from throughput growth to output

Port	Throughput growth sets				
Busan North	$H^{throughput}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (*geq* 25%, 0)}				
Gwangyang	$H^{throughput}$ = {(leq 0%, 0), (5%, 0.732), (10%, 0.268), (15%, 0), (20%, 0), (*geq* 25%, 0)}				
Incheon	$H^{throughput}$ = {(leq 0%, 0), (5%, 0), (10%, 0.16), (15%, 0.84), (20%, 0), (*geq* 25%, 0)}				
Busan New	$H^{throughput}$ = {(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0.758), (20%, 0.242), (*geq* 25%, 0)}				
Throughput growth to Output	Very Low	Low	Medium	High	Very High
Busan North	1	0	0	0	0
Gwangyang	0.183	0.683	0.134	0	0
Incheon	0	0.08	0.5	0.42	0
Busan New	0	0	0.379	0.5605	0.0605

Vessel capacity growth to output

Table 6.13 Mapping results from vessel capacity growth to output

Port	Vessel call size growth				
Busan North	$H^{capacity}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (*geq* 20%, 0)}				
Gwangyang	$H^{capacity}$ = {(leq 0%, 0), (5%, 0), (10%, 0.816), (15%, 0.184), (*geq* 20%, 0)}				
Incheon	$H^{capacity}$ = {(leq 0%, 0.025), (5%, 0.975), (10%, 0), (15%, 0), (*geq* 20%, 0)}				
Busan New	$H^{capacity}$ = {(leq 0%, 0), (5%, 0.298), (10%, 0.702), (15%, 0), (*geq* 20%, 0)}				
Vessel capacity growth to Output	Very Low	Low	Medium	High	Very High
Busan North	1	0	0	0	0
Gwangyang	0	0.204	0.408	0.342	0.046
Incheon	0.269	0.731	0	0	0
Busan New	0	0.399	0.351	0.176	0

6.3.3.2 Mapping to productivity

Table 6.14 Mapping results from ship load rate to productivity

Port	Ship load rate				
Busan North	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0), (70TEU, 0.221), (85TEU, 0.779), (geq 100TEU, 0)}				
Gwangyang	$H^{loadrate}$ = {(leq 25TEU, 1), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}				
Incheon	$H^{loadrate}$ = {(leq 25TEU, 0.529), (40TEU, 0.471), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}				
Busan New	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0.645), (55TEU, 0.355), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}				
Ship load rate to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0	0	0.1105	0.6948	0.1948
Gwangyang	1	0	0	0	0
Incheon	0.6468	0.3533	0	0	0
Busan New	0.1613	0.6613	0.1775	0	0

Berth utilisation to productivity

Table 6.15 Mapping results from berth utilisation to productivity

Port	Berth utilization				
Busan North	$H^{berth\ U} = \{(\text{leq } 300TEU, 0), (600TEU, 0), (900TEU, 0.4), (1200TEU, 0.6), (1500TEU, 0), (\text{geq } 1800TEU, 0)\}$				
Gwangyang	$H^{berth\ U} = \{(\text{leq } 300TEU, 0), (600TEU, 0.943), (900TEU, 0.057), (1200TEU, 0), (1500TEU, 0), (\text{geq } 1800TEU, 0)\}$				
Incheon	$H^{berth\ U} = \{(\text{leq } 300TEU, 0), (600TEU, 0), (900TEU, 0.243), (1200TEU, 0.757), (1500TEU, 0), (\text{geq } 1800TEU, 0)\}$				
Busan New	$H^{berth\ U} = \{(\text{leq } 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0.69), (\text{geq } 1800TEU, 0.31)\}$				
Berth utilisation to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0	0.2	0.5	0.3	0
Gwangyang	0.2358	0.7358	0.0285	0	0
Incheon	0	0.1215	0.5	0.3785	0
Busan New	0	0	0	0.5175	0.4825

Berth occupancy rate to productivity

Table 6.16 Mapping results from berth occupancy rate to productivity

Port	Berth occupancy				
Busan North	$H^{berth\ O} = \{(\text{leq } 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (\text{geq } 80\%, 0)\}$				
Gwangyang	$H^{berth\ O} = \{(\text{leq } 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (\text{geq } 80\%, 0)\}$				
Incheon	$H^{berth\ O} = \{(\text{leq } 45\%, 0), (50\%, 1), (55\%, 0), (60 - 80\%, 0), (\text{geq } 80\%, 0)\}$				
Busan New	$H^{berth\ O} = \{(\text{leq } 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (\text{geq } 80\%, 0)\}$				
Berth occupancy rate to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0	0	0	0	1
Gwangyang	1	0	0	0	0
Incheon	0.25	0.75	0	0	0
Busan New	1	0	0	0	0

Crane efficiency to productivity

Table 6.17 Mapping results from crane efficiency to productivity

Port	Crane efficiency				
Busan North	$H^{crane} = \{(\text{leq } 20moves, 0), (25moves, 0), (30moves, 0.32), (35moves, 0.68), (40moves, 0), (\text{geq } 45moves, 0)\}$				
Gwangyang	$H^{crane} = \{(\text{leq } 20moves, 0), (25moves, 0), (30moves, 0.4), (35moves, 0.6), (40moves, 0), (\text{geq } 45moves, 0)\}$				
Incheon	$H^{crane} = \{(\text{leq } 20moves, 0), (25moves, 0), (30moves, 0.4), (35moves, 0.6), (40moves, 0), (\text{geq } 45moves, 0)\}$				
Busan New	$H^{crane} = \{(\text{leq } 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 1), (40moves, 0), (\text{geq } 45moves, 0)\}$				
Crane efficiency to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0	0.16	0.5	0.34	0
Gwangyang	0	0.2	0.5	0.3	0
Incheon	0	0.2	0.5	0.3	0
Busan New	0	0	0.5	0.5	0

Yard utilisation to productivity

Table 6.18 Mapping results from yard utilisation to productivity

Port	Yard utilization				
Busan North	$H^{yard} = \{(leq\ 2TEU, 0.35), (4TEU, 0.65), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$				
Gwangyang	$H^{yard} = \{(leq\ 2TEU, 0.9), (4TEU, 0.1), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$				
Incheon	$H^{yard} = \{(leq\ 2TEU, 0.95), (4TEU, 0.05), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$				
Busan New	$H^{yard} = \{(leq\ 2TEU, 0), (4TEU,), (6TEU, 0.65), (8TEU, 0.35), (geq\ 10TEU, 0)\}$				
Yard utilisation to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0.513	0.488	0	0	0
Gwangyang	0.925	0.075	0	0	0
Incheon	0.963	0.038	0	0	0
Busan New	0	0.163	0.325	0.425	0.088

Labour utilisation to productivity

Table 6.19 Mapping results from labour utilisation to productivity

Port	Labour utilization
Busan North	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.702), (4000TEU, 0.298), (5000TEU, 0), (geq 6000TEU, 0)}
Gwangyang	-
Incheon	-
Busan New	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.271), (4000TEU, 0.729), (5000TEU, 0), (leq 6000TEU, 0)}

Labour utilisation to Productivity	Very Low	Low	Medium	High	Very High
Busan North	0	0.351	0.5	0.149	0
Gwangyang	-	-	-	-	-
Incheon					
Busan New	0	0.1355	0.5	0.3645	0

6.3.3.3 Mapping to lead-time

Vessel turnaround to lead-time

Table 6.20 Mapping results from vessel turnaround to lead-time

Port	Vessel turnaround time
Busan North	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Gwangyang	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Incheon	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Busan New	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}

Vessel turnaround to Lead-time	Very Low	Low	Medium	High	Very High
Busan North	0	0	0	0	1
Gwangyang	0	0	0	0	1
Incheon	0	0	0	0	1
Busan New	0	0	0	0	1

Truck turnaround to lead-time

Table 6.21 Mapping results from truck turnaround to lead-time

Port	Truck turnaround time
Busan North	$H^{truck\ T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.84), (leq 15mins, 0.16)}
Gwangyang	$H^{truck\ T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.36), (20mins, 0.64), (leq 15mins, 0)}
Incheon	$H^{truck\ T}$ = {(geq 40mins, 0), (35mins, 0.5), (30mins, 0.5), (25mins, 0), (20mins, 0), (leq 15mins, 0)}
Busan New	$H^{truck\ T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0), (leq 15mins, 1)}

Truck turnaround to Lead-time	Very Low	Low	Medium	High	Very High
Busan North	0	0	0	0.63	0.37
Gwangyang	0	0	0.18	0.66	0.16
Incheon	0.125	0.625	0.25	0	0
Busan New	0	0	0	0	1

Container dwell time to lead-time

Table 6.22 Mapping results from container dwell time to lead-time

Port	Container dwell time
Busan North	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.55), (leq 3days, 0.45)}
Gwangyang	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.45), (5days, 0.55), (leq 3days, 0)}
Incheon	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.9), (leq 3days, 0.1)}
Busan New	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.45), (leq 3days, 0.55)}

Container dwell time to Lead-time	Very Low	Low	Medium	High	Very High
Busan North	0	0	0	0.4125	0.5875
Gwangyang	0	0	0.225	0.6375	0.1375
Incheon	0	0	0	0.675	0.325
Busan New	0	0	0	0.3375	0.6625

6.3.3.4 Mapping to profitability

Revenue growth to profitability

Table 6.23 Mapping results from revenue growth to profitability

Port	Revenue growth				
Busan North	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}				
Gwangyang	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0.815), (8%, 0.185), (geq 10%, 0)}				
Incheon	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 1)}				
Busan New	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 1)}				
Revenue growth to Profitability	Very Low	Low	Medium	High	Very High
Busan North	1	0	0	0	0
Gwangyang	0	0	0.4075	0.5463	0.0463
Incheon	0	0	0	0	1
Busan New	0	0	0	0	1

Operating margin to profitability

Table 6.24 Mapping results from operating margin to profitability

Port	Operating profit margin				
Busan North	$H^{operating\ M}$ = {(leq 0%, 1), (10%, 0), (15%, 0), (20%, 0), (25%, 0), (geq 30%, 0)}				
Gwangyang	$H^{operating\ M}$ = {(leq 0%, 1), (10%, 0), (15%, 0), (20%, 0), (25%, 0), (geq 30%, 0)}				
Incheon	$H^{operating\ M}$ = {(leq 0%, 0), (10%, 0), (15%, 0.54), (20%, 0.46), (25%, 0), (geq 30%, 0)}				
Busan New	$H^{operating\ M}$ = {(leq 0%, 0), (10%, 0), (15%, 0), (20%, 0.812), (25%, 0.188), (geq 30%, 0)}				
Operating margin to Profitability	Very Low	Low	Medium	High	Very High
Busan North	1	0	0	0	0
Gwangyang	1	0	0	0	0
Incheon	0	0.27	0.5	0.23	0
Busan New	0	0	0.406	0.547	0.047

Net margin to profitability

Table 6.25 Mapping results from net margin to profitability

Port	Net profit margin				
Busan North	$H^{net\ M}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}				
Gwangyang	$H^{net\ M}$ = {(leq 0%, 0.332), (5%, 0.668), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}				
Incheon	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.72), (15%, 0.28), (20%, 0), (geq 25%, 0)}				
Busan New	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.798), (15%, 0.202), (20%, 0), (geq 25%, 0)}				
Net margin to Profitability	Very Low	Low	Medium	High	Very High
Busan North	1	0	0	0	0
Gwangyang	0.499	0.501	0	0	0
Incheon	0	0.36	0.5	0.14	0
Busan New	0	0.399	0.5	0.101	0

6.3.3.5 Mapping to liquidity and solvency

Current ratio to liquidity and solvency

Table 6.26 Mapping results from current ratio to liquidity and solvency

Port	Current ratio
Busan North	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
Gwangyang	$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
Incheon	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
Busan New	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$

Current ratio to Liquidity and Solvency	Very Low	Low	Medium	High	Very High
Busan North	1	0	0.25	0.5	0.25
Gwangyang	0.25	0.5	0.25	0	0
Incheon	0	0	0.25	0.5	0.25
Busan New	0	0	0.25	0.5	0.25

Debt to total assets to liquidity and solvency

Table 6.27 Mapping results from debt to total assets to liquidity and solvency

Port	Debt to total assets sets
Busan North	$H^{DA} = \{(geq\ 0.5{,}0), (leq\ 0.5, 1)\}$
Gwangyang	$H^{DA} = \{(geq\ 0.5{,}0), (leq\ 0.5, 1)\}$
Incheon	$H^{DA} = \{(geq\ 0.5{,}1), (leq\ 0.5, 0)\}$
Busan New	$H^{DA} = \{(geq\ 0.5{,}0), (leq\ 0.5, 1)\}$

Debt to assets to Liquidity and Solvency	Very Low	Low	Medium	High	Very High
Busan North	0	0	0.25	0.25	0.5
Gwangyang	0	0	0.25	0.25	0.5
Incheon	0.25	0.5	0.25	0	0
Busan New	0	0	0.25	0.25	0.5

Debt to equity to liquidity and solvency

Table 6.28 Mapping results from debt to equity to liquidity and solvency

Port	Debt to owner's equity
Busan North	$H^{DE} = \{(geq\ 2{,}0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
Gwangyang	$H^{DE} = \{(geq\ 2{,}1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$
Incheon	$H^{DE} = \{(geq\ 2{,}0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
Busan New	$H^{DE} = \{(geq\ 2{,}1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$

Debt to equity to Liquidity and Solvency	Very Low	Low	Medium	High	Very High
Busan North	0	0	0	0	1
Gwangyang	1	0	0	0	0
Incheon	0	0	0	0	1
Busan New	1	0	0	0	0

6.3.3.6 Qualitative PPIs (Busan New Port)

In this section, Busan New port is demonstrated as an example case. The other alternative ports are presented in Appendix VI. For further information, please refer to Appendix VI.

Mapping to human capital

Table 6.29 Results of mapping to human capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Knowledge and skills	0.00	0.00	0.11	0.71	0.18
Capability	0.00	0.07	0.36	0.57	0.00
Training and education opportunity	0.00	0.18	0.36	0.43	0.04
Commitment and Loyalty	0.00	0.00	0.43	0.46	0.11
Mapping to Human Capital					
Knowledge and skills	0.000	0.028	0.055	0.560	0.358
Capability	0.018	0.143	0.180	0.518	0.143
Training and education opportunity	0.045	0.225	0.180	0.413	0.148
Commitment and Loyalty	0.000	0.108	0.215	0.453	0.225

Mapping to organisational capital

Table 6.30 Results of mapping to organisational capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Culture	0.00	0.04	0.29	0.64	0.04
Leadership	0.00	0.00	0.36	0.43	0.21
Alignment	0.00	0.04	0.43	0.50	0.04
Teamwork	0.00	0.07	0.32	0.46	0.14
Mapping to Organisation Capital					
Culture	0.010	0.103	0.145	0.553	0.200
Leadership	0.000	0.090	0.180	0.413	0.318
Alignment	0.010	0.138	0.215	0.483	0.165
Teamwork	0.018	0.133	0.160	0.425	0.255

Mapping to information capital

Table 6.31 Results of mapping to information capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
IT systems	0.04	0.07	0.21	0.61	0.07
Databases	0.00	0.14	0.32	0.50	0.04
Networks	0.00	0.04	0.54	0.39	0.04
Mapping to Information Capital					
IT systems	0.058	0.105	0.105	0.510	0.223
Databases	0.035	0.185	0.160	0.455	0.165
Networks	0.010	0.165	0.270	0.428	0.138

Mapping to service fulfilment

Table 6.32 Results of mapping to service fulfilment

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service reliability	0.00	0.12	0.37	0.42	0.10
Responsiveness to special requests	0.01	0.10	0.45	0.38	0.06
Accuracy of document & information	0.00	0.17	0.33	0.37	0.13
Incidence of cargo damage	0.00	0.17	0.38	0.42	0.04
Incidence of service delay	0.01	0.17	0.39	0.30	0.13
Mapping to Service Fulfilment					
Overall service reliability	0.030	0.183	0.185	0.408	0.205
Responsiveness to special requests	0.035	0.188	0.225	0.398	0.155
Accuracy of document & information	0.043	0.210	0.165	0.360	0.223
Incidence of cargo damage	0.043	0.223	0.190	0.410	0.145
Incidence of service delay	0.053	0.225	0.195	0.323	0.205

Mapping to service costs

Table 6.33 Results of mapping to service costs

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service costs	0.00	0.13	0.55	0.20	0.12
Cargo handling charges	0.01	0.12	0.46	0.33	0.07
Cost of terminal ancillary services	0.00	0.24	0.37	0.30	0.10
Mapping to Service Costs					
Overall service costs	0.033	0.235	0.275	0.288	0.170
Cargo handling charges	0.040	0.205	0.230	0.363	0.153
Cost of terminal ancillary services	0.060	0.273	0.185	0.318	0.175

Mapping to intermodal transport systems

Table 6.34 Results of mapping to intermodal transport systems

PPIs	Very Poor	Poor	Medium	Good	Very Good
Sea side connectivity	0.03	0.08	0.26	0.48	0.15
Land side connectivity	0.02	0.10	0.27	0.49	0.12
Reliability of multimodal operations	0.02	0.06	0.29	0.45	0.18
Efficiency of multimodal operations	0.03	0.04	0.34	0.44	0.15
Mapping to Intermodal Transport Systems					
Sea side connectivity	0.050	0.125	0.130	0.425	0.270
Land side connectivity	0.045	0.143	0.135	0.435	0.243
Reliability of multimodal operations	0.035	0.118	0.145	0.410	0.293
Efficiency of multimodal operations	0.040	0.115	0.170	0.415	0.260

Mapping to value-added services

Table 6.35 Results of mapping to value-added services

PPIs	Very Poor	Poor	Medium	Good	Very Good
Facilities for adding value to cargos	0.06	0.09	0.33	0.45	0.07
Capacity to handle different types of cargo	0.01	0.07	0.30	0.44	0.17
Service adaptation to customers	0.03	0.12	0.26	0.44	0.16
Tailored services to customers	0.04	0.08	0.31	0.46	0.11
Mapping to Value-Added Services					
Facilities for adding value to cargos	0.083	0.150	0.165	0.420	0.183
Capacity to handle different types of cargo	0.028	0.128	0.150	0.405	0.280
Service adaptation to customers	0.060	0.155	0.130	0.395	0.270
Tailored services to customers	0.060	0.138	0.155	0.423	0.225

Mapping to information/communication integration

Table 6.36 Results of mapping to information/communication integration

PPIs	Very Poor	Poor	Medium	Good	Very Good
Integrated EDI for communication	0.00	0.03	0.33	0.43	0.20
Integrated IT to share data	0.00	0.07	0.30	0.46	0.17
Collaborate with channel members	0.00	0.06	0.35	0.47	0.12
Latest IT in the industry	0.00	0.09	0.29	0.45	0.16
Mapping to Information/Communication Integration					
Integrated EDI for communication	0.008	0.105	0.165	0.405	0.308
Integrated IT to share data	0.018	0.128	0.150	0.420	0.285
Collaborate with channel members	0.015	0.133	0.175	0.440	0.238
Latest IT in the industry	0.023	0.140	0.145	0.410	0.273

Mapping to safety and security

Table 6.37 Results of mapping to safety and security

PPIs	Very Poor	Poor	Medium	Good	Very Good
Identifying restricted areas and access control	0.00	0.00	0.03	0.33	0.64
Formal safety and security training practices	0.00	0.02	0.03	0.43	0.52
Adequate monitoring and threat awareness	0.00	0.02	0.03	0.28	0.67
Safety and security officers and facilities	0.00	0.00	0.02	0.21	0.77
Mapping to Safety and Security					
Identifying restricted areas and access control	0.000	0.008	0.015	0.255	0.723
Formal safety and security training practices	0.005	0.023	0.015	0.330	0.628
Adequate monitoring and threat awareness	0.005	0.023	0.015	0.218	0.740
Safety and security officers and facilities	0.000	0.005	0.010	0.163	0.823

Mapping to environment

Table 6.38 Results of mapping to environment

PPIs	Very Poor	Poor	Medium	Good	Very Good
Carbon footprint	0.02	0.15	0.33	0.30	0.21
Total water consumption	0.00	0.03	0.16	0.46	0.34
Total energy consumption	0.00	0.00	0.03	0.61	0.36
Waste recycling	0.00	0.05	0.33	0.38	0.25
Environment management programs	0.00	0.11	0.51	0.15	0.23
Mapping to Environment					
Carbon footprint	0.058	0.195	0.165	0.308	0.285
Total water consumption	0.008	0.063	0.080	0.385	0.455
Total energy consumption	0.000	0.008	0.015	0.465	0.513
Waste recycling	0.013	0.120	0.165	0.368	0.345
Environment management programs	0.028	0.210	0.255	0.240	0.268

Mapping to social engagement

Table 6.39 Results of mapping to social engagement

PPIs	Very Poor	Poor	Medium	Good	Very Good
Employment	0.00	0.00	0.50	0.30	0.20
Regional GDP	0.00	0.00	0.20	0.47	0.33
Disclose of information	0.00	0.17	0.67	0.17	0.00
Mapping to Social Engagement					
Employment	0.000	0.125	0.250	0.350	0.275
Regional GDP	0.000	0.050	0.100	0.403	0.448
Disclose of information	0.043	0.295	0.335	0.295	0.043

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

6.3.4.1 Identification of 6 dimensions' interdependency using DEMATEL

The ten experts (i.e. port stakeholders, academia and government)[8] were asked to determine the interdependency among six dimensions. The initial direct-relation $6 \times 6\, matrix\, Z$ is obtained using Eq. (6.1) by pairwise comparisons in terms of influences and directions as shown in Table 6.40. Then, the normalised direct-relation matrix D is calculated by Eq. (6.2). The maximum value of the sums of each row and column is identified as 13.5 which can be used to obtain the normalised direct-relation matrix D as shown in Table 6.41.

The total-relation matrix T and sum of influence given and received by each dimension are obtained by Eqs. (6.3)-(6.4) (Table 6.42). A threshold value of 0.82 (=$29.63/36$) is calculated using Eq. (6.5). Based on threshold value, the diagraph of the 6 dimensions is shown in Figure 6.3.

Derived from the results of interdependency among the six dimensions, core activities are affected by all dimensions and itself (inner dependency) as well as affecting all dimensions including itself. Supporting activities are influenced by core activities, financial strength, user satisfaction and terminal supply chain integration while financial strength is affected by core activities, supporting activities and user satisfaction. User satisfaction is affected by core activities, supporting activities and terminal supply chain integration. Terminal supply chain integration is affected by core activities and supporting activities. Lastly, sustainable growth is affected by core activities and supporting activities and financial strength.

In terms of pr_i^+ (factors importance), core activities are the most important dimension, followed by supporting activities and users' satisfaction. On top of that, core activities, supporting activities and terminal supply chain integration are identified as cause dimensions (i.e. positive pr_i^- value) while financial strength, users' satisfaction and sustainable growth are classified in effect dimensions (i.e. negative pr_i^- value). This classification is fully or partially in line with previous studies. The literature on port performance measurement has used a technical or physical container terminal specification such as berth length, terminal area, number of cranes in berth and yard, labour, transport modes' turnaround as input data to measure efficiency and productivity of the container port industry (Tongzon, 1995a, Cullinane and Song, 2003, Cullinane and Wang, 2006b). Tangible and intangible resources such as

[8] The same panel of the experts in the previous survey (in Chapter 3) participated in the judgements.

human resources, information/ communication technology and organisational values cannot be overlooked as cause factors to investigate a 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 investments 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 outcomes are driven by a series of value creation activities. Hence, there is no doubt that the CA, SA and TSCI are belonging to cause factors while FS and US are effect factors. Therefore, the DEMATEL model is verified by both contents and technical validity.

Table 6.40 The initial influence matrix (6 dimensions)

	CA	SA	FS	US	TSCI	SG	SUM
CA	0	2.40	2.70	3.80	2.50	2.10	**13.5**
SA	2.30	0	2.30	2.70	2.40	2.20	11.9
FS	2.00	2.30	0	1.60	1.70	3.10	10.7
US	2.70	2.40	2.20	0	2.20	1.70	11.2
TSCI	2.20	2.20	2.10	2.20	0	1.70	10.4
SG	2.90	2.40	1.50	1.20	1.40	0	9.4
SUM	12.1	11.7	10.8	11.5	10.2	10.8	

Table 6.41 The normalised direct-relation matrix (6 dimensions)

	CA	SA	FS	US	TSCI	SG
CA	0	0.18	0.20	0.28	0.19	0.16
SA	0.17	0	0.17	0.20	0.18	0.16
FS	0.15	0.17	0	0.12	0.13	0.23
US	0.20	0.18	0.16	0	0.16	0.13
TSCI	0.16	0.16	0.16	0.16	0	0.13
SG	0.21	0.18	0.11	0.09	0.10	0

Table 6.42 The total influence matrix (6 dimensions)

	CA	SA	FS	US	TSCI	SG	R_i	pr_i^+	pr_i^-
CA	**0.88**	**1.01**	**0.97**	**1.08**	**0.92**	**0.93**	5.80	11.07	0.53
SA	**0.94**	0.77	**0.87**	**0.93**	**0.84**	**0.86**	5.19	10.32	0.07
FS	**0.85**	**0.84**	0.65	0.80	0.73	**0.84**	4.70	9.50	-0.10
US	**0.92**	**0.89**	**0.83**	0.74	0.80	0.80	4.98	10.08	-0.12
TSCI	**0.85**	**0.83**	0.78	**0.83**	0.61	0.75	4.65	9.22	0.08
SG	**0.83**	0.79	0.70	0.73	0.67	0.59	4.31	9.09	-0.46
C_j	5.27	5.12	4.80	5.10	4.57	4.77	29.63(sum)		

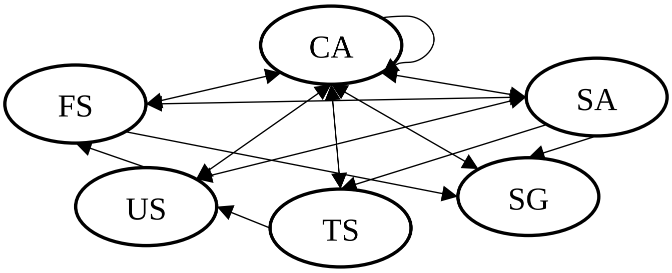

Figure 6.3 Interdependency between 6 dimensions

6.3.4.2 Identification of 16 principal-PPIs' interdependency using DEMATEL

Based on the direct influence matrix, the experts [9] were asked to determine the interdependency among the 16 principal-PPIs. The same process is carried out to obtain a direct influence matrix for principal-PPIs. The initial direct-relation $16 \times 16\ matrix\ Z$ is obtained using Eq. (6.1) by pairwise comparisons in terms of influences and directions as shown in Table 6.43. It is noteworthy that a zero value is given in the matrix when there are no influences involving the investigated pairs because no pairwise comparisons are conducted. Then, the normalised direct-relation matrix D is calculated by Eq. (6.2). The maximum value of the sums of each row and column is calculated as 37.63, which can be used to obtain the normalised direct-relation matrix D as shown in Table 6.44. The total-relation matrix T and sum of influence given and received by each principal-PPI are obtained by Eqs. (6.3)-(6.4) (Table 6.45). A threshold value of 0.11 (=$29/256$) is calculated using Eq. (6.5). Based on threshold value, the diagraph of the 16 principal-PPIs can be presented (Figure 6.4).

Amongst 16 principal-PPIs (i.e. the highest pr_i^+values), productivity, output and lead-time in core activities are found to be the most influential whilst environment and social engagement are the least influential principal-PPI. On top of that, output can be improved particularly by improving productivity, lead-time, information capital, human capital, organisational capital and service fulfilment, as shown by the highest values in Table 6.45. Productivity is mainly affected by lead-time, output, information capital, human capital, organisational capital, service fulfilment and information & communication integration. Lead-time is supported by productivity, information capital, output and information & communication integration. Service fulfilment is particularly influenced by lead-time, productivity, output, information capital and organisational capital. Human capital, organisational capital and information capital

[9] The 8 experts (2 terminal operators, 1 liner, 1 forwarder, 2 academia and 2 governments) from among the 10 experts in the previous survey responded in this survey. The other two experts showed the lack of confidence to determine the interdependency among the 16 principal-PPIs.

are affected by principal-PPIs in core activities, users' satisfaction and terminal supply chain integration. Service costs are influenced by productivity, lead-time, output, human capital and information capital.

In terms of pr_i^+ (factors importance), productivity is the most important principal-PPI, followed by lead-time, output, information capital, human capital, organisational capital, service fulfilment and service costs. In terms of pr_i^- values, productivity, lead-time, human capital, organisational capital, information capital, intermodal transport systems, value-added services and information/communication integration are classified in causal factors while output, profitability, liquidity and solvency, service fulfilment, service costs, safety and security, environment and social engagement belong to the effect factors.

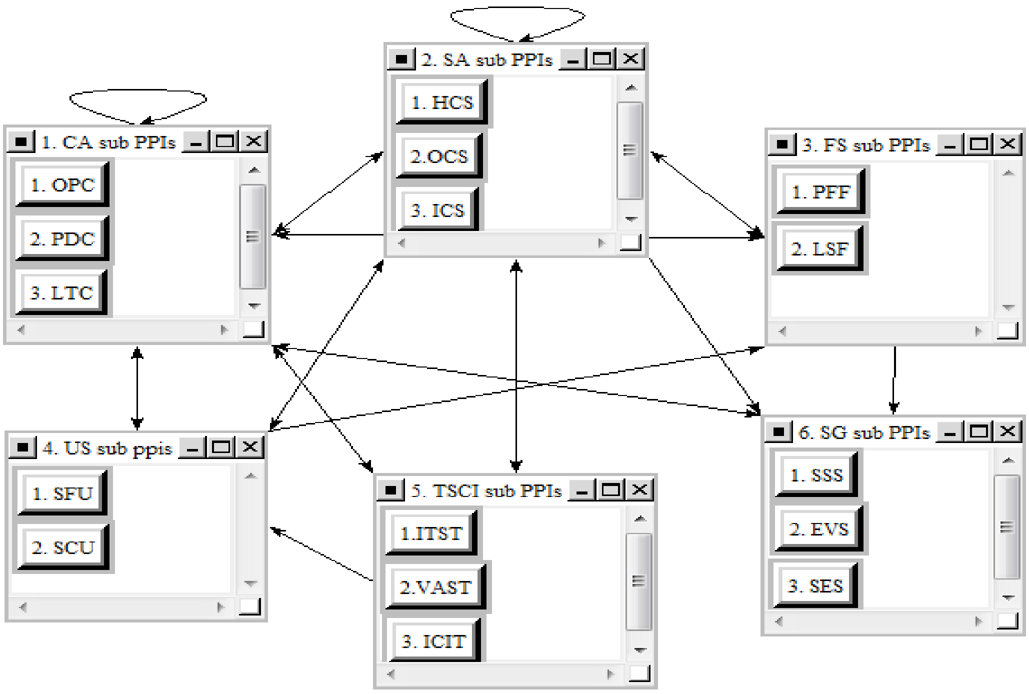

Figure 6.4 Interdependency between 16 principal-PPIs
Source: Created by Author using the super decisions software

Table 6.43 The initial influence matrix (16 principal-PPIs)

		CA			SA			FS		US		TSCI			SG			SUM
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES	
CA	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	36.00
	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	**37.63**
	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	37.38
SA	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	31.63
	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	30.88
	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	32.25
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	19.63
	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	19.63
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	22.13
	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	19.38
TSCI	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	19.88
	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	18.25
	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	21.88
SG	SSS	2.25	2.50	2.75	0	0	0	0	0	0	0	0	0	0	0	0	0	7.50
	EVS	1.50	1.75	1.63	0	0	0	0	0	0	0	0	0	0	0	0	0	4.88
	SES	1.38	1.38	1.38	0	0	0	0	0	0	0	0	0	0	0	0	0	4.13
SUM		37.00	37.13	37.13	23.13	23.00	25.38	20.88	18.63	25.50	22.88	13.88	13.00	15.13	17.75	16.50	16.13	

Table 6.44 The normalised direct-relation matrix (16 principal-PPIs)

		CA			SA			FP		US		TSCI			SG		
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
CA	OPC	0	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.07	0.08	0.06	0.05	0.06	0.06	0.05	0.05
	PDC	0.09	0	0.09	0.07	0.07	0.07	0.07	0.06	0.07	0.08	0.07	0.05	0.06	0.05	0.05	0.05
	LTC	0.08	0.08	0	0.06	0.06	0.07	0.07	0.05	0.09	0.08	0.07	0.05	0.07	0.06	0.05	0.04
SA	HCS	0.07	0.08	0.07	0	0	0	0.06	0.06	0.07	0.06	0.05	0.07	0.07	0.07	0.06	0.05
	OCS	0.07	0.07	0.07	0	0	0	0.07	0.06	0.08	0.06	0.06	0.06	0.07	0.06	0.05	0.05
	ICS	0.08	0.09	0.09	0	0	0	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.07	0.05	0.04
FP	PFF	0.05	0.05	0.05	0.06	0.06	0.06	0	0	0	0	0	0	0	0.06	0.06	0.08
	LSF	0.05	0.05	0.05	0.06	0.06	0.06	0	0	0	0	0	0	0	0.06	0.07	0.07
US	SFU	0.08	0.08	0.07	0.07	0.08	0.08	0.07	0.07	0	0	0	0	0	0	0	0
	SCU	0.08	0.08	0.07	0.04	0.04	0.04	0.08	0.08	0	0	0	0	0	0	0	0
TSCI	ITST	0.08	0.06	0.08	0.06	0.06	0.08	0	0	0.07	0.05	0	0	0	0	0	0
	VAST	0.06	0.06	0.05	0.05	0.05	0.06	0	0	0.07	0.07	0	0	0	0	0	0
	ICIT	0.07	0.07	0.08	0.07	0.06	0.09	0	0	0.08	0.06	0	0	0	0	0	0
SG	SSS	0.06	0.07	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0
	EVS	0.04	0.05	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
	SES	0.04	0.04	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.45 The total influence matrix (16 principal-PPIs)

		CA			**SA**			**FP**		**US**		**TSCI**			**SG**					
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES	R_i	pr_i^+	pr_i^-
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	5.47	-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	5.63	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	5.59	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	4.14	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	4.08	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	4.41	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	3.23	-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	3.04	-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	3.97	-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	3.52	-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	3.04	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	2.75	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	3.31	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	2.24	-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	1.86	-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	1.74	-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	29.00(sum)		

6.3.4.3 Interdependent weighting assignments using ANP[10]

After determining interdependent relationships between principal-PPIs, the ANP method is used to obtain the final adjusted weights (i.e. global weights). Based on Table 6.42 - Table 6.45, the experts[11] are asked to respond questions, for example, "which dimension influences 'core activities (CA)' more: 'supporting activities (SA)' or 'financial strength (FS)'? and how much more?" for dimensions, and "which PPI influences 'productivity' more: 'output' or 'lead-time'? and how much more?" for principal-PPIs. In terms of this process, a number of comparison matrices can be formed. First, interdependent matrices for six dimensions are derived as follows (Table 6.46-Table 6.50). The weights obtained in each table are placed in each column in Table 6.51. Zero value represents no interdependency between dimensions.

Similarly, the interdependent matrix of sixteen principal-PPIs can be obtained (i.e. unweighted super matrix, Table 6.52). The values in Table 6.51 can be used to weight the unweighted super matrix by multiplying the value in the (CA, CA) cell in Table 6.51 times the value in each cell in the (CA (OPC, PDC, LTC), CA (OPC, PDC, LTC)) component of the unweighted super matrix (Table 6.52) to produce the weighted super matrix (Table 6.53). For instance, the weighted value 0.08 in OPC, OPC cell (Table 6.53) can be obtained by 0.27 (value in CA, CA cell, Table 6.51) × 0.31 (value in OPC, OPC cell, Table 6.52). Every component can be weighted with its corresponding weight in the dimension matrix in the same way. However, the sum of columns for some principal-PPIs (i.e. HCS, OCS and PFF) is not equal to one, thus the weighted super matrix needs to be normalised.

By calculating the limiting power of the weighted super matrix a limited super matrix can be generated using $W^{\infty} = \lim_{k\to\infty} W^k$ (Table 6.55). This was obtained using super decisions software (http://www.superdecisions.com/). The results in the limited super matrix can be used as global weights of sixteen principal PPIs. 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, mode turnaround time and labour productivity, competency of information technology are important criteria for port performance measurement. However, being cost and price competitive is

[10] If the outcomes from DEMATEL analysis show no strong dependency among the PPIs the model presented in chapter 5 will be used.
[11] 4 experts (1 terminal operator, 1 shipping line, 1 forwarder, 1 academic) from among the 10 experts have verified with the CR of 0.10 or less, which is sufficient to provide a reasonable ANP outcome (Büyüközkan et al., 2012).

crucial but not sufficient for port performance measurement (0.05). This finding is 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 and hinterland connectivity (Chang *et al*., 2008, Yeo *et al*., 2008, Monios and Wilmsmeier, 2012). 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 to sustain themselves in a highly competitive environment.

The final step is to obtain local weights of 60 PPIs that are obtained by AHP in chapter 5. For further information, please refer to section 5.4.4. The global weights of 60 PPIs at the bottom level are demonstrated in Table 6.56 and Figure 6.5. 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), IT systems (ICS 1, 0.036), networks (ICS 3, 0.033), database (ICS 2, 0.029), net profit margin (PFF3, 0.028) and operating profit margin (PFF2, 0.026). In the contrast, 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 top 10 rank PPIs in the ANP results include four PPIs under core activities (CA), three PPIs under supporting activities (SA), two PPIs under financial strength and one PPIs under users' satisfaction (US).

The ANP results are mostly dependent on the interdependent relationships between principal-PPIs/dimensions. For instance, SA is an effect dimension that is affected by CA, FP, US and TSCI, at the same time SA is a cause dimension that has an effect on CA, FS, US, TSCI and SG. While FP is affected by CA, SA and US and simultaneously influences on CA, SA and SG. Hence, SA is more influential dimension than FS, leading to higher global weights of its associated PPIs than FS's. The ANP findings denote that, on the one hand, the internal activities of container terminal operators such as cargo operations in berth and yard, competency on port equipment and information technology are important criteria for port performance measurement. On top of that, the internal effectiveness factors such as financial performance are also crucial criteria. On the other hand, the importance of the external effectiveness factors with regard to customer satisfaction cannot be overlooked. The strong internal competency leads to the high customer' satisfactions, which is in line with Brooks and Schellinck (2013) argument.

Using an integrated method of DEMATEL and ANP, this chapter identified PPIs' interdependency and their relative importance in all hierarchical levels. The next step is to synthesise the evaluations of each terminal against all PPIs together with their weights using intelligent decision system (IDS; Yang and Xu, 2000) incorporating the ER algorithm.

Table 6.46 Pairwise comparisons of 6 dimensions with respect to CA

	CA	SA	FS	US	TSCI	SG	Weights
CA	1	1.68	1.68	1.41	2.00	3.87	0.27
SA	0.59	1	1.68	1.00	2.00	3.13	0.20
FS	0.59	0.59	1	1.00	1.68	3.22	0.17
US	0.71	1.00	1.00	1	1.86	3.22	0.19
TSCI	0.50	0.50	0.59	0.54	1	1.86	0.11
SG	0.26	0.32	0.31	0.31	0.54	1	0.06

Table 6.47 Pairwise comparisons of 5 dimensions with respect to SA

	CA	SA	FS	US	TSCI	SG	Weights
CA	1	0.91	0.71	0.84	1.68	2.71	0.18
SA	1.10	1	1.30	1.50	1.84	2.80	0.23
FS	1.41	0.77	1	1.41	2.00	3.22	0.22
US	1.19	0.67	0.71	1	1.68	3.13	0.18
TSCI	0.59	0.54	0.50	0.59	1	2.00	0.12
SG	0.37	0.36	0.31	0.32	0.50	1	0.07

Table 6.48 Pairwise comparisons of 3 dimensions with respect to FS

	CA	SA	SG	Weights
CA	1	1.68	6.19	0.56
SA	0.59	1	4.47	0.36
SG	0.16	0.22	1	0.08

Table 6.49 Pairwise comparisons of 3 dimensions with respect to US

	CA	SA	FS	Weights
CA	1	2.00	3.66	0.55
SA	0.50	1	3.13	0.33
FS	0.27	0.32	1	0.13

Table 6.50 Pairwise comparisons of 3 dimensions with respect to TSCI

	CA	SA	US	Weights
CA	1	0.41	0.41	0.17
SA	2.45	1	1.32	0.45
US	2.45	0.76	1	0.38

Table 6.51 Interdependent weights of 6 dimensions

	CA	SA	FS	US	TSCI	SG
CA	0.27	0.18	0.56	0.55	0.17	1.00
SA	0.20	0.23	0.36	0.33	0.45	0
FS	0.17	0.22	0	0.13	0	0
US	0.19	0.18	0	0	0.38	0
TSCI	0.11	0.12	0	0	0	0
SG	0.06	0.07	0.08	0	0	0

Table 6.52 Unweighted super matrix

		CA			SA			FP		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
FP	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 6.53 Weighted super matrix

		CA			SA			FP		US		TSCI			SG		
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
CA	OPC	0.08	0.05	0.05	0.07	0.08	0.04	0.30	0.29	0.08	0.25	0.05	0.09	0.05	0	0	0
	PDC	0.12	0.15	0.11	0.07	0.06	0.08	0.16	0.15	0.28	0.17	0.05	0.04	0.05	0	0	0
	LTC	0.06	0.07	0.11	0.04	0.04	0.06	0.10	0.12	0.18	0.12	0.07	0.04	0.07	1	0	0
SA	HCS	0.08	0.08	0.06	0	0	0	0	0	0.12	0.12	0.14	0.16	0.16	0	0	0
	OCS	0.07	0.06	0.05	0	0	0	0	0	0.10	0.12	0.16	0.21	0.14	0	0	0
	ICS	0.05	0.06	0.09	0	0	0.23	0	0.36	0.10	0.09	0.15	0.09	0.15	0	0	0
FP	PFF	0.10	0.10	0.08	0.12	0.11	0.11	0	0	0.07	0.08	0	0	0	0	0	0
	LSF	0.07	0.07	0.08	0.10	0.11	0.11	0	0	0.05	0.05	0	0	0	0	0	0
US	SFU	0.14	0.14	0.13	0.13	0.11	0.13	0	0	0	0	0.28	0.15	0.22	0	0	0
	SCU	0.05	0.05	0.06	0.05	0.07	0.05	0	0	0	0	0.10	0.23	0.16	0	0	0
TSCI	ITST	0.05	0.05	0.04	0.04	0.08	0.04	0	0	0	0	0	0	0	0	0	0
	VAST	0.04	0.03	0.02	0.05	0	0.02	0	0	0	0	0	0	0	0	0	0
	ICIT	0.01	0.04	0.05	0.03	0.04	0.05	0	0	0	0	0	0	0	0	0	0
SG	SSS	0.04	0.03	0.04	0.03	0.02	0.05	0	0	0	0	0	0	0	0	0	0
	EVS	0.01	0.02	0.01	0.02	0.02	0.02	0	0.08	0	0	0	0	0	0	0	0
	SES	0.01	0.01	0.01	0.02	0.02	0	0.08	0	0	0	0	0	0	0	0	0
SUM		1.00	1.00	1.00	0.77	0.77	1.00	0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00

Table 6.54 Normalised super matrix

		CA			SA			FP		US		TSCI			SG		
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES
CA	OPC	0.08	0.05	0.05	0.09	0.10	0.04	0.46	0.29	0.08	0.25	0.05	0.09	0.05	0	0	0
	PDC	0.12	0.15	0.11	0.09	0.08	0.08	0.25	0.15	0.28	0.17	0.05	0.04	0.05	0	0	0
	LTC	0.06	0.07	0.11	0.06	0.05	0.06	0.16	0.12	0.18	0.12	0.07	0.04	0.07	1.00	0	0
SA	HCS	0.08	0.08	0.06	0	0	0	0	0	0.12	0.12	0.14	0.16	0.16	0	0	0
	OCS	0.07	0.06	0.05	0	0	0	0	0	0.10	0.12	0.16	0.21	0.14	0	0	0
	ICS	0.05	0.06	0.09	0	0	0.23	0	0.36	0.10	0.09	0.15	0.09	0.15	0	0	0
FP	PFF	0.10	0.10	0.08	0.16	0.15	0.11	0	0	0.07	0.08	0	0	0	0	0	0
	LSF	0.07	0.07	0.08	0.13	0.15	0.11	0	0	0.05	0.05	0	0	0	0	0	0
US	SFU	0.14	0.14	0.13	0.17	0.15	0.13	0	0	0	0	0.28	0.15	0.22	0	0	0
	SCU	0.05	0.05	0.06	0.07	0.09	0.05	0	0	0	0	0.10	0.23	0.16	0	0	0
TSCI	ITST	0.05	0.05	0.04	0.05	0.10	0.04	0	0	0	0	0	0	0	0	0	0
	VAST	0.04	0.03	0.02	0.06	0.00	0.02	0	0	0	0	0	0	0	0	0	0
	ICIT	0.01	0.04	0.05	0.04	0.05	0.05	0	0	0	0	0	0	0	0	0	0
SG	SSS	0.04	0.03	0.04	0.04	0.03	0.05	0	0	0	0	0	0	0	0	0	0
	EVS	0.01	0.02	0.01	0.02	0.03	0.02	0	0.08	0	0	0	0	0	0	0	0
	SES	0.01	0.01	0.01	0.02	0.03	0.00	0.13	0	0	0	0	0	0	0	0	0
SUM		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00

Table 6.55 Limited super matrix

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

Table 6.56 Global weights of 60 PPIs (interdependent)

OPC1	OPC2	PDC1	PDC2	PDC3	PDC4	PDC5	PDC6	LTC1	LTC2
0.083	0.036	0.022	0.018	0.015	0.048	0.014	0.021	0.071	0.022
LTC3	HCS1	HCS2	HCS3	HCS4	OCS1	OCS2	OCS3	OCS4	ICS1
0.025	0.015	0.014	0.021	0.009	0.009	0.016	0.010	0.017	0.036
ICS2	ICS3	PFF1	PFF2	PFF3	LSF1	LSF2	LSF3	SFU1	SFU3
0.029	0.033	0.025	0.026	0.028	0.021	0.022	0.019	0.037	0.015
SFU4	SFU6	SFU7	SCU1	SCU2	SCU3	ITST1	ITST2	ITST3	ITST4
0.014	0.019	0.017	0.025	0.015	0.006	0.014	0.005	0.006	0.005
VAST1	VAST2	VAST3	VAST4	ICST1	ICST2	ICST3	ICST4	SSS1	SSS2
0.007	0.003	0.003	0.005	0.007	0.006	0.005	0.005	0.007	0.005
SSS3	SSS4	EVS1	EVS2	EVS3	EVS4	EVS5	SES1	SES2	SES3
0.005	0.006	0.002	0.002	0.004	0.002	0.005	0.010	0.005	0.003

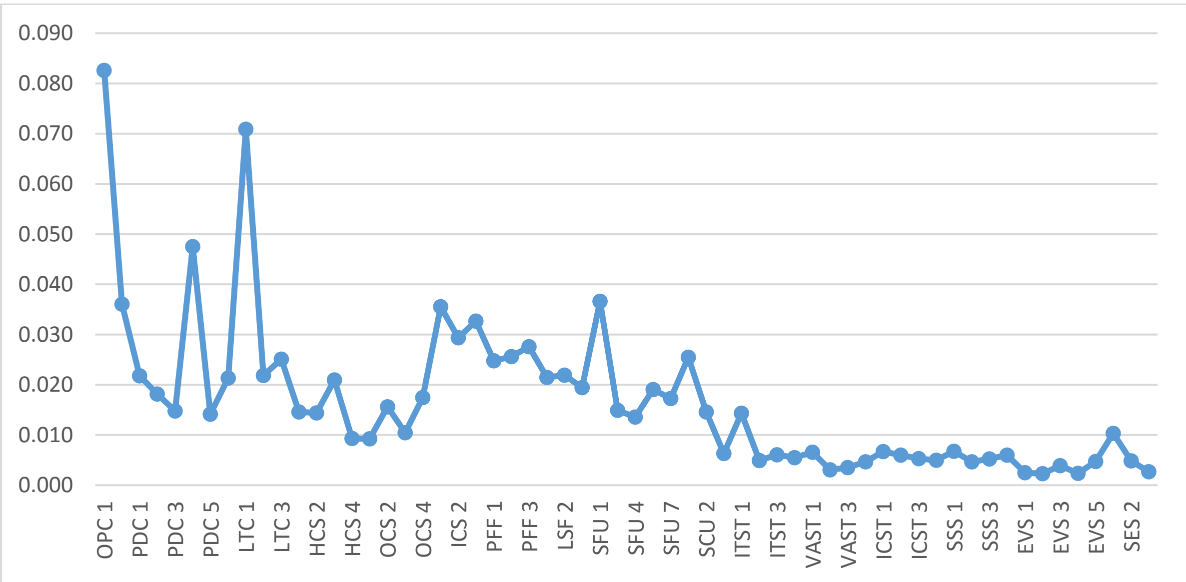

Figure 6.5 Global weights of 60 PPIs

6.3.5 Synthesis of the DoB and weights of PPIs using evidential reasoning algorithm

The same approach that was conducted in chapter 5 can be applied. In order to avoid duplication, the transformed results from the lowest level PPIs to the top level goal and their interdependent weights for 4 alternative container ports are synthesised by IDS incorporating the ER algorithm and utility technique. For further information on this process please refer to section 5.4.5.

The results derived from IDS are shown in Tables 6.57-6.60 and Figure 6.6. The performance of individual PPIs with respect to the alternative ports is shown in Table 6.57. They provide direct information on analysing performance of each port activity driven by each stakeholder, which makes port mangers possible to interpret the performance results straightforwardly. For example, both the container throughput growth and vessel call size growth PPIs in Busan North Port are shown as a negative growth. However, the ship load rate, a ratio of the combined two PPIs of container throughput volume (TEU) and an average vessel call size (GT), is performing well with a performance score of 0.8471. Even though the number of vessel calls to Busan North Port saw a relatively small decrease from 7,702 in 2012 to 7,386 in 2013 (-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 2013 compared to the vessel size in 2012. 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 2013 (81.69 TEU/GT). Moreover, the higher number of small sized vessel calls 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, but relatively lower the berth utilisation performance (TEU/berth length, 0.704). Busan North Port performs moderately in other PPIs but shows a very poor performance on all profit PPIs. This is an expected result due to the poorest performance on the container throughput PPI that generates revenues for terminal operators. It might be noted from the result that terminal operators in Busan North Port are required to make an effort to create the coopetition strategy recommended by Song (2002) to face intensified port competition.

Table 6.57 Performanc score on 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 (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

Beyond the individual PPI's performance, port managers can analyse performance at a higher level of abstraction (i.e. 16 principal PPIs and 6 dimensions). Table 6.58 demonstrates the performance scores of the sixteen principal-PPIs, which is derived from the transformed values through the mapping process from the lowest level PPIs to their associated principal-PPIs, and the lowest level PPIs' weights. The results can lead to performance scores for the six dimensions (Table 6.59) and the overall performance results of each alternative port (Table 6.60). From the results the following conclusions can be drawn. The results suggest that Busan New Port shows the best results, followed by Incheon Port. The difference is significant especially between the adjacent ports of Busan New Port and Busan North Port. Busan North Port is assessed to be 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 such as liquidity & solvency and service costs. This is because the five terminal operators in Busan New Port started up operations from 2005 to 2011 respectively. So there has been a rather recent heavy initial capital spending for port superstructure, state-of-the-art systems and equipment. The required capital is generally raised from financial institutions and investors through project finances. With regard to the service costs, the adjacent port, 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 in a changing business environment characterised by intense port competition. On the other hand, Incheon Port has its strengths in terms of human capital, organisation capital, information capital and liquidity & solvency, accordingly in supporting activities and financial strength. Another striking feature of ports demonstrates that a very similar trend but a clear difference in performance score and ranking. For example, they show relatively poor performance results on output, productivity, environment, social engagement and profitability while they outperform in terms of lead-time and safety and security. These results can provide a validation of the proposed methodology as the case ports are in pursuing similar objectives[12] under a similar logistics environment (i.e. similar organisational structure, port governance, policy and economic condition, etc.). At the same time they are also a

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[12] In terms of the taxonomy developed by Baird (1995, 1997), the port 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.

weakness of this study as the results are only drawn from Korean port cases which indicates further empirical study in different regions/areas needs to be conducted. From the investigation results it is possible to provide the strengths and weaknesses of the four ports. Accordingly, decision makers in the ports can identify the particular areas for improvement to enhance their competitiveness. These results provide an important contribution for decision makers to enhance their port performance based on any necessary comparisons. Furthermore, it can be used for a longitudinal study to investigate the improvement of ports within different timeframes.

Table 6.58 Performance score on 16 principal-PPIs

16 principal-PPIs	Busan North	Gwangyang	Incheon	Busan New	Ranking
Output	0	0.2360	0.2979	0.6718	BN>I>G>B
Productivity	0.5759	0.2835	0.3714	0.5029	B> BN>I>G
Lead time	0.9835	0.9615	0.9627	0.9947	BN>B>I>G
Human capital	0.6642	0.6287	0.7943	0.7255	I> BN>B>G
Organisation capital	0.7223	0.6770	0.7627	0.7522	I> BN>B>G
Information capital	0.7363	0.6453	0.7552	0.6978	I>B> BN>G
Profitability	0	0.2287	0.6101	0.6849	BN>I>G>B
Liquidity & Solvency	0.6569	0.5847	0.9466	0.3364	I>B>G>BN
Service fulfilment	0.6738	0.7504	0.6493	0.7186	G> BN>B>I
Service costs	0.6010	0.6214	0.5970	0.5648	G>B>I>BN
Intermodal transport systems	0.6780	0.6865	0.6928	0.7289	BN>I>G>B
Value-added services	0.6312	0.6702	0.5940	0.6951	BN>G>B>I
Info./communi.integration	0.6839	0.6921	0.6961	0.7495	BN>I>G>B
Safety and security	0.8875	0.9020	0.8818	0.9549	BN>G>I>B
Environment	0.6514	0.4537	0.5110	0.7635	BN>B>I>G
Social engagement	0.6583	0.4654	0.4647	0.7318	BN>B>G>I

Table 6.59 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 6.60 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.

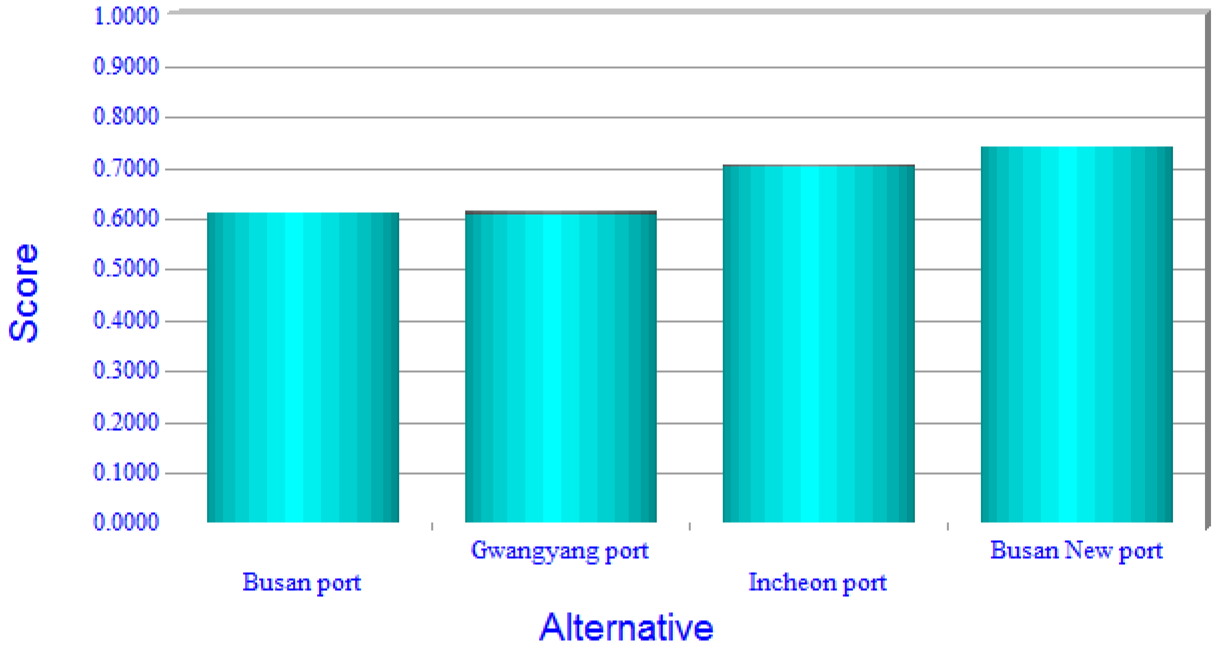

Figure 6.6 Port performance ranking

6.3.6 Sensitivity analysis

To validate the feasibility and robustness of the proposed model, this chapter conducts sensitivity analysis, using three axioms introduced in section 5.4.6. To test the Axions 1 and 2, the degrees of belief associated with the highest evaluation assessment grades of all PPIs at the bottom level are decreased by 0.1 and 0.2 one by one, and simultaneously the degrees of belief associated with the lowest assessment grades of corresponding PPIs are increased by 0.1 and 0.2 one by one. The example of decrement of the PPI at the bottom level by 0.1 and 0.2 is shown in Table 6.61. The effect of 'throughput growth' by 0.1 in Busan New Port decreases the model output (i.e. overall performance) from 0.7407 to 0.7368, while the effect of 'throuhput growth' by 0.2 decreases the model output from 0.7407 to 0.7324. Similar analysis has been conducted to investigate the influence of the other PPIs at the bottom level, which is depicted in Figure 6.7. The effects of belief degrees (i.e. either 0.1 or 0.2) associated with the bottom level PPIs indicate that the model outputs are sensitive to them. The significance is clearly found in which the belief degree changes from the highest evaluation grade (i.e. S. satisfied) to the lowest evaluation grade (i.e. S. dissatisfied). For example, 'overall service quality' of Busan New Port is evaluated as '0.14' belonging to 'strongly satisfied' while 'throughput growth' of Busan New Port is evaluated as '0.242' belonging to '20%', however, the effects of 'overall service quality' by 0.1 and 0.2 are 0.7349 and 0.7301, which is far much magnitudes than the ones (i.e. 0.7368 and 0.7324) of the 'throughput growth' effect, even though ‘throughput growth’ is the most crucial PPI (0.083). In addition, it is clear that the influence magnitudes of the belief degree changes of the PPIs to the model outputs are significantly different (i.e. the difference between 0.1 and 0.2), and the changes closely follow the weight distributions of the PPIs in Table 6.56. The results obtained in Figure 6.7 are in line with axioms 1 and 2.

To test the axiom 3, the same way applied in chapter 5 is conducted. The performance score of Busan New Port is evaluated as 0.5245 when the degrees of belief associated with the highest-evaluation assessment grades of all PPIs at the bottom level (i.e. 60 PPIs) are decreased by 0.2. On the other hand, the performance score is evaluated as 0.6072 by decreasing the degrees of belief associated with the highest-evaluation assessment grades of the 32 PPIs by 0.2, which is in line with axiom 3.

Table 6.61 Decrement of the PPIs by 0.1 and 0.2

PPIs	Degrees of Belief	Performance
Throughput volume growth	{(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0.758), (20%, 0.242), (*geq* 25%, 0)}	0.7407
Vessel call size growth	{(leq 0%, 0), (5%, 0.298), (10%, 0.702), (15%, 0), (*geq* 20%, 0)}	
Ship load rate	{(leq 25TEU, 0), (40TEU, 0.645), (55TEU, 0.355), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	
Overall service reliability	{(S. dissatisfied, 0), (satisfied, 0.19), (neutral, 0.26), (satisfied, 0.42), (S. satisfied, 0.14)}	
Employment	{(very poor, 0), (poor, 0), (medium, 0.67), (good, 0.16), (very good, 0.17)}	
………….	....	
	The decrement of the PPIs by 0.1	
Throughput volume growth	{(leq 0%, 0.1), (5%, 0), (10%, 0), (15%, 0.758), (20%, 0.142), (*geq* 25%, 0)}	0.7368
Vessel call size growth	{(leq 0%, 0.1), (5%, 0.298), (10%, 0.602), (15%, 0), (*geq* 20%, 0)}	0.7404
Ship load rate	{(leq 25TEU, 0.1), (40TEU, 0.645), (55TEU, 0.255), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	0.7405
Overall service reliability	{(S. dissatisfied, 0.1), (satisfied, 0.19), (neutral, 0.26), (satisfied, 0.42), (S. satisfied, 0.04)}	0.7349
Employment	{(very poor, 0.1), (poor, 0), (medium, 0.67), (good, 0.16), (very good, 0.07)}	0.7372
…………..	....	
	The decrement of the PPIs by 0.2	
Throughput volume growth	{(leq 0%, 0.2), (5%, 0), (10%, 0), (15%, 0.758), (20%, 0.042), (*geq* 25%, 0)}	0.7324
Vessel call size growth	{(leq 0%, 0.2), (5%, 0.298), (10%, 0.502), (15%, 0), (*geq* 20%, 0)}	0.7400
Ship load rate	{(leq 25TEU, 0.2), (40TEU, 0.645), (55TEU, 0.155), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}	0.7402
Overall service reliability	{(S. dissatisfied, 0.2), (satisfied, 0.19), (neutral, 0.26), (satisfied, 0.36), (S. satisfied, 0)}	0.7301
Employment	{(very poor, 0.2), (poor, 0), (medium, 0.67), (good, 0.13), (very good, 0)}	0.7335
……………	....	

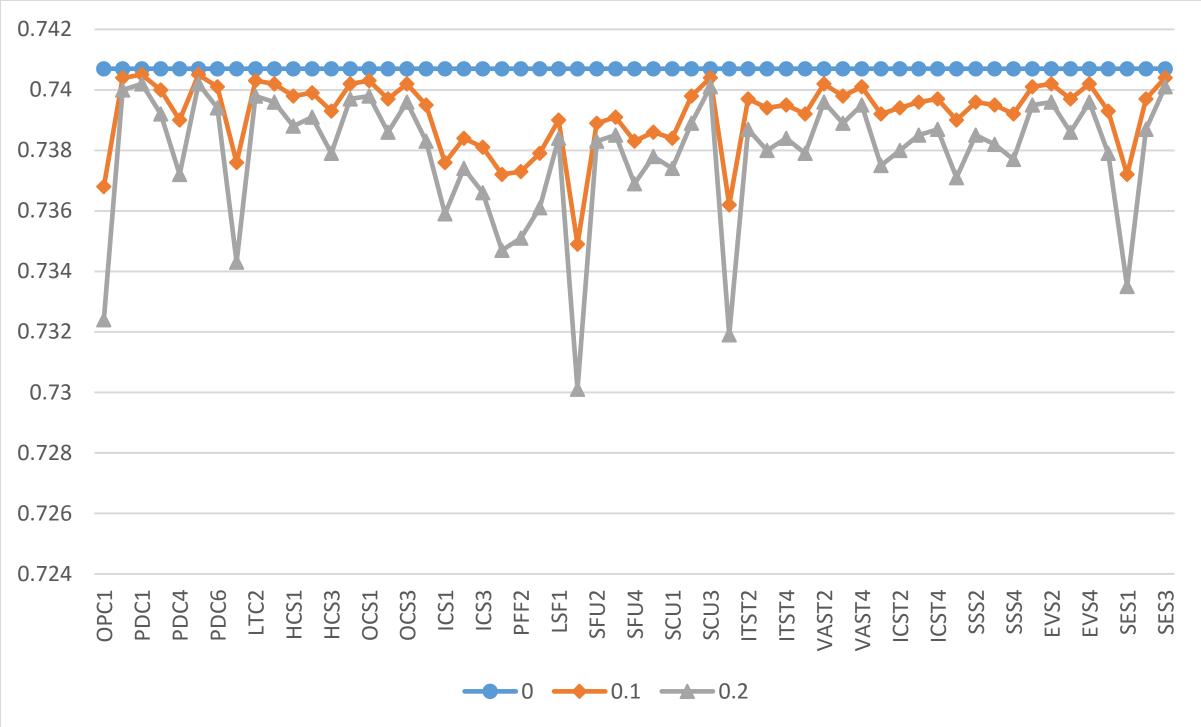

Figure 6.7 Sensitivitiy analysis of Busan New Port

6.4 CONCLUSION

This study presented a hybrid port performance measurement model that deals with PPIs' interdependency instead of PPIs' independency and measures them 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. This offers diagnostic instruments to decision makers in identifying the particular areas for improvement. In order to strengthen the research validation and its contribution to industry and academic research, this study adopts the feedback from four senior managers in terminal operating companies located in each port.

A systematic approach to develop a PPM framework is presented. The development of the measurement instruments and the hybrid quantitative model to measure port performance is perceived as a major contribution. They include both quantitative and qualitative items to offer diagnostic instruments to port managers, aiming to meet the different needs of port stakeholders. According to the feedback from the senior managers, a set of quantitative PPIs have generally been utilised because the data can be readily available, or because the qualitative PPIs are too ambiguous to interpret them in a meaningful way. Accordingly, they cannot be used frequently together despite the need for performance measurement. The implication is that the hybrid approach can successfully deal with both quantitative and qualitative PPIs within a single framework. The results yielded by the hybrid approach provide for the ranking of the ports in terms of their overall performance with respect to multiple PPIs as well as a PPI's ranking with a single performance value. The interpretation of the results of the hybrid approach is very straightforward. This feature enables port managers to identify the strengths and weaknesses of the ports in terms of each individual PPI, principal-PPI and dimension, and offers insights into them to find the particular areas in need of special attention.

Therefore, on the basis of the conclusions derived from the case study, this study provides port managers with valuable insights as this framework allows them (1) to recognise current strengths and weaknesses of each port; (2) to better understand the conditions and status of their competitive ports; (3) to prioritise investment to improve competitiveness and customers' satisfaction by focusing on the poor performing areas or by adjusting their strategies based on the relative importance of PPIs.

Nevertheless, further studies for identifying factor correlation and result validity are to be conducted. Based on the research findings, further empirical study to benchmark port performance in different regions/areas and for different timeframes can be carried out to identify the best practices/solutions of the leading performers in view of an improvement of weaker PPIs.

CHAPTER 7 A NEW DECISION MAKING FRAMEWORK FOR SELECTING PORT PERFORMANCE IMPROVEMENT STRATEGIES

This chapter aims to propose a decision making framework for selecting port performance improvement strategies. It can be achieved by the concepts of benchmarking best practices using an AHP incorporating a fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) method. The leading performer and the poor performer are analysed as real cases to demonstrate the feasibility of the proposed methodology. The results yielded by the framework present the ranking of strategy options in terms of their preference to different terminal operating companies (TOCs), which enables decision makers to find optimal solutions to improve performance under their own dynamic business environments.

7.1 INTRODUCTION

A number of management tools such as benchmarking, total quality management (TQM), 6 sigma, objectives based management, just-in-time, quality assurance and the like in the context of quality and strategic management have been developed to aid organisations to improve their performance. In the past three decades, companies have been dedicated to the quality control practices in order to adapt themselves into total quality management of the whole business practices (Lema and Price, 1995). Companies in either private or public businesses have paid much effort and time to obtain the international certification and integrated management systems such as Malcolm Baldrige National Quality Award and ISO 9000(1) series. They enable companies to adopt quality practices, and to improve their business process and operational efficiency, compromising toward competitive advantages (Kafetzopoulos *et al*., 2013).

In this regard, previous chapters (i.e. chapters 5 and 6) proposed port performance measurement models that enable us to identify the strengths and weaknesses of the container ports/terminals and offered insights to find optimal strategies to improve their performance. The poor PPI score needs to be improved with reference to the associated PPI performance in a leading performer. This chapter is a consecutive work of port performance measurement. In this chapter, the best practices of the leading performer are used as a benchmark to improve the weak PPIs in poor performer as a case study[13]. The list of performance improvement

[13] They are obtained from the result of chapter 6.

strategies is identified through interviews with TOCs in major Asian ports and literature review. Through benchmarking the best practices of the leading performers the poor performer can manage its idle resources' problems, to control the effective costs allocations and to encourage better relationships with port stakeholders in an effective way. However, scholars and practitioners have done little on the development of the novel framework for prioritising port performance improvement strategies in the literature. This study therefore aims to propose a conceptual decision making framework for modelling PPI improvement strategies. This can be achieved by the concepts of benchmarking the best practices using an AHP incorporating a FTOPSIS method in MADM problems.

In the next section, the literature on benchmarking modelling and MADM approaches applicable in selecting port performance improvement strategies (i.e. AHP and FTOPSIS) is reviewed. In section 7.3, a new hybrid decision aid tool on port performance improvement by incorporating AHP and FTOPSIS in a benchmarking framework is presented within the context of a Busan North Port case study. Finally, the paper concludes with a discussion of results and recommendation for further research in section 7.4.

7.2 ADVANCED EVALUATION METHOD

The measurement of PPIs' improvement strategies is a typical MCDM under uncertainty. The MCDM problems can be often assessed imprecisely due to uncertain and incomplete data related to different quantitative and qualitative determinants (Yang *et al*., 2009b, Liu and Wang, 2009). In order to tackle the problems, it needs sophisticated tools that are already proven to be successfully applicable for dealing with MCDM problems under uncertainty. In the MCDM practical applications, a number of linear weighting techniques (i.e. AHP and TOPSIS) have been successfully applied (Deng *et al*., 2000, Olson, 2004, Bottani and Rizzi, 2006, Shyur, 2006, Wang and Chang, 2007, Kumar, 2008, Mahdavi *et al*., 2008, Chamodrakas *et al*., 2009, Min and Perçin, 2009, Ren *et al*., 2010, Jiang *et al*., 2011, Zeydan *et al*., 2011, Erkayman *et al*., 2012). These techniques are based on the principle that the higher the weights (or the performances) are, the more desirable the alternatives. The weights/performance ratings assigned to/against criteria are mostly obtained through subjective judgements and the scores are synthesised as a single value for each alternative to select the best solution from the alternatives. In this study, a hybrid approach of AHP and fuzzy TOPSIS for solving MCDM problems under a fuzzy environment is applied to address the choice of TOCs' strategies for improving performance. An AHP is a suitable application when comparing the importance or rating of a criterion against that of other criteria at the same level in a hierarchy decision tree (Saaty, 1980). A fuzzy set theory is a powerful tool in dealing with vagueness of human thoughts and expressions in making decisions (Zadeh, 1965). It permits vague information, knowledge and concepts to be used in an exact mathematical manner. Normally, in a fuzzy environment, the assessment grades (i.e. linguistic terms) for criteria are expressed by fuzzy numbers (i.e. triangular or trapezoidal fuzzy numbers) rather than crisp numbers. Furthermore, the fuzzy set theory can be easily combined with other methods for selection issue. A TOPSIS method is well suited to modelling multiple conflicting objectives and sub objectives to determine the ranking order of alternatives (Hwang and Yoon, 1981).

In this framework, the weighting technique, AHP, is applied to assign the weights to criteria (i.e. strategies), the fuzzy theory makes it possible to tackle the imprecise evaluation of the defined criteria, whilst the TOPSIS is used to determine the ranking order of the port performance improvement strategies through the Euclidean distance from the positive and negative ideal solutions. The algorithms of the hybrid method are described in the next sections.

7.2.1 AHP for determining the importance weights of the criteria

The importance weights of criteria in the fuzzy TOPSIS technique can be obtained using pair-wise comparisons or simple rating methods (Chen, 2000). However, the latter does not cater for the assurance of the assessment consistency between the criteria (Yang *et al*., 2011). An AHP method makes the judgements more reliable through consistency ratio investigation (Saaty, 1980). The characteristics and calculations of the AHP were described in chapter 5. For further information, please refer to 5.2.2.

7.2.2 Fuzzy TOPSIS

A TOPSIS technique (Hwang and Yoon, 1981) has been considered as one of the most powerful techniques for dealing with MCDM problems. After introducing the conventional TOPSIS, its usage has been extended to the fuzzy environment (i.e. FTOPSIS) (Chen, 2000, Yang *et al*., 2011). Basically, TOPSIS/FTOPSIS is grounded in the intuitive principle that the alternatives have the shortest geometric distance from a Positive-Ideal Solution (PIS) and the longest geometric distance from a Negative-Ideal Solution (NIS) (Hwang and Yoon, 1981, Chen, 2000, Chen *et al*., 2006, Ren *et al*., 2010, Yang *et al*., 2011, Büyüközkan *et al*., 2012). The PIS, comprised of the best attainable values of the criteria, increases the benefit criteria and reduces the cost criteria, whilst the NIS, formed by the worst attainable values of the criteria, increases the cost criteria and reduces the benefit criteria. The advantages of the TOPSIS are demonstrated as (1) a sound logic that represents the rationale of human choice (2) a unique visualisation of the alternatives on a polyhedron (3) a scalar value that accounts for the best and the worst alternative choices simultaneously (4) a simple calculation process (Wang and Chang, 2007, Tavana and Hatami-Marbini, 2011). For these reasons, a modified form of the MCDM methodology, TOPSIS/FTOPSIS, has been applied by many researchers in various applications such as a recruiting problem (Chen, 2000), a supplier selection problem (Chen *et al*., 2006), a 3PL selection problem (Bottani and Rizzi, 2006), a strategic alliance partner selection problem (Büyüközkan *et al*., 2008), customer behavioural patterns (Chamodrakas *et al*., 2009), a vessel selection framework (Yang *et al*., 2011) and a logistics tool selection framework (Büyüközkan *et al*., 2012).

This study employs the proposed FTOPSIS technique by (Chen, 2000) and (Yang *et al*., 2011). The procedure of the employed FTOPSIS is summarized as follows.

The MCDM problem can be demonstrated in a matrix format as shown in Eq. (7.1). Let us assume that $A_i(i = 1, 2, ..., m)$ is a set of m alternatives and $C_j(j = 1, 2, ..., n)$ is a set of n criteria, x_{ij} is a rating of the ith alternative A_i with respect to the jth criterion C_j. The rating x_{ij} is assessed using linguistic variables, which can be expressed by Triangular Fuzzy Numbers (TFNs) $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$. In this study, the five linguistic variables including 'strongly disagree, 'disagree', 'neither agree nor disagree', 'agree' and 'strongly agree' for criteria and their corresponding TFNs are determined as shown in Table 7.1 (Wang and Chang, 2007). The advantage of using a fuzzy method for port performance improvement strategies selection is to reduce the imprecise judgement problem that may be raised in accordance with individual experience, intuition or knowledge and uncertain or incomplete data.

$$\boldsymbol{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdots \\ A_i \\ \cdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & x_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & \cdots & \cdots & x_{mn} \end{bmatrix} \end{array} \quad (7.1)$$

The first step is to aggregate individual fuzzy performance rating of each alternative with respect to each criterion. This study employs Chen's (2000) method that applies an average value to integrate the fuzzy ratings x_{ij} judged by k evaluators, that is

$$x_{ij} = \frac{1}{k}(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k) \tag{7.2}$$

where x_{ij}^k is a rating of the ith alternative A_i with respect to the jth criterion C_j evaluated by kth evaluator, and $x_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k)$.

Chen (2000) used the linear scale transformation to transform the various criteria scales into the normalised TFNs that are ranges of $[0,1]$. In this normalisation process, different equations for the *benefit criteria* (B) and *cost criteria* (C) are used. The normalised fuzzy decision matrix R can be obtained as follows.

$$\begin{gathered} R = [r_{ij}]_{m\times n}, i = 1, 2, \dots, m;\ j = 1, 2, \dots, n \\ r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right), j \in B \\ r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), j \in C \\ c_j^+ = \max_i c_{ij}\ \ if\ j \in B \\ a_j^- = \min_i a_{ij}\ if\ j \in C \end{gathered} \tag{7.3}$$

In the Chen's approach, the next step is to obtain a weighted normalised decision matrix through multiplying the normalised decision matrix by the importance weights of the criteria. However, we use a weighted distance measurement rather than the weighted normalised decision matrix. This approach is more appropriately applied to reduce the influence of the approximation fuzzy calculation caused by the multiplication of two TFNs (Yang *et al*., 2011). In addition, we also choose the AHP technique for the importance weights of the criteria rather than the simple weighting method with fuzzy numbers to avoid the aforementioned problems. Prior to the weighted distance measurement, it needs to define a fuzzy positive-ideal solution (FPIS, A^+) and a fuzzy negative-ideal solution (FNIS, A^-). From the normalised fuzzy decision matrix, the TFNs are normalised and their ranges are included in the interval $[0,1]$. Hence, the fuzzy positive-ideal solution (FPIS, A^+) and fuzzy negative-ideal solution (FNIS, A^-) can be defined as

$$\begin{gathered} A^+ = (v_1^+, \dots, v_j^+, \dots, v_n^+) \\ A^- = (v_1^-, \dots, v_j^-, \dots, v_n^-) \end{gathered} \tag{7.4}$$

where $v_j^+ = (1, 1, 1)\ if\ j \in B\ and\ v_j^+ = (0, 0, 0)\ if\ j \in C$; $v_j^- = (0, 0, 0)\ if\ j \in B\ and\ v_j^- = (1, 1, 1)\ if\ j \in C$, $j = 1, 2, \dots, n$.

The next step is to calculate the weighted distance measurement for each alternative by multiplying the distance between two TFNs d and the weights w_j. First, the distance measurement of each TOC from $A^+$and A^-can be calculated as

$$d_i^+ = \sum_{j=1}^{n} d(v_{ij}, v_j^+), i = 1, 2, \dots, m$$
$$d_i^- = \sum_{j=1}^{n} d(v_{ij}, v_j^-), i = 1, 2, \dots, m \quad (7.5)$$

where d is the distance measurement between two fuzzy numbers, d_i^+ denotes the distance of alternative A_i from FPIS, and d_i^-represents the distance of alternative A_i from FNIS.

Then, the weighted distances s_i^+ and s_i^+ for each alternative are computed by combining d_i^+ and d_i^- with weights w_j.

$$s_i^+ = \sum_{j=1}^{n} d_i^+ w_j, i = 1, 2, \dots, m$$
$$s_i^- = \sum_{j=1}^{n} d_i^- w_j, i = 1, 2, \dots, m \quad (7.6)$$

where s_i^+denotes the weighted distance of alternative A_i from FPIS, and s_i^-represents the weighted distance of alternative A_i from FNIS.

Finally, a closeness coefficient is defined to determine the ranking order of all alternatives by means of Eq. (7.7).

$$CC_i = \frac{s_i^-}{s_i^+ + s_i^-}, i = 1, 2, \dots, m \quad (7.7)$$

The closeness coefficient CC_i approaches to 1 means that an alternative A_i is closer to the FPIS (A^+) and further from FNIS (A^-). Accordingly, the higher CC_i will be selected as the best one from the alternatives.

Table 7.1 Linguistic variables and their corresponding TFNs

Linguistic variables	Corresponding triangular fuzzy numbers
Strongly disagree (SD)	(0, 1, 3)
Disagree (D)	(1, 3, 5)
Neither agree nor disagree (NAD)	(3, 5, 7)
Agree (A)	(5, 7, 9)
Strongly Agree (SD)	(7, 9, 10)

Note: The linguistic variables and their corresponding TFNs are defined based on Wang and Chang (2007).

7.3 APPLICATION OF FTOPSIS ON PPIs' IMPROVEMENT STRATEGIES

An effective benchmarking management tool needs to be capable of searching for the optimal benchmarking strategy option given multiple uncertain attributes. In other words, the 'optimal strategy option' should provide a practical and effective solution that is adaptive to the port/terminal's own situation and style. The implementation of the scenario can be conducted in various manners but essentially presents itself in a continuous manner (Camp, 1992, Pulat, 1994). Different scenarios have been introduced, for example, Xerox's 10 steps benchmarking process (Camp, 1992) and IBM's 5 phase/14 steps process (Eyrich, 1991). They are variant processes, but the core of them is based on the iterative four-step management process, which is called PDCA (plan-do-check-act (adjust)) or Deming Circle (Partovi, 1994). Pulat (1994) described the benchmarking process in the context of the Deming cycle (PDCA) as follows:

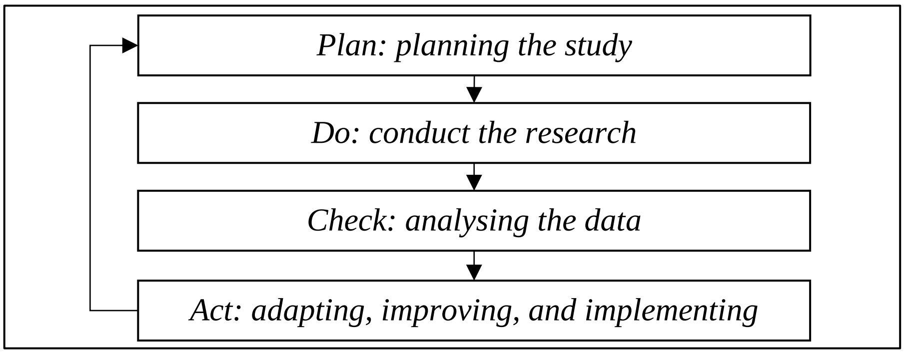

Figure 7.1 Deming cycle (plan-do-check-act)
Source: adapted from Watson 1993 and Pulat 1994

7.3.1 Plan phase

In a "plan" phase, issues such as "identify what is to be benchmarked", "identify comparative companies" and "determine data collection method" are generally considered (Pulat, 1994). In this step, the interdependent relationships between the PPIs are reviewed to determine a benchmarking goal and to draw a benchmarking strategy map.

Table 7.2 reveals the interdependency among PPIs by DEMETAL. With respect to pr_i^-values, the principal-PPIs including output, profitability, liquidity and solvency, service fulfilment, service costs safety and security, environment and social engagement are classified as effect factors (i.e. negative pr_i^- value). In addition, some individual principal PPIs play either an effect or a cause role (i.e. those indicated by bold numbers in Table 7.2), which makes the interrelationships between the principal-PPIs very complicated. For instance, output can be improved particularly by improving productivity, lead-time, information capital, human capital, organisational capital and service fulfilment. Productivity is mainly affected by lead-time, output, information capital, human capital, organisational capital, service fulfilment and information & communication integration. Lead-time is supported by productivity, information capital, output and information & communication integration. Service fulfilment is particularly influenced by lead-time, productivity, output, information capital and organisational capital. Human capital, organisational capital and information capital are affected by the principal-PPIs in core activities, users' satisfaction and terminal supply chain integration. Service costs are influenced by productivity, lead-time, output, human capital and information capital.

Thus, the cause-effect factors are reclassified based on the above findings as well as those from the previous studies in the literature. For instance, the technical or physical container terminal specification such as berth length, terminal area, number of cranes in berth and yard, labour, transport modes' turnaround as input data to measure efficiency and productivity of the container port industry (Tongzon, 1995b, Cullinane *et al*., 2002, Barros and Athanassiou, 2004, Talley, 2006). The tangible and intangible resources such as human resources, information/ communication technology and organisational values cannot be overlooked as cause factors to investigate TOC'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 earnings from the company's investment using resources such as land, labour and capital (SU *et al*., 2003). Customer satisfaction can be measured by the perceived service qualities delivered by service providers (Brooks and Schellinck, 2013). In the long term, an appropriate safety and security scheme constitutes a powerful element in improving port efficiency and competitiveness (Beresford *et al*., 2004, Woo *et al*., 2011a). Consequently, the principal-PPIs of OPC (output), PFF (profitability), LSF (liquidity and solvency) and SFU (service fulfilment) are obviously classified in an effect factor.

The extent to which a cause factor influences an effect factor is determined by the individual $R_i$and $C_j$values (in Eq. (6.4)) of the investigated principal-PPIs. For instance, in Table 7.2, PDC is determined as a cause factor of the OPC due to (0.02 (positive pr_i^- value) =0.26 (in OPC, PDC cell) – 0.24 (in PDC, OPC cell)). In a similar way, the interrelationships between the principal-PPIs can be obtained (See Table 7.3). The effect factor can sometimes be used as a cause factor as well (i.e. OPC and SFU). It is noteworthy that the cause factors of PFF and LSF include only OPC and SCU, because the others are already being applied for the cause factors of OPC. In addition, with regard to 'SC (service costs)' in users' satisfaction, an alternative port can be judged with a good performance on 'SC' when the port provides low port service charges with ascertained service qualities. However, the situation could simultaneously damage the PF (profitability) and LS (liquidity and solvency) of the TOC, leading to poor financial performance. For this reason, SC is taken into account as 'revenue perspective' rather than 'users' satisfaction perspective.' This is demonstrated as a strategy map in Figure 7.2. Based on the diagram, this study assumes that;

- The performance of SFU can be improved by enhancing the performance of PDC, LT C, HCS, OCS, ICS, ITST, VAST and ICIT (direct relationships).
- The performance of OPC can be improved by enhancing the performance of SFU, PD C, LTC, HCS, OCS, ICS, ITST, VAST and ICIT (direct relationships).
- The principal-PPI, SC, is an intermediate factor between OPC and PFF/LSF.
- The performance of PFF can be improved by enhancing the performance of SC (direct relationship), OPC (including its cause factors, indirect relationships) and SFU (inclu ding its cause factors, direct and indirect relationships).

Table 7.2 The total influence matrix (16 principal-PPIs)

		CA				**SA**		**FP**		**US**			**TSCI**			**SG**				
		OPC	PDC	LTC	HCS	OCS	ICS	PFF	LSF	SFU	SCU	ITST	VAST	ICIT	SSS	EVS	SES	R_i	pr_i^+	pr_i^-
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	5.47	-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	5.63	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	5.59	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	4.14	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	4.08	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	4.41	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	3.23	-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	3.04	-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	3.97	-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	3.52	-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	3.04	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	2.75	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	3.31	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	2.24	-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	1.86	-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	1.74	-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	29.00(sum)		

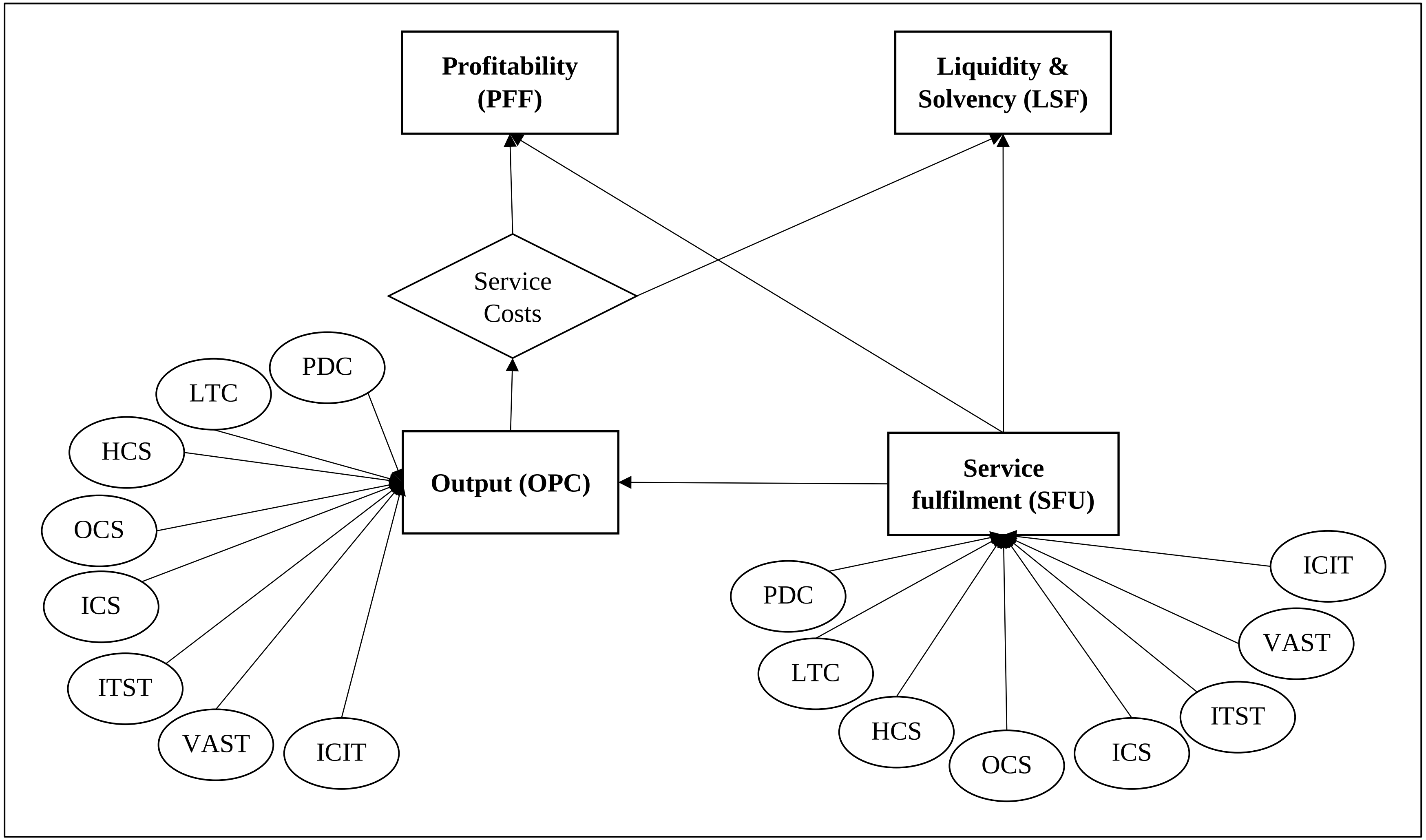

Figure 7.2 Strategy map

Table 7.3 Effect principal-PPIs and their associated cause principal-PPIs

Effect factors	Cause factors (positive pr_i^- value)
OPC	PDC (0.26-0.24=0.02), LTC (0.25-0.23=0.02), HCS (0.21-0.17=0.04), OCS (0.21-0.18=0.03), ICS (0.23-0.19=0.04), SFU (0.2-0.19=0.01), ITST (0.19-0.14=0.05), VAST (0.17-0.12=0.05), ICIT (0.2-0.14=0.06)
PFF	OPC (0.18-0.14=0.04), PDC (0.19-0.14=0.05), LTC (0.18-0.14=0.04), HCS (0.15-0.11=0.04),OCS (0.16-0.11=0.05), ICS (0.16-0.11=0.05), SFU (0.15-0.07=0.08) and SCU (0.15-0.06=0.09)
LSF	OPC (0.16-0.14=0.02), PDC (0.16-0.13=0.03), LTC (0.16-0.13=0.03), HCS (0.14-0.11=0.03), OCS (0.13-0.11=0.02), ICS (0.14-0.11=0.03), SFU (0.14-0.07=0.07) and SCU (0.14-0.06=0.08)
SFU	PDC (0.202-0.195=0.007), LTC (0.22-0.19=0.03), HCS (0.17-0.15=0.02), OCS (0.18-0.16=0.02), ICS (0.18-0.16=0.02), ITST (0.16-0.07=0.09), VAST (0.15-0.06=0.09) and ICIT (0.17-0.07=0.1)

Note: The obtained values in the brackets denote the pr_i^- values of the associated factors.

7.3.2 Do phase

In a "do" phase, related data (i.e. internal and external) is collected and self-study is conducted to identify weakness and strength of both the benchmarking company and benchmarking partner using matrix and documenting business practices (Pulat, 1994). As shown in Table 7.4, the comparison of performance score between the leading performer (Busan New Port) and the poorest performer (Busan North Port) enables each port to identify their strengths and weaknesses. Busan North Port is assessed to be a poor performer with weaker performance especially in OPC1-2, PFF1-3. In addition, it turns out that port users' satisfaction on service costs is higher than that in Busan New Port, which simultaneously leads to poor performance on PF (profitability) and LS (liquidity and solvency) of Busan North Port. Therefore, the goal of the case study is to improve FS (financial strength) performance of Busan North Port. Based on the strategy map, this study assumes that this can be achieved by:

- improving SFU performance through improving performance of its cause factors
- improving OPC performance through improving performance of its cause factors
- increasing in earnings from port service charges

First, it needs to investigate the cause factors of SFU in order to identify less competitive PPIs compared to the ones in Busan New Port. In terms of values (B2-B1) in Table 7.4, Busan North Port is identified with weaknesses especially in

- Productivity (PDC): Berth utilization (PDC2), **Crane productivity (PDC4), Yard utilization (PDC5)**
- Lead time (LTC): Vessel turnaround (LTC1), Truck turnaround (LTC2), Container dwell time (LTC3)
- Human capital (HCS): Knowledge and skills (HCS1), Capabilities (HCS2), **Training and education (HCS3), Commitment and loyalty (HCS4)**
- Organisation capital (OCS): **Culture (OCS1), Leadership (OCS2)**, Teamwork (OCS4)
- Intermodal transport systems (ITST): **Sea-side connectivity (ITST1)**, Land-side connectivity (ITST2), Reliability for multimodal operations (ITST3), Efficiency of multimodal operations (ITST4)
- Value-added services (VAST): Facilities to add value to cargos (VAST1), **Service adaptation to customers (VAST2)**, Capacity to handle different types of cargo (VAST3), **Tailored services to customers (VAST4)**
- Information/communication integration (ICIT): **Integrated EDI for communication (ICIT1)**, Integrated IT to share data (ICIT2), Collaborate with Channel members for channel optimisation (ICIT3), **Latest port IT systems (ICIT4)**

Secondly, for OPC performance, the performance of the cause in Busan North Port is identified with weaknesses especially in

- Service fulfilment (SFU): Overall service reliability (SFU1), Responsiveness to special requests (SFU2), **Accuracy of documents & information (SFU3)**, Incidence of cargo damage (SFU4), **Incidence of service delay (SFU5)**
- Productivity (PDC): Berth utilization (PDC2), **Crane productivity (PDC4)**, **Yard utilization (PDC5)**
- Lead time (LTC): Vessel turnaround (LTC1), Truck turnaround (LTC2), Container dwell time (LTC3)
- Human capital (HCS): Knowledge and skills (HCS1), Capabilities (HCS2), **Training and education (HCS3)**, **Commitment and loyalty (HCS4)**
- Organisation capital (OCS): **Culture (OCS1)**, **Leadership (OCS2)**, Teamwork (OCS4)
- Intermodal transport systems (ITST): **Sea-side connectivity (ITST1)**, Land-side connectivity (ITST2), Reliability for multimodal operations (ITST3), Efficiency of multimodal operations (ITST4)

- Value-added services (VAST): Facilities to add value to cargos (VAST1), **Service adaptation to customers (VAST2)**, Capacity to handle different types of cargo (VAST3), **Tailored services to customers (VAST4)**
- Information/communication integration (ICIT): **Integrated EDI for communication (ICIT1)**, Integrated IT to share data (ICIT2), Collaborate with Channel members for channel optimisation (ICIT3), **Latest port IT systems (ICIT4)**

Thirdly, the earnings from port service charges can be increased by

- Output (OPC): **Throughput growth (OPC1), Vessel call size growth (OPC2)** and OPC's cause factors

Table 7.4 Performance scores in two ports with respect to each PPI

	Busan North (B1)	Busan New (B2)	B2-B1
Output (OPC)	0.0000	0.6718	0.6718
Throughput growth (OPC1)	**0.0000**	**0.7227**	**0.7227**
Vessel call size growth (OPC2)	**0.0000**	**0.4211**	**0.4211**
Productivity (PDC)	0.5759	0.5029	-0.073
Ship load rate (PDC1)	0.8471	0.1817	-0.6654
Berth utilization (PDC2)	0.7040	0.7635	0.0595
Berth occupancy (PDC3)	1.0000	0.0000	-1
Crane productivity (PDC4)	**0.4353**	**0.6797**	**0.2444**
Yard utilization (PDC5)	**0.1055**	**0.5000**	**0.3945**
Labour productivity (PDC6)	0.5967	0.3954	-0.2013
Lead time (LTC)	0.9835	0.9947	0.0112
Vessel turnaround (LTC1)	1.0000	1.0000	0
Truck turnaround (LTC2)	0.9114	1.0000	0.0886
Container dwell time (LTC3)	0.9367	0.9473	0.0106
Human capital (HCS)	0.6642	0.7255	0.0613
Knowledge and skills (HCS1)	0.8270	0.8701	0.0431
Capabilities (HCS2)	0.6531	0.6973	0.0442
Training and education (HCS3)	**0.5345**	**0.6136**	**0.0791**
Commitment and loyalty (HCS4)	**0.6686**	**0.7361**	**0.0675**
Organisation capital (OCS)	0.7223	0.7522	0.0299
Culture (OCS1)	**0.6613**	**0.7517**	**0.0904**
Leadership (OCS2)	**0.7294**	**0.7746**	**0.0452**
Alignment (OCS3)	0.7081	0.6965	-0.0116
Teamwork (OCS4)	0.7081	0.7289	0.0208
Information capital (ICS)	0.7363	0.6978	-0.0385
IT systems (ICS1)	0.7828	0.7280	-0.0548
Database (ICS2)	0.6807	0.6620	-0.0187
Networks (ICS3)	0.6857	0.6531	-0.0326
Profitability (PFF)	0.0000	0.6849	0.6849
Revenue growth (PFF1)	0.0000	1.0000	1
EBIT(operating profit) margin (PFF2)	0.0000	0.7201	0.7201
Net profit margin (PFF3)	0.0000	0.3929	0.3929
Liquidity & Solvency (LSF)	0.6569	0.3364	-0.3205
Current ratio (LSF1)	0.8047	0.8047	0
Debt to total asset (LSF2)	0.1953	0.1953	0
Debt to equity (LSF3)	1.0000	0.0000	-1

Table 7.4 Continued

	Busan North (B1)	Busan New (B2)	B2-B1
Service fulfilment (SFU)	0.6738	0.7186	0.0448
Overall service reliability (SFU1)	0.6891	0.7048	0.0157
Responsiveness to special requests (SFU2)	0.6247	0.6307	0.006
Accuracy of documents & information (SFU3)	**0.6831**	**0.7518**	**0.0687**
Incidence of cargo damage (SFU4)	0.7125	0.7560	0.0435
Incidence of service delay (SFU5)	**0.5634**	**0.6720**	**0.1086**
Service costs (SCU)	0.6010	0.5648	-0.0362
Overall service cost (SCU1)	0.6060	0.5760	-0.03
Cargo handling charges (SCU2)	0.5842	0.5395	-0.0447
Cost of terminal ancillary services (SCU3)	0.5702	0.5079	-0.0623
Intermodal transport systems (ITST)	0.6780	0.7289	0.0509
Sea-side connectivity (ITST1)	**0.6526**	**0.7128**	**0.0602**
Land-side connectivity (ITST2)	0.6915	0.7049	0.0134
Reliability of multimodal operations (ITST3)	0.7002	0.7299	0.0297
Efficiency of multimodal operations (ITST4)	0.6741	0.7189	0.0448
Value-added services (VAST)	0.6312	0.6951	0.0639
Facilities to add value to cargos (VAST1)	0.6300	0.6560	0.026
Service adaptation to customers (VAST2)	**0.6181**	**0.7310**	**0.1129**
Capacity to provide different value-added (VAST3)	0.6321	0.6863	0.0542
Tailored services to customers (VAST4)	**0.6031**	**0.6889**	**0.0858**
Information/communication integration (ICIT)	0.6839	0.7495	0.0656
Integrated EDI for communication (ICIT1)	**0.6963**	**0.7589**	**0.0626**
Integrated IT to share data (ICIT2)	0.6963	0.7399	0.0436
Collaborate with Channel members for channel optimisation (ICIT3)	0.6712	0.7218	0.0506
Latest port IT systems (ICIT4)	**0.6189**	**0.7181**	**0.0992**
Safety and Security (SSS)	0.8875	0.9549	0.0674
Identifying restricted areas and access control (SSS1)	0.8841	0.9452	0.0611
Formal safety and security training practices (SSS2)	0.8478	0.9178	0.07
Adequate monitoring and threat awareness (SSS3)	0.8486	0.9326	0.084
Safety and security officers and facilities (SSS4)	0.8915	0.9700	0.0785
Environment (EVS)	0.6514	0.7635	0.1121
Carbon footprint (EVS1)	0.4269	0.6681	0.2412
Water consumption (EVS2)	0.7086	0.8278	0.1192
Energy consumption (EVS3)	0.8023	0.9136	0.1113
Waste recycling (EVS4)	0.7228	0.7512	0.0284
Environment management programmes (EVS5)	0.5479	0.6218	0.0739
Social engagement (SES)	0.6583	0.7318	0.0735
Employment (SES1)	0.6552	0.7184	0.0632
Regional GDP (SES2)	0.6915	0.8504	0.1589
Disclose of information (SES3)	0.5473	0.4961	-0.0512

7.3.3 Check phase

In the "check" phase, the collected data is analysed for pinpointing gaps in performance, process and practices between the benchmarking company and benchmarking partner (Pulat, 1994). In the previous step, Busan North Port was identified with less competitive PPIs throughout the principal-PPIs. But we exclude the PPIs having similar performance level to, or better than, the ones in the benchmark company (i.e. Busan New Port). On top of that, every port user uses an integrated EDI system in Korean ports, called KL-NET, so ICIT1 should also be excluded. The list of PPIs improvement strategies was identified through structured interviews with port/terminal operating companies in major Asian ports. A sample of the population based on representativeness of a relevant peer group of ports in Asia is helpful in identifying the potential performance strategies to improve the weak PPIs in poor performer. A sampling for the interviews was determined based on the previous studies that investigated port performance rankings among a relevant peer group of ports (Tongzon and Ganesalingam, 1994, Cullinane *et al*., 2006, Lin and Tseng, 2007, Hung *et al*., 2010, Wu and Goh, 2010, Yeo *et al.*, 2014) as well as port rankings in Containerisation International 2014. The experts in Hong Kong (MTL and HIT), Singapore (PSA), Sanghai, Shenzhen, Busan (PNC, HJNC and HPNT), Kobe (KICT) and Tanjung Pelepas (APM) accepted to have interview and the interviews were undertaken in May 2015. The information sheet and related questions were sent to the interviewees at least three days in advance before commencing the interviews. The interviews were conducted through a computer-assisted device (Skype) and in person. The interviews were recorded by note-taking and using a recorder.

As mentioned, the interviews were conducted to identify appropriate strategies that the leading container ports have implemented, hence the related questions are very straightforward based on Table 7.4. Examples of the questions were used to identify performance improvement strategies, which the ports/terminals have implemented or plan to implement.

"What is (are) the main strageties of your port/terminal for improving crane productivity? How they are effective? Is there any new strategy your port/terminal plans to implement?"

"How does your port/terminal improve yard utilisation? How they are effective? Is there any new strategy does your port/terminal plan to implement?"

Other questions were used in a similar way. Along with the interviews, the list of the strategies was identified and supplemented through literature review. The identified strategies were further verified by the findings from previous studies as follows.

First, the strategies for crane productivity (PDC4) improvement in practice include improving crane's capability (purchasing advanced crane), optimising crane availability (crane numbers and hours) and training crane drivers. Theoretically, the crane productivity measuring the ability to handle containers from vessel to shore (or vice-versa) can be increased either by improving crane efficiency or crane utilisation (The Tioga Group, 2010).

Secondly, the strategies for yard utilisation (PDC5) improvement in practice include effective yard stacking planning, permission to use any types of cargo and utilising CY as a storage purpose for customers. A yard stacking system strongly influences yard performance (Günther and Kim, 2006). In order to minimise traffic congestion from yard to berth (or vice versa) effective yard stacking planning is essential (Li and Yip, 2013). A dedicated container terminal in Korea means that any type of cargo except for container boxes cannot be handled in terms of the Harbour Transport Business Act. In order to handle or store non-containerised cargos in the terminal, it needs a special permission from the relevant authority. Utilising CY as a storage purpose for customers mirrors the concept of port-centric logistic. It can reduce containers-road miles, leading to environmental benefits (Mangan *et al*., 2008).

Thirdly, the strategies for training and education (HCS3) improvement in practice include formal training/education programs, mentoring, participation in task forces and job rotation. The strategies for commitment and loyalty (HCS4) improvement in practice include increasing pay, increasing organisational support (welfare, training and education, etc.) and increasing job satisfaction. These strategies have been empirically recognised as an effective way to improve an organisation's performance in the context of human resource (HR) management (Saari *et al*., 1988, Guest, 1997, Gooderham *et al*., 2008).

Fourthly, the strategies for culture (OCS1) improvement in practice include improving staff or human capital driven culture, customer driven culture, clear organisational performance standard and an accountability system. Leadership (OCS2) improvement strategy includes the essential role of moral judgement, executive coaching, emotional intelligence and cognitive intelligence. These strategies have also been empirically proved as effective ways to improve an organisation's performance (Flamholtz, 2001, Irani *et al*., 2004).

Fifthly, the strategies for accuracy of documents & information (SFU3) improvement in practice include appropriate staff deployment, training and recognising frequent mistakes. According to terminal operators, in general, documents & information mistakes are generally caused by human error including delay of information update. Hence, the best way to reduce documents & information errors is to strengthen HR through deploying the right staff in the right place, training and making a mental note to recognise the frequent mistakes.

Sixthly, the strategies for incidence of service delay (SFU5) improvement in practice include ship to shore (or vice versa) operations, berth to yard (or vice versa) operations, yard to gate (or vice versa) operations and preventing incidents and accidents (i.e. human incidents and accidents and machinery failures). Establishing effective ship-berth-yard-gate (and vice versa) operations can minimise the duration of the ship loading/unloading process (Günther and Kim, 2006). Especially, yard-berth operations for export containers are crucial to shorten the loading time, hence, the export containers should be stacked and grouped by their size, type, weight, vessel and discharging port (Li and Yip, 2013).

Seventhly, the strategies for sea-side connectivity (ITST1) improvement in practice include marketing to shipping lines/shippers, improving port reputation and extending and improving port facility and equipment. Shippers generally make a contract with a single carrier (shipping line) that can provide efficient and cost effective services. Accordingly, the shipping line looks for a single port operator in order to seek cost effective and efficient services (Mangan *et al*., 2008). In this case, the bargaining power of the buyer (shipper, shipping line) is always superior to that of the provider (shipping line, port operating company). Therefore, marketing to both shippers and shipping lines is essential. Port reputation also influences port choice (Haezendonck and Notteboom, 2002). On top of that, adequate port infrastructure has been recognised as one of most important indicators for port selection and port competitiveness (Yeo *et al*., 2008, Tongzon, 2009).

Eighthly, the strategies for service adaptation to customers (VAST2) and tailored services to customers (VAST4) include identifying customers' requirements, collaborating with customers for service improvement and pursing customer oriented service strategy. The one critical component in the port/terminal supply chain integration contexts is to provide value-added logistics services through the co-operation and coordination among port stakeholders (Panayides and Song, 2009). On top of that, Paixão and Bernard Marlow (2003) argued that the critical role of ports is developing several valued-added services such as transport consolidation, product mixing, or cross-docking activities alongside their basic operations of cargo handling and storage in order to fulfil customers' requirements. Therefore, the co-operative and coordinated role of channel participants and service diversity are very crucial for improving VAST2 and VAST4.

Lastly, the strategies for the latest port IT systems (ICIT4) improvement include purchasing advanced IT systems, updating the existing IT systems and improving management quality of information and data. The latest port IT systems may denote 'how reliable are the systems/information?', 'how easy are the systems to use?' and 'how useful to users is the information?' IT investment and management of a higher quality of data have also been empirically recognised as performance effective strategies (Weill, 1992, Dewett and Jones, 2001, Sheng and Mykytyn Jr, 2002, Keramati, 2007). Table 7.5 summarises the list of PPIs improvement strategies.

Prior to finalising the questionnaires which can ensure appropriateness of a hierarchical model and reflect professionals' opinions, a number of meetings with three senior practitioners in three terminal operating companies in Busan North Port were conducted. On top of that, two senior professionals in a terminal operating company, two professionals in Busan Port Authority, two professionals in shipping lines and two academics in the area of shipping and port management were invited to judge on the AHP questionnaire. They well covered the knowledge scope required to assess the AHP questionnaire and to derive the relative weights of all criteria. TOPSIS questionnaires were collected from the practitioners in three terminal operating companies in Busan North Port. In the next section, the priority of investment in the strategies to improve Busan North Port's competitiveness is determined by FTOPSIS method in MADM problems.

Table 7.5 PPIs improvement strategies

PPIs	Strategies
Crane productivity (PDC4)	• Improving cranes' capability (purchasing advanced crane) (S1) • Optimising crane availability (crane numbers and hours) (S2) • Training crane drivers (S3)
Yard utilisation (PDC5)	• Optimisation of yard stacking planning (S4) • Permission to use any types of cargo (container box plus other car go types) (S5) • Utilising CY as a storage purpose for customers (S6)
Training and education (HCS3)	• Formal training/education programs from external professionals (S7) • Internal mentoring programme (S8) • Participation in task forces (S9) • Job rotation (S10)
Commitment and loyalty (HCS4)	• Increasing pay (S11) • Individualised reward systems (including promotion) (S12) • Increasing organisational support (welfare, training and education, etc.) (S13) • Increasing job satisfaction (S14)
Culture (OCS1)	• Improving staffs or human capital driven culture (S15) • Customer driven culture (S16) • Clear organisational performance standard (S17) • Accountability system (S18)
Leadership (OCS2)	• Essential role of moral judgement (S19) • Executive coaching (S20) • Emotional intelligence (S21) • Cognitive intelligence (S22)
Accuracy of documents & information (SFU3)	• Appropriate staff deployment (S23) • Training and education programme (internal and external) (S24) • Recognising frequent mistakes (S25)
Incidence of service delay (SFU5)	• Ship to shore (or vice versa) operations (S26) • Berth to yard (or vice versa) operations (S27) • Yard to gate (or vice versa) operations (S28) • Preventing incidents and accidents (i.e. human incidents and accid ents and machinery failures) (S29)
Sea-side connectivity (ITST1)	• Marketing to shipping liners/shippers (S30) • Improving port reputation (S31) • Expending and improving port facility and equipment (S32)
Value-added service to customers (VAST2,4)	• Identifying customers' requirements (S33) • Collaborating with customers for service improvements (S34) • Pursing customer oriented value-added service strategy (S35)
Latest port IT systems (ICIT4)	• Purchasing advanced IT systems (S36) • Updating the existing IT systems (S37) • Improving management quality of information and data (S38)

7.3.4 Act phase

In the "act" phase, findings and gain acceptance are communicated, performance goal is set to improve and surpass the best in the industry and an implementing plan is launched to bridge the gap and the results (Pulat, 1994)

7.3.4.1 Relative weights of strategies

The judgements of four among the eight evaluators have been verified with the CR of 0.10 or less. Generally, the value of CR is greater than 0.1 and the evaluators need to revise their pairwise judgements. However, 4 judgements presenting consistent input data, which are sufficient to provide a reasonable AHP outcome (Büyüközkan *et al*., 2012) are used to derive the weights of the strategies.

It is noteworthy that the relative weights of the 11 PPIs at the second level are reused from the global weights obtained in chapter 5 in order to reduce the number of pairwise comparisons. Then the global weights were normalised in order to use them appropriately for this framework. The weights on the 11 PPIs (i.e. crane productivity (PDC4), yard utilisation (PDC5), training and education (HCS3), commitment and loyalty (HCS4), culture (OCS1), leadership (OCS2), accuracy of documents & information (SFU3), incidence of service delay (SFU5), sea-side connectivity (ITST1), value-added service to customers (VAST2,4) and latest port IT systems (ICIT4)) at the second level that represent the priorities in the pairwise comparison matrix are obtained by using Eqs. (5.9)-(5.10) as 0.2715, 0.0811, 0.0923, 0.0209, 0.0354, 0.1163, 0.1487, 0.1388, 0.0205 and 0.0335 respectively. Crane productivity (PDC4) is considered to be the most important PPI, followed by incidence of service delay (SFU5) and sea-side connectivity (ITST1).

The geometric means judged by 4 evaluators on the PPIs improvement strategies at the bottom level are obtained using Eq. (5.9). Table 7.6 shows the geometric means judged by 4 evaluators on the crane productivity (PDC4) improvement strategies (i.e. improving cranes' capability (S1), optimising crane availability (S2) and training crane drivers (S3)). Then the weights in the pairwise comparison matrix are obtained by using Eq. (5.10) as 0.36, 0.45, and 0.20 respectively (Table 7.7). S2 is considered to be the most important strategy and followed by S1 and S3. Based on Eq. (5.11) and Table 7.8, λ_{max} can be obtained as follows:

$$\frac{\boldsymbol{e_{ji}}}{\boldsymbol{w_i}} = \frac{1.0702}{0.3557} = 3.009,\ \frac{1.3433}{0.4461} = 3.0109,\ \frac{0.5955}{0.1982} = 3.0049, \lambda_{max} = \frac{9.0248}{3} = 3.0083, CI = \frac{3.00832-3}{2} = 0.0041, RI = 0.58,\ CR = \frac{0.015}{1.24} = 0.0071.$$

Similarly, the weights of the other PPIs improvement strategies can be obtained. It is noteworthy that the weights obtained are local weights at the same level. Further computation has been conducted to obtain global 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 'improving cranes' capability' can be obtained as 0.0966 (=0.2715 (the weight of crane productivity) × 0.3557 (the local weight of Improving cranes' capability)). Consequently, the local weights of all criteria and the normalised weights of the bottom level criteria are shown in Table 7.9. For more information for AHP calculation and the weights, please refer to chapter 5.

Table 7.6 The geometric means of PDC4 improvement strategies judged by 4 experts

	S1	S2	S3
Purchasing advanced crane (S1)	1	0.7274	1.9680
Optimising crane availability (S2)	1.3747	1	2.0598
Training crane drivers (S3)	0.5081	0.4855	1
Sum	2.88	2.21	5.03

Table 7.7 Local weights of PDC4 improvement strategies

	S1	S2	S3	Weights
Purchasing advanced crane (S1)	0.3469	0.3287	0.3914	0.3557
Optimising crane availability (S2)	0.4769	0.4519	0.4097	0.4461
Training crane drivers (S3)	0.1763	0.2194	0.1989	0.1982

Table 7.8 Calculation of $\boldsymbol{e_{ji}} \times \boldsymbol{w_i}$

	S1	S2	S3		Weights		Priority
Purchasing advanced crane (S1)	1	0.7274	1.9680		0.3557		1.0702
Optimising crane availability (S2)	1.3747	1	2.0598	×	0.4461	=	1.3433
Training crane drivers (S3)	0.5081	0.4855	1		0.1982		0.5955

Table 7.9 The local and global weights of strategies

	Weight	NW	Strategies	LW	GW
Crane productivity (PDC4)	0.0558	0.2715	Improving cranes' capability	0.3557	0.0966
			Optimising crane availability	0.4461	0.1211
			Training crane drivers	0.1982	0.0538
Yard utilisation (PDC5)	0.0167	0.0811	Optimisation of yard stacking planning	0.3024	0.0245
			Permission to use any types of cargo	0.1265	0.0103
			Port centric logistics (storage function)	0.5711	0.0463
Training and education (HCS3)	0.0190	0.0923	Formal training/education programs	0.4039	0.0373
			Internal mentoring programme	0.3140	0.0290
			Participation in task forces	0.1432	0.0132
			Job rotation	0.1390	0.0128
Commitment and loyalty (HCS4)	0.0084	0.0410	Increasing pay	0.3481	0.0143
			Individualised reward systems	0.2788	0.0114
			Increasing organisational support	0.2454	0.0100
			Increasing job satisfaction	0.2140	0.0088

Table 7.9 Continued

	Weight	NW	Strategies	LW	GW
Culture (OCS1)	0.0043	0.0209	Staffs driven culture	0.1624	0.0034
			Customer driven culture	0.5057	0.0106
			Performance standard	0.1946	0.0041
			Accountability system	0.1373	0.0029
Leadership (OCS2)	0.0073	0.0354	Moral judgement	0.2136	0.0076
			Executive coaching	0.4191	0.0148
			Emotional intelligence	0.1559	0.0055
			Cognitive intelligence	0.2115	0.0075
Doc & info accuracy (SFU3)	0.0239	0.1163	Appropriate staff deployment	0.2219	0.0258
			Training and education	0.6935	0.0807
			Recognising frequent mistakes	0.0845	0.0098
Incidence of service delay (SFU5)	0.0306	0.1487	Ship to shore operations	0.3370	0.0501
			Berth to yard operations	0.2093	0.0311
			Yard to gate operations	0.1836	0.0273
			Preventing incidents and accidents	0.2701	0.0402
Sea-side connectivity (ITST1)	0.0285	0.1388	Marketing to liners/shippers	0.4078	0.0566
			Port reputation	0.1812	0.0251
			Improving port facilities	0.4110	0.0570
VA Service to customers (VAST2,4)	0.0042	0.0205	Identifying customers' requirements	0.3515	0.0072
			Collaborating with customers	0.1363	0.0028
			Customer oriented VA services	0.5122	0.0105
Port IT systems (ICST4)	0.0069	0.0335	Purchasing advanced IT systems	0.3201	0.0107
			Updating the existing IT systems	0.4860	0.0163
			Infor/data quality management	0.1939	0.0065

7.3.4.2 Performance improvement strategy ratings of Busan North Port using FTOPSIS

The evaluators from 3 TOCs among the 4 TOCs in Busan North port took part in the survey to evaluate the preference strategy for Busan North Port's performance improvement. The eight evaluators (total twenty-four) including four senior managers (representing the group of decision makers) in top management level of each TOC took part in the evaluating process. The fuzzy decision matrix of each terminal operator with respect to each strategy option can be obtained by Eqs. (7.1)-(7.2) and is shown in Table 7.10.

The next step is to establish a normalised fuzzy decision matrix. The normalised fuzzy decision matrix $R = [r_{ij}]_{m \times n}$, where the TFNs of each criterion in matrix R is $0 \leq r_{ij} \leq 1$, can be obtained by Eq.(7.3). The maximum value c_j^+ for *benefit criteria* and the minimum value a_j^- for *cost criteria* in Table 7.10 are separately used to normalise TFNs and the results are presented in Table 7.11. For example, the maximum TFN of three TOCs with respect to S2 in Table 7.10 is 9.75, hence, the normalised TFNs of all alternatives with respect to S2 can be obtained through being divided by 9.75. On the other hand, the minimum TFN of three TOCs with respect to S1 is 5.5 that it can be used as a numerator to normalise the TFNs of all alternatives with respect to S1. Similarly, the normalised TFNs of other strategies can be obtained.

In the TOPSIS approach, the strategies can be classified either into *benefits (B)* or *costs (C)*, hence the TOCs who want to improve their performance with minimum expenses using existing internal resources represent the higher score at benefits strategies and the lower score at costs strategies. It is noteworthy that 4 TOCs in Busan North Port reached their accumulated deficits of 150 billion KRW (122 million USD) in the fiscal year of 2015. In other words, they cannot afford to invest for new port facilities. In this framework, eight strategies (i.e. improving cranes' capability (purchasing advanced crane) (S1), training crane drivers (S3), formal training/education programs from external professionals (S7), increasing pay (S11), increasing organisational support (welfare, training and education, etc) (S13), training and education programme (internal and external) (S24), expending and improving port facility and equipment (S32) and purchasing advanced IT systems (S36) belong to the *costs (C)*, but others are obviously considered as *benefits (B)*.

Based on the classification, the FPIS (A^+) and FNIS (A^-) are determined, respectively. The TFNs in the normalised fuzzy decision matrix are defined in the interval$[0,1]$, hence the FPIS (A^+) and FNIS (A^-) are defined using Eq. (7.4) as follows:

$$A^+ = [(0,0,0),(1,1,1),(0,0,0),(1,1,1),(1,1,1),(1,1,1),\dots\ \dots\dots$$
$$\dots\dots\dots\dots\dots,(1,1,1),(1,1,1),(1,1,1),(0,0,0),(1,1,1),(1,1,1)]$$

$$A^- = [(1,1,1),(0,0,0),(1,1,1),(0,0,0),(0,0,0),(0,0,0),\dots\dots\dots$$
$$\dots\dots\dots\dots\dots,(0,0,0),(0,0,0),(0,0,0),(1,1,1),(0,0,0),(0,0,0)]$$

Then, the weighted distance can be obtained using Eqs.(7.5)-(7.6). First, the distance measurement of each TOC to FPIS (A^+) and FNIS (A^-) is measured by using Eq. (7.5) and the example of the alternative 1 (TOC1) with respect to strategy 1 (improving cranes' capability (purchasing advanced crane): S1) is shown as follows:

$$d_1^+ = d(v_{11}, v_1^+) = \sqrt{\frac{1}{3}[(0.59-0)^2 + (0.73-0)^2 + (1-0)^2]} = 0.7940$$

$$d_1^- = d(v_{11}, v_1^-) = \sqrt{\frac{1}{3}[(0.59-1)^2 + (0.73-1)^2 + (1-1)^2]} = 0.2802$$

Similarly, the distances of the TOCs with respect to other strategies can be derived. Then, the weighted distance of the TOC1 with regard to all strategies is obtained using Eq.(7.7) and the distances and weighted distances of all TOCs against all strategies are calculated in the similar way.

$$s_1^+ = \sum_{j=1}^{38} d_1^+ w_j = 0.4766$$

$$s_1^- = \sum_{j=1}^{38} d_1^- w_j = 0.5966$$

Lastly, a closeness coefficient is required to determine the ranking order of all TOCs and the example of the TOC1 is shown as:

$$CC_1 = \frac{s_1^-}{s_1^+ + s_1^-} = \frac{0.5966}{0.4766+0.5966} = 0.5559$$

The closeness coefficient of the other 2 TOC can be obtained in a similar way and the results are shown as follows:

$$CC_2 = 0.6281, CC_3 = 0.5734$$

The TOC can be ranked in terms of their closeness coefficient value. A TOC with a closeness coefficient close to 1 indicates a strong intention to adopt the given strategies. On the other hand, a TOC with a closeness coefficient far from 1 means the longest distance from the FPIS (A^+) and the shortest distance from the FNIS (A^-). The ranking order of the 3 TOCs is identified as follows:

$$T2 > T3 > T1$$

On the grounds of the results, the TOC2 with the largest closeness coefficient value represents a strong desire to choose the given strategies to improve its performance, followed by TOC3, while TOC1 is the least preference to adopt the given strategies (Table 7.12). Despite the ranking, the result also indicates that the overall priority evaluations of the three alternative TOCs are not significantly different given that the three selected TOCs are faced with a similar difficulty in running their business. In addition, the result obtained by the aggregated approach using 24 samples together represents the closeness coefficient value of 0.5802.

Table 7.13 demonstrates the closeness coefficient and ranking index of 3 TOCs with respect to each strategy. TOC2 shows the highest priorities on 30 strategies, followed by TOC1 and TOC3 with 4 strategies, respectively. This indicates that each TOC has different opinions in the usefulness of the strategies to improve individual PPI's performance in terms of its own situation. For example, TOC2 shows a stronger intention to improve its performance than others since the terminal has shown a poor performance in terms of performance index and rank in chapter 5 (see Table 5.62). In other words, TOC2 realises the seriousness of the situation and the recognition has been reflected in the results.

Table 7.13 Continued

Strategy	TOC1	TOC2	TOC3	Ranking
Staffs driven culture (S15, B)	0.647	0.772	0.733	TOC2>TOC3>TOC1
Customer driven culture (S16, B)	0.684	0.766	0.707	TOC2>TOC3>TOC1
Performance standard (S17, B)	0.730	0.772	0.690	TOC2>TOC3>TOC1
Accountability system (S18, B)	0.670	0.733	0.772	TOC3>TOC2>TOC1
Moral judgement (S19, B)	0.744	0.784	0.784	TOC2=TOC3>TOC1
Executive coaching (S20, B)	0.724	0.765	0.784	TOC3>TOC2>TOC1
Emotional intelligence (S21, B)	0.687	0.772	0.712	TOC2>TOC3>TOC1
Cognitive intelligence (S22, B)	0.715	0.760	0.760	TOC2=TOC3>TOC1
Appropriate staff deployment (S23, B)	0.738	0.795	0.776	TOC2>TOC3>TOC1
Training and education (S24, C)	0.278	0.332	0.295	TOC2>TOC3>TOC1
Recognising frequent mistakes (S25, B)	0.704	0.784	0.784	TOC2>TOC3>TOC1
Ship to shore operations (S26, B)	0.687	0.806	0.748	TOC2>TOC3>TOC1
Berth to yard operations (S27, B)	0.729	0.806	0.806	TOC2>TOC3>TOC1
Yard to gate operations (S28, B)	0.670	0.806	0.748	TOC2>TOC3>TOC1
Preventing incidents and accidents (S29, B)	0.675	0.795	0.738	TOC2>TOC3>TOC1
Marketing to liners/shippers (S30, B)	0.739	0.778	0.717	TOC2>TOC1>TOC3
Port reputation (S31, B)	0.699	0.778	0.695	TOC2>TOC1>TOC3
Improving port facilities (S32, C)	0.345	0.412	0.283	TOC2>TOC1>TOC3
Identifying customers' requirements (S33, B)	0.692	0.790	0.712	TOC2>TOC3>TOC1
Collaborating with customers (S34, B)	0.739	0.778	0.741	TOC2>TOC3>TOC1
Customer oriented VA services (S35, B)	0.699	0.778	0.719	TOC2>TOC3>TOC1
Purchasing advanced IT systems (S36, C)	0.304	0.342	0.283	TOC2>TOC1>TOC3
Updating the existing IT systems (S37, B)	0.738	0.795	0.736	TOC2>TOC1>TOC3
Infor/data quality management (S38, B)	0.717	0.795	0.757	TOC2>TOC3>TOC1

Table 7.14 shows the ranking of each strategy with respect to benefit and cost strategies in terms of closeness efficient index (based on aggregated approach). Amongst benefits, optimisation of yard stacking planning (S4, B) is ascertained as the most crucial strategy that needs to be urgently implemented for improving performance, followed by berth to yard operations (S27, B), optimising crane availability (S2, B) and ship to shore operations (S26, B) as shown by the highest values (CC_i). However, the strategies of permission to use any types

of cargo (S5, B) and port centric logistics (storage function) (S6, B) for improving yard utilisation (PDC5) are the least preferred strategies among the 30 benefit items. On the other hand, the formal training/education programs from external professionals (S7, C) is identified as the most useful strategy amongst the 8 cost items. However, the results also represent that the closeness coefficient values either among the benefit or the cost items are not significantly different. In general, the traditional TOPSIS approach uses different benefit and cost criteria (i.e. PPIs) to select desirable the alternatives (i.e. strategies). However, this study uses PPIs improvement strategies as criteria to address the choice of TOCs' strategies for improving performance. This differentiates the proposed FTOPSIS from the traditional way of using different benefit and cost criteria to select each strategy with respect to TOC1, TOC2 and TOC3.

Table 7.10 The fuzzy decision matrix

	S1 (C)	S2 (B)	S3 (C)	S4 (B)	S5 (B)	S6 (B)	S7 (C)	S8 (B)
T1	(5.5,7.5,9.25)	(5.25,7.25,9)	(5,7,8.75)	(5.5,7.5,9.25)	(3.5,5.5,7.38)	(3.75,5.75,7.75)	(4,6,8)	(4,6,8)
T2	(6.25,8.25,9.63)	(6.5,8.5,9.75)	(6.25,8.25,9.63)	(6.75,8.75,9.88)	(3,5,6.88)	(3.25,5.25,7.13)	(4.75,6.75,8.5)	(4.75,6.75,8.5)
T3	(6,8,9.5)	(6.25,8.25,9.63)	(6.25,8.25,9.63	(6.25,8.25,9.5)	(1.75,3.25,5.25)	(0.88,2.25,4.25)	(4.5,6.5,8.25)	(5.25,7.25,9)
	S9 (B)	S10 (B)	S11 (C)	S12 (B)	S13 (C)	S14 (B)	S15 (B)	S16 (B)
T1	(3,5,7)	(4.5,6.5,8.25)	(5.75,7.75,9.25)	(5,7,8.75)	(4.75,6.75,8.63)	(4.25,6.25,8.25)	(4.25,6.25,8.25)	(4.5,6.5,8.5)
T2	(4.5,6.5,8.38)	(5.5,7.5,9.25)	(6.25,8.25,9.63)	(5,7,8.75)	(6,8,9.5)	(6.5,8.5,9.75)	(5.75,7.75,9.38)	(5.5,7.5,9.13)
T3	(4.25,6.25,8.13)	(6.25,8.25,9.5)	(3.75,5.75,7.75)	(4.25,6.25,8.25)	(4.25,6.25,8.25)	(5.75,7.75,9.38)	(5.25,7.25,9.13)	(4.75,6.75,8.75)
	S17 (B)	S18 (B)	S19 (B)	S20 (B)	S21 (B)	S22 (B)	S23 (B)	S24 (C)
T1	(5.25,7.25,8.88)	(4.5,6.5,8.5)	(5.5,7.5,9.13)	(5.25,7.25,9)	(4.75,6.75,8.5)	(5,7,8.63)	(5.5,7.5,9.25)	(5,7,8.88)
T2	(5.75,7.75,9.38)	(5.25,7.25,9.13)	(6,8,9.5)	(5.75,7.75,9.38)	(5.75,7.75,9.38)	(5.5,7.5,9.25)	(6.25,8.25,9.63)	(5.75,7.75,9.38)
T3	(4.75,6.75,8.63)	(5.75,7.75,9.38)	(6,8,9.5)	(6,8,9.5)	(5,7,8.88)	(5.5,7.5,9.25)	(6,8,9.5)	(5.25,7.25,9)
	S25 (B)	S26 (B)	S27 (B)	S28 (B)	S29 (B)	S30 (B)	S31 (B)	S32 (C)
T1	(5,7,8.88)	(5,7,8.75)	(5.5,7.50,9.13)	(4.75,6.75,8.75)	(4.75,6.75,8.63)	(5.25,7.25,9.)	(4.75,6.75,8.75)	(5.5,7.5,9.25)
T2	(6,8,9.5)	(6.5,8.5,9.75)	(6.5,8.5,9.75)	(6.5,8.5,9.75)	(6.25,8.25,9.63)	(5.75,7.75,9.25)	(5.75,7.75,9.25)	(6.5,8.5,9.75)
T3	(6,8,9.5)	(5.75,7.75,9.25)	(6.5,8.5,9.75)	(5.75,7.75,9.25)	(5.5,7.5,9.25)	(5,7,8.75)	(4.75,6.75,8.5)	(4.75,6.75,8.5)
	S33 (B)	S34 (B)	S35 (B)	S36 (C)	S37 (B)	S38 (B)		
T1	(4.75,6.75,8.75)	(5.25,7.25,9)	(4.75,6.75,8.75)	(5,7,8.75)	(5.5,7.5,9.25)	(5.25,7.25,9)		
T2	(6,8,9.38)	(5.75,7.75,9.25)	(5.75,7.75,9.25)	(5.5,7.5,9.13)	(6.25,8.25,9.63)	(6.25,8.25,9.63)		
T3	(5,7,8.88)	(5.25,7.25,9.13)	(5,7,8.88)	(4.75,6.75,8.5)	(5.5,7.5,9.13)	(5.75,7.75,9.38)		

Table 7.11 The normalised fuzzy decision matrix

	S1 (C)	S2 (B)	S3 (C)	S4 (B)	S5 (B)	S6 (B)	S7 (C)	S8 (B)
T1	(0.59,0.73,1)	(0.54,0.74,0.92)	(0.57,0.71,1)	(0.56,0.76,0.94)	(0.47,0.75,1)	(0.48,0.74,1)	(0.50,0.67,1)	(0.44,0.67,0.89)
T2	(0.57,0.67,0.88)	(0.67,0.87,1)	(0.52,0.61,0.8)	(0.68,0.89,1)	(0.41,0.68,0.93)	(0.42,0.68,0.92)	(0.47,0.59,0.84)	(0.53,0.75,0.94)
T3	(0.58,0.69,0.92)	(0.64,0.85,0.99)	(0.52,0.61,0.8)	(0.63,0.84,0.96)	(0.24,0.44,0.71)	(0.11,0.29,0.55)	(0.48,0.62,0.89)	(0.58,0.81,1)
	S9 (B)	S10 (B)	S11 (C)	S12 (B)	S13 (C)	S14 (B)	S15 (B)	S16 (B)
T1	(0.36,0.6,0.84)	(0.47,0.68,0.87)	(0.41,0.48,0.65)	(0.57,0.8,1)	(0.49,0.63,0.89)	(0.44,0.64,0.85)	(0.45,0.67,0.88)	(0.49,0.71,0.93)
T2	(0.54,0.78,1)	(0.58,0.79,0.97)	(0.39,0.45,0.6)	(0.57,0.8,1)	(0.45,0.53,0.71)	(0.67,0.87,1)	(0.61,0.83,1)	(0.6,0.82,1)
T3	(0.51,0.75,0.97)	(0.66,0.87,1)	(0.48,0.65,1)	(0.49,0.71,0.94)	(0.52,0.68,1)	(0.59,0.79,0.96)	(0.56,0.77,0.97)	(0.52,0.74,0.96)
	S17 (B)	S18 (B)	S19 (B)	S20 (B)	S21 (B)	S22 (B)	S23 (B)	S24 (C)
T1	(0.56,0.77,0.95)	(0.48,0.69,0.91)	(0.58,0.79,0.96)	(0.55,0.76,0.95)	(0.51,0.72,0.91)	(0.54,0.76,0.93)	(0.57,0.78,0.96)	(0.56,0.71,1)
T2	(0.61,0.83,1)	(0.56,0.77,0.97)	(0.63,0.84,1)	(0.61,0.82,0.99)	(0.61,0.83,1)	(0.59,0.81,1)	(0.65,0.86,1)	(0.53,0.65,0.87)
T3	(0.51,0.72,0.92)	(0.61,0.83,1)	(0.63,0.84,1)	(0.63,0.84,1)	(0.53,0.75,0.95)	(0.59,0.81,1)	(0.62,0.83,0.99)	(0.56,0.69,0.95)
	S25 (B)	S26 (B)	S27 (B)	S28 (B)	S29 (B)	S30 (B)	S31 (B)	S32 (C)
T1	(0.53,0.74,0.93)	(0.51,0.72,0.9)	(0.56,0.77,0.94)	(0.49,0.69,0.9)	(0.49,0.70,0.9)	(0.57,0.78,0.97)	(0.51,0.73,0.95)	(0.51,0.63,0.86)
T2	(0.63,0.84,1)	(0.67,0.87,1)	(0.67,0.87,1)	(0.67,0.87,1)	(0.65,0.86,1)	(0.62,0.84,1)	(0.62,0.84,1)	(0.49,0.56,0.73)
T3	(0.63,0.84,1)	(0.59,0.79,0.95)	(0.67,0.87,1)	(0.59,0.79,0.95)	(0.57,0.78,0.96)	(0.54,0.76,0.95)	(0.51,0.73,0.92)	(0.56,0.70,1)
	S33 (B)	S34 (B)	S35 (B)	S36 (C)	S37 (B)	S38 (B)		
T1	(0.51,0.72,0.93)	(0.57,0.78,0.97)	(0.51,0.73,0.95)	(0.54,0.68,0.95)	(0.57,0.78,0.96)	(0.55,0.75,0.94)		
T2	(0.64,0.85,1)	(0.62,0.84,1)	(0.62,0.84,1)	(0.52,0.63,0.86)	(0.65,0.86,1)	(0.65,0.86,1)		
T3	(0.53,0.75,0.95)	(0.57,0.78,0.99)	(0.54,0.76,0.96)	(0.56,0.70,1)	(0.57,0.78,0.95)	(0.60,0.81,0.97)		

Table 7.12 The closeness coefficient and rank of 3 TOCs

TOC	s_i^+	s_i^-	CC_i	Ranking
TOC1	0.4766	0.5966	0.5559	3
TOC2	0.3947	0.6665	0.6281	1
TOC3	0.4556	0.6123	0.5734	2
Aggregated approach*	0.4539	0.6273	0.5802	-

Note: *The FTOPSIS approach used in this chapter represents two different outcomes in terms of data classification, indicating, on the one hand, the use of separated data in terms of TOC (i.e. each 8 samples) and on the other, the use of aggregated data (i.e. 24 samples).

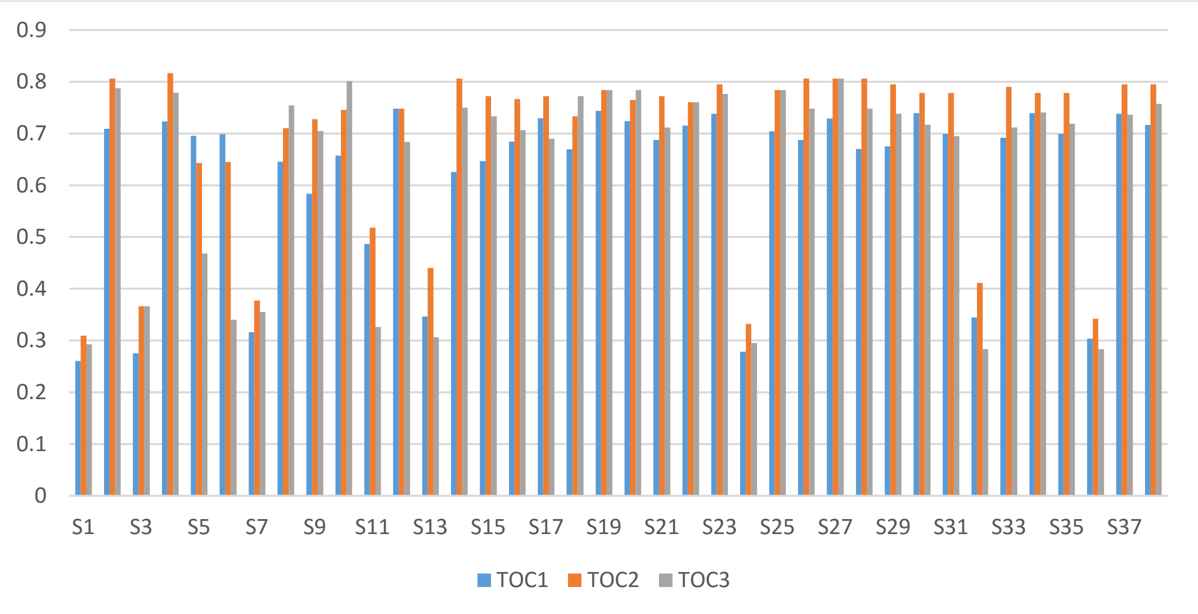

Figure 7.3 The closeness coefficient and rank of 3 TOCs with respect to each strategy

Table 7.13 The closeness coefficient and rank of 3 TOCs with respect to each strategy

Strategy	TOC1	TOC2	TOC3	Ranking
Improving cranes' capability (S1,C)	0.261	0.309	0.293	TOC2>TOC3>TOC1
Optimising crane availability (S2, B)	0.709	0.806	0.788	TOC2>TOC3>TOC1
Training crane drivers (S3, C)	0.275	0.366	0.366	TOC2=TOC3>TOC1
Optimisation of yard stacking planning (S4, B)	0.723	0.817	0.779	TOC2>TOC3>TOC1
Permission to use any types of cargo (S5, B)	0.696	0.643	0.468	TOC1>TOC2>TOC3
Port centric logistics (storage function) (S6, B)	0.698	0.645	0.340	TOC1>TOC2>TOC1
Formal training/education programs (S7, C)	0.316	0.377	0.355	TOC2>TOC3>TOC1
Internal mentoring programme (S8, B)	0.645	0.710	0.754	TOC3>TOC2>TOC1
Participation in task forces (S9, B)	0.584	0.728	0.705	TOC2>TOC3>TOC1
Job rotation (S10, B)	0.657	0.745	0.801	TOC3>TOC2>TOC1
Increasing pay (S11, C)	0.487	0.518	0.326	TOC1>TOC1>TOC1
Individualised reward systems (S12, B)	0.748	0.748	0.684	TOC1=TOC2>TOC1
Increasing organisational support (S13, C)	0.347	0.441	0.306	TOC2>TOC1>TOC3
Increasing job satisfaction (S14, B)	0.626	0.806	0.750	TOC2>TOC3>TOC1

Table 7.13 Continued

Strategy	TOC1	TOC2	TOC3	Ranking
Staffs driven culture (S15, B)	0.647	0.772	0.733	TOC2>TOC3>TOC1
Customer driven culture (S16, B)	0.684	0.766	0.707	TOC2>TOC3>TOC1
Performance standard (S17, B)	0.730	0.772	0.690	TOC2>TOC3>TOC1
Accountability system (S18, B)	0.670	0.733	0.772	TOC3>TOC2>TOC1
Moral judgement (S19, B)	0.744	0.784	0.784	TOC2=TOC3>TOC1
Executive coaching (S20, B)	0.724	0.765	0.784	TOC3>TOC2>TOC1
Emotional intelligence (S21, B)	0.687	0.772	0.712	TOC2>TOC3>TOC1
Cognitive intelligence (S22, B)	0.715	0.760	0.760	TOC2=TOC3>TOC1
Appropriate staff deployment (S23, B)	0.738	0.795	0.776	TOC2>TOC3>TOC1
Training and education (S24, C)	0.278	0.332	0.295	TOC2>TOC3>TOC1
Recognising frequent mistakes (S25, B)	0.704	0.784	0.784	TOC2>TOC3>TOC1
Ship to shore operations (S26, B)	0.687	0.806	0.748	TOC2>TOC3>TOC1
Berth to yard operations (S27, B)	0.729	0.806	0.806	TOC2>TOC3>TOC1
Yard to gate operations (S28, B)	0.670	0.806	0.748	TOC2>TOC3>TOC1
Preventing incidents and accidents (S29, B)	0.675	0.795	0.738	TOC2>TOC3>TOC1
Marketing to liners/shippers (S30, B)	0.739	0.778	0.717	TOC2>TOC1>TOC3
Port reputation (S31, B)	0.699	0.778	0.695	TOC2>TOC1>TOC3
Improving port facilities (S32, C)	0.345	0.412	0.283	TOC2>TOC1>TOC3
Identifying customers' requirements (S33, B)	0.692	0.790	0.712	TOC2>TOC3>TOC1
Collaborating with customers (S34, B)	0.739	0.778	0.741	TOC2>TOC3>TOC1
Customer oriented VA services (S35, B)	0.699	0.778	0.719	TOC2>TOC3>TOC1
Purchasing advanced IT systems (S36, C)	0.304	0.342	0.283	TOC2>TOC1>TOC3
Updating the existing IT systems (S37, B)	0.738	0.795	0.736	TOC2>TOC1>TOC3
Infor/data quality management (S38, B)	0.717	0.795	0.757	TOC2>TOC3>TOC1

Table 7.14 Ranking of strategies with respect to benefits and costs (aggregated results)

Strategy	s_i^+	s_i^+	s_i^-	CC_i	Ranking
Improving cranes' capability (S1,C)	0.078	0.078	0.026	0.248	7
Optimising crane availability (S2, B)	**0.028**	**0.028**	**0.102**	**0.786**	**3**
Training crane drivers (S3, C)	0.043	0.043	0.014	0.245	8
Optimisation of yard stacking planning (S4, B)	**0.005**	**0.005**	**0.021**	**0.793**	**1**
Permission to use any types of cargo (S5, B)	**0.004**	**0.004**	**0.007**	**0.644**	**5**
Port centric logistics (storage function) (S6, B)	0.018	0.018	0.034	0.659	29
Formal training/education programs (S7, C)	**0.029**	**0.029**	**0.012**	**0.297**	**1**
Internal mentoring programme (S8, B)	0.008	0.008	0.023	0.735	27
Participation in task forces (S9, B)	0.004	0.004	0.010	0.708	28
Job rotation (S10, B)	0.003	0.003	0.011	0.766	12
Increasing pay (S11, C)	0.011	0.011	0.004	0.265	5
Individualised reward systems (S12, B)	0.003	0.003	0.009	0.737	26
Increasing organisational support (S13, C)	**0.008**	**0.008**	**0.003**	**0.276**	**2**
Increasing job satisfaction (S14, B)	0.002	0.002	0.007	0.766	13
Staffs driven culture (S15, B)	0.001	0.001	0.003	0.746	23
Customer driven culture (S16, B)	0.003	0.003	0.008	0.739	25
Performance standard (S17, B)	0.001	0.001	0.003	0.756	18
Accountability system (S18, B)	0.001	0.001	0.002	0.748	22

Table 7.14 Continued

Strategy	s_i^+	s_i^+	s_i^-	CC_i	Ranking
Moral judgement (S19, B)	0.002	0.002	0.006	0.778	6
Executive coaching (S20, B)	0.004	0.004	0.012	0.770	11
Emotional intelligence (S21, B)	0.001	0.001	0.004	0.752	20
Cognitive intelligence (S22, B)	0.002	0.002	0.006	0.758	17
Appropriate staff deployment (S23, B)	**0.006**	**0.006**	**0.022**	**0.780**	**5**
Training and education (S24, C)	0.064	0.064	0.023	0.266	4
Recognising frequent mistakes (S25, B)	0.002	0.002	0.008	0.770	10
Ship to shore operations (S26, B)	**0.012**	**0.012**	**0.042**	**0.782**	**4**
Berth to yard operations (S27, B)	**0.007**	**0.007**	**0.026**	**0.793**	**2**
Yard to gate operations (S28, B)	0.007	0.007	0.023	0.772	8
Preventing incidents and accidents (S29, B)	0.010	0.010	0.033	0.764	14
Marketing to liners/shippers (S30, B)	0.015	0.015	0.046	0.760	15
Port reputation (S31, B)	0.007	0.007	0.020	0.746	24
Improving port facilities (S32, C)	0.046	0.046	0.016	0.254	6
Identifying customers' requirements (S33, B)	0.002	0.002	0.006	0.754	19
Collaborating with customers (S34, B)	0.001	0.001	0.002	0.760	16
Customer oriented VA services (S35, B)	0.003	0.003	0.009	0.750	21
Purchasing advanced IT systems (S36, C)	0.008	0.008	0.003	0.272	3
Updating the existing IT systems (S37, B)	0.004	0.004	0.014	0.772	9
Infor/data quality management (S38, B)	0.002	0.002	0.005	0.774	7

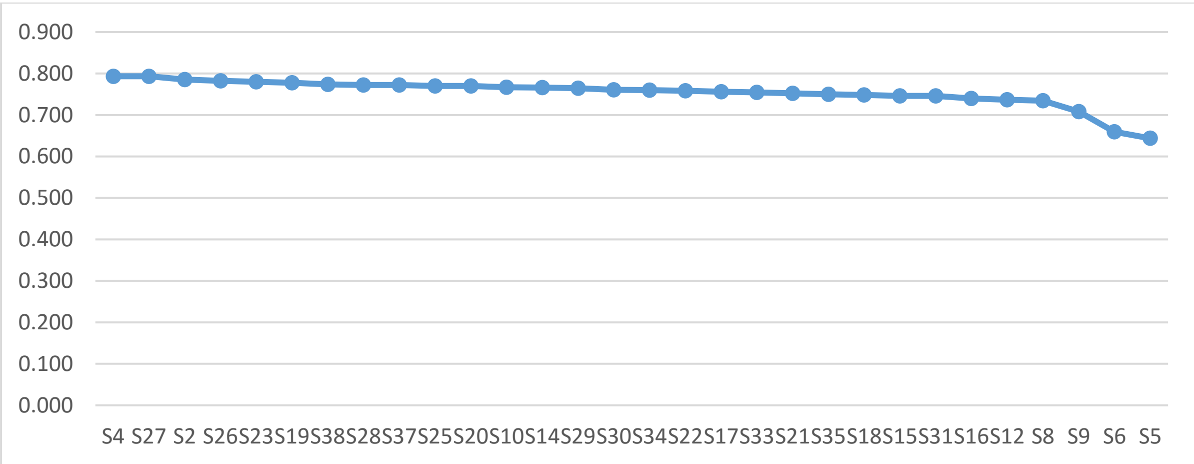

Figure 7.4 Ranking of benefits strategies

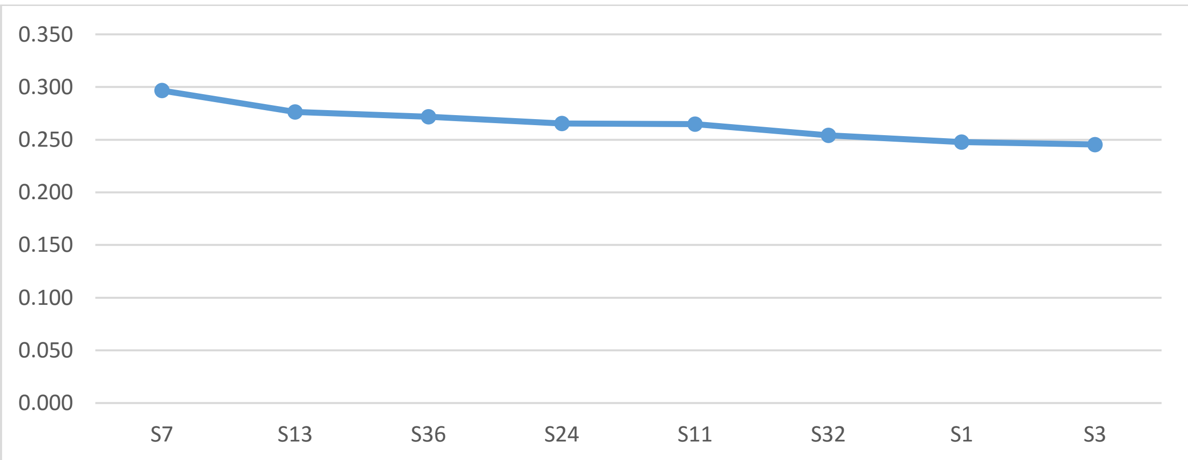

Figure 7.5 Ranking of costs strategies

7.4 CONCLUSION

This chapter proposes a decision making approach for modelling PPI improvement strategies based on a new hybrid approach by incorporating AHP and FTOPSIS into a benchmark framework. The performance of Busan New Port (leading performer) is used as a benchmark to improve the weak PPIs of Busan North Port (poor performer). A number of benchmark indexes were identified through interviews with port/terminal operating companies in major Asian ports and the literature review. The judgement on optimal strategies was conducted by 28 staff (including 12 board directors) from 3 TOCs in Busan North Port.

It is a challenging task to develop a framework for performance improvement strategies with regard to applicability and practicability. In other words, it is not a simple task using a number of strategies and then prioritising investment order among the selected strategies. Instead it is a complex and sophisticated task that needs to take into account all necessary conditions with respect to all process of port business practices. Hence, investigating and acquiring ample and accurate internal/external information is a prerequisite phase and then the performance improvement strategies can be suggested in a different manner based on own resources (i.e. HR and finance) and market situations. In this regard, the executives and staff members from 3 TOCs who have the necessary expertise in strategic policy making are employed for this work. Despite this effort, the underlying problems identified from the interviews were external factors (i.e. government policy, shipping alliance and mega-vessel) rather than internal factors (i.e. TOC’s internal problems). Due to relatively small TOCs’ capacity in Busan North Port, shipping lines prefer to call TOCs in Busan New Port rather than TOCs in Busan North Port. In addition, the Korean government seemed to believe the benefit of port competition that would bring a win-win consequence for both Busan North Port and New Port, but it resulted in shifting the centre of gravity from Busan North Port to Busan New Port. This led to a huge financial loss to the terminal operators in Busan North Port. In order to tackle these problems, Busan Port Authority (BPA) has implemented a horizontal integration of terminal operators in Busan North Port. Busan Port Authority (and the Korean Government) and associated terminal operators have currently been discussing the Busan North Port integration programme and for establishing a new firm but still there are a number of conflicts between them with regard to lease fee, share ratio of the terminal operators and BPA and the objective and function of the Busan North Port. Further studies for consideration of these issues need to be conducted. This situation can be considered as beyond the terminal business activities, which is may hard to overcome in terms of TOC's internal business practices. In this regard, this study emphasises more on developing a decision-making tool in terms of TOC's internal business practices.

Despite the shortcomings aforementioned, the results yielded by AHP and FTOPSIS framework present the ranking of strategy options in terms of their preference to different TOCs. This feature enables decision makers to find optimal strategies to improve performance under their own dynamic business environment.

CHAPTER 8 CONCLUSIONS AND FUTURE RESEARCH

This study has attempted to answer the research questions raised in section 1.2 about the important issues related to the port performance measurement, especially for container ports/terminals: the selection of multi-stakeholder dimensions and their associated port performance indicators (PPIs); the development of the port performance measurement models to deal with quantitative data and qualitative data together, PPIs uncertainty and interdependency in a unified manner; and the development of a framework for prioritising port performance improvement strategies. These are crucial questions that any researcher and practitioner needs to deal with if they are directly or indirectly involved in the port industry. To answer the questions, this study proposed a novel port performance measurement framework including PPIs selection, modelling PPIs performance (i.e. independency and interdependency) and modelling PPI improvement strategies. Korean container Ports were considered the empirical study to validate the proposed framework.

This chapter briefly summarises overall results and findings of this study and provides academic and practical implications for port/terminal managers, policy makers and academics. Finally, this chapter finishes with a discussion of research limitations and recommendations for further research.

8.1 RESEARCH CONTRIBUTION

Port performance measurement has become a key tool of TOCs and PAs in stakeholder management. Stakeholder driven management has been playing an increasingly important role in port business practices. Port performance measurement needs to consider multiple dimensions of both quantitative and qualitative factors to represent the port evolutionary changes and to meet the needs of port stakeholders. In addition, the performance measurement framework needs to enrich the diagnostic tools available to support decision-making in complex port/terminal systems operating in an uncertain environment. However, findings from the literature have revealed that there are few conceptual port performance measurement frameworks in the port industry. Thus, this thesis has developed the different frameworks in pre-performance measurement (i.e. what to measure), performance measurement (i.e. how to measure) and post-performance measurement (i.e. how to control and improve) phases to answer the research questions. They have been developed for academic and practical implications to deal with various problems and issues in an uncertain port business environment. The frameworks use a number of decision making tools and procedures and propose different hybrid approaches for each phase. The methods and techniques are demonstrated as follows:

- A conceptual discussion on the selection of Port Performance Indicators (PPIs) using deductive approach (i.e. literature review and industrial best practices (secondary data)) and abductive approach (i.e. industrial real data (secondary data), semi-structured interview (primary data)
- A new conceptual PPI measurement model using a hybrid approach of a fuzzy logic based evidential reasoning (FER) and an analytic hierarchy process (AHP) (PPIs independent model)
- A new port performance measurement model using a hybrid approach based on a fuzzy logic based evidential reasoning (FER) method, a decision making trial and evaluation laboratory (DEMATEL) and an analytic network process (ANP) technique (PPIs interdependent model)
- A decision making approach for modelling PPI improvement strategies based on the concepts of benchmarking-best practices using an analytic hierarchy process (AHP) incorporating a fuzzy order preference by similarity to ideal solution (FTOPSIS) method

The PPIs identified come across the range of port activities and are integrated into the cargo/vessel operational level of management but also the business level strategies and objectives of management. They are such a mechanistic view to represent an overall business practices of TOC/port and to incorporate multiple objectives of key stakeholders into an overall port performance measurement framework.

The objectives of two performance measurement models (i.e. PPIs independent and interdependent models) are to find a suitable approach through convincing better results than another. If there are high interdependency among PPIs after the use of DEMATEL then the second model (chapter 6), otherwise the first model (chapter 5). The two models with different disciplines represent a new performance measurement method to address the challenges in port performance measurement. The proposed models are validated using case studies of terminals/ports in South Korea from different port stakeholders' perspectives. The empirical results indicate that the hybrid approaches attempting to use quantitative modelling for dealing with the uncertain logistics environments and interdependency problems can be successfully fulfilled. The hybrid models represent an effective performance measurement tool and offer a diagnostic instrument to ports/terminals to satisfy the port stakeholders in a flexible manner.

Chapter 7 aims to propose a decision making framework for prioritising port performance improvement strategies. The performance of Busan New Port (leading performer) is used as a benchmark to improve the weak PPIs of Busan North Port (poor performer). A number of benchmark indexes were identified through interviews with port/terminal operating companies in major Asian ports and the literature review. The judgement on optimal strategies was conducted by 28 staff (including 12 board directors) who have the necessary expertise in strategic policy making from 3 TOCs in Busan North Port. In this regard, this study emphasises more on developing a decision-making tool in terms of a TOC's internal business practices. The results yielded by AHP and FTOPSIS framework present the ranking of strategy options in terms of their preference to different TOCs. This feature enables decision makers to find optimal strategies to improve performance under their own dynamic business environment.

The application of the frameworks proposed in this study is particular useful in dealing with the following issues.

Firstly, FER makes it possible to model uncertainties of various type in a flexible manner (Yang and Xu, 2002). This study used a belief structure (i.e. degrees of belief, DoB) to offer assessors judgement flexibility by assessing on either one grade or even more instead of assessing only on one grade to avoid uncertainties in subjective judgement. On top of that we permitted incomplete judgements (i.e. the sum of DoB is less than 1) when assessors are not able to conduct a precise judgement due to inadequacy of information, which can be assigned to unknown scale (UK). In this regard, we could minimise the missing data problems, which is hard to find in other methodologies.

Secondly, the PPIs which are most crucially needed to be used for measuring port performance were identified to come across the range of port activities and to cope with new evolutionary port changes. They consist of both quantitative and qualitative natures. The quantitative and qualitative PPIs were measured flexibly within a single framework. In other words, the pure data of primary and secondary data were directly used for port performance measurement without any changes.

Thirdly, regardless of the number of assessment grades, the mapping techniques to convert DoB of the bottom-level PPIs to their associated upper level principal-PPIs can be conducted in a unified manner. This study defined various and different assessment grades in terms of the terms (i.e. linguistic terms for qualitative; numerical terms for quantitative PPIs) and number (from 2 to 7 scales). This complexity is soundly calculated through the unified mapping techniques. This is another novelty of the approach, which has never been used in port performance studies.

Fourthly, DoB in a belief structure can be assigned to an interval including several grades instead of a single grade (Xu *et al*., 2006). This study utilised a number of quantitative data that are confidential and sensitive for terminal operators. From real observations, they were reluctant to provide the data, hence there was a need to develop a powerful assessment tool capable of dealing with the inherent data uncertainties. Where there is no precise data available, using interval grades can be a second best solution to collect the required data.

Fifthly, this study uses a combined method of DEMATEL and ANP (or AHP single manner) for PPIs' relative weights instead of absolute weights to determine interdependent weights of the PPIs. Next, these weights were incorporated into performance values of each port to measure overall port performance.

Lastly, the hybrid methodology has proven to be a sound approach in dealing with MCDM problems under uncertainty which the previous studies have done little with on the measurement of port performance. The combination of various methods (i.e. a hybrid approach) can yield more powerful decision-making support tools in MCDM problems. A number of linear weighting techniques (i.e. AHP, ANP, DEMATEL, ER and TOPSIS) for MCDM can be used either singly or in a combined manner in various applications. These techniques are based on the principle of the higher the weights/performance ratings, the more desirable the alternatives. The weights/performance ratings assigned to criteria are mostly obtained through subjective judgements and the scores are synthesised as a single value for each alternative to select the best solution from the alternatives. However, the MCDM problems can be often assessed imprecisely due to uncertain and incomplete data related to different quantitative and qualitative determinants. In order to tackle the problem, a hybrid approach of two or more methodologies that are already proven to be successfully applicable for dealing with MCDM problems under uncertainty has shown more appropriate applications. For instance, in chapter 7, a hybrid approach of AHP and fuzzy TOPSIS for solving MCDM problems under fuzzy environment was applied to address the choice of TOCs' performance improvement strategies. An AHP was used to compare the importance or rating of a criterion against that of other criteria at the same level in the hierarchy decision tree. In this methodology, the judgement reliability can be obtained using CR calculation. A fuzzy set theory was applied to deal with vagueness of human thoughts and expressions (using linguistic terms such as 'very poor', 'poor', 'medium', 'good' and 'very good') in making decisions and the assessment grades (i.e. linguistic terms) are expressed by fuzzy numbers (i.e. triangular or trapezoidal fuzzy numbers) rather than crisp numbers. In this approach, judgement uncertainty can be minimised permitting overlapping between the linguistic terms using fuzzy numbers. A TOPSIS method was used to modelling multiple conflicting objectives and sub objectives to determine the ranking order of alternatives.

The empirical investigations are conducted to demonstrate the feasibility of the proposed frameworks (chapters 5, 6 and 7). In chapter 5, an analysis of 12 container terminals in 3 major ports in South Korea is conducted (terminal level). In chapter 6, an analysis of 4 container ports in South Korea is conducted (port level). In chapter 7, an analysis of terminals and port in South Korea is conducted (terminal and port level).

The results obtained from empirical investigations provide both port operators and port authorities with valuable insights as this framework allows them (1) to recognise current strengths and weaknesses of each port; (2) to better understand the conditions and status of their competitive ports; (3) to prioritise investment to improve competitiveness and customers' satisfaction by adjusting their strategies based on the relative importance of PPIs; (4) to find optimal strategies to improve performance under their business environment.

8.2 LIMITATIONS OF RESEARCH AND FUTURE RESEARCH

Although the research attempts to provide a comprehensive analysis for port performance measurement and decision-making framework, this study has several limitations due to time constraints.

Firstly, the empirical investigations were conducted in South Korea. Further empirical study to benchmark port performance in different regions/areas and for different timeframes can be carried out to identify the best practices/solutions of the leading performers in view of an improvement of weaker PPIs. In order for this, the numerical assessment grades for quantitative PPIs were defined based on various references (i.e. consulting reports, journal papers and secondary data produced by port authorities, governments and terminal operators) produced in various countries in Asia, Europe, America, Oceania and Africa. For instance, the assessment grades of ‘throughput growth’ are developed based on the top 50 world container ports (Containerisation International, 2010-2012), while the assessment grades of ‘revenue growth’ are obtained based on the revenue growth (between 2008 and 2012) of four major global terminal operators (GTOs) such as PSA (Port of Singapore Authority), HPH (Hutchison Port Holdings), APM terminals and DP (Dubai Ports) world.

Secondly, the selected PPIs are mixed forms of operational, tactical and strategical levels of management. The PPIs need to be classified into different levels of management (i.e. operational, tactical and strategical) in terms of port/terminal business process. For instance, in users’ satisfaction dimension, ‘overall service reliability’ is strategical level of management, while ‘responsiveness to special requests’ is tactical and ‘accuracy of documents & information’ is operational level of management, respectively. This classification may well-represent the dynamic activity of business process, leading to a higher applicability and practicability.

Thirdly, this study used relative weight assignment techniques (i.e. pairwise comparison) instead of absolute weight to determine weights of the PPIs. When using absolute weight technique (i.e. Likert scale), factor correlation (i.e. cause-effect relation) and construct validity can be easily obtained through factor analysis or other research methodologies such as regression and structural equation model. It will be interesting to compare the results for new findings in future.

Fourthly, the three groups of port stakeholders assessed their own associated PPIs. However, it needs to investigate performance difference between terminal operator and other stakeholders to guide port managers for performance-improving investment decisions by analysing on performance difference perceived between terminal operators and other port stakeholders. The difference indicates, for example, inefficiency or inadequacy in areas which need to be fixed in order to meet users’ needs or expectations or to solve users’ problems.

Fifthly, for PPIs weights assignment, this study used the judgement by less than 10 experts. Through CR calculation in AHP, for example, the judgement reliability can be obtained as far as consistency ratio (CR) is 0.10 or less, but this does not mean a result reliability. The weights of PPIs can be changed when more experts take part in the judgement, which may lead to a more accurate result. In addition, when using more experts from different stakeholders, the importance difference between different stakeholder groups can be analysed. Hence, a future study should gather multiple responses from each stakeholder.

Last but not least, for modelling PPI improvement strategies, the selected strategies are not representing current crucial issues in Busan North Port (i.e. port integration) but including general strategies of TOC’s internal business practices. The terminal operators in Busan North Port believe that the integration practice is a more important strategy than anything else to stabilise their business (identified from interview). In this regard, further study for port integration is to be required.

REFERENCE

ALAVI, M., KAYWORTH, T. R. & LEIDNER, D. E. 2006. An empirical examination of the influence of organizational culture on knowledge management practices. *Journal of Management Information Systems,* 22**,** 191-224.

ALBADVI, A., KERAMATI, A. & RAZMI, J. 2007. Assessing the impact of information technology on firm performance considering the role of intervening variables: Organizational infrastructures and business processes reengineering. *International Journal of Production Research,* 45**,** 2697-2734.

BAGOZZI, R. P., YI, Y. & PHILLIPS, L. W. 1991. Assessing construct validity in organizational research. *Administrative Science Quarterly,* 36**,** 421-458.

BAIRD, A. J. 1995. Privatisation of trust ports in the United Kingdom: Review and analysis of the first sales. *Transport Policy,* 2**,** 135-143.

BAIRD, A. J. 1997. Port privatization: An analytical framework. *Proceedings of International Association of Maritime Economist Conference.* London, UK.

BANKS, R. L. & WHEELWRIGHT, S. C. 1979. Operations VS Strategy-trading tomorrow for today. *Harvard Business Review,* 57**,** 112-120.

BARNEY, J. 1991. Firm resources and sustained competitive advantage. *Journal of Management,* 17**,** 99-120.

BARROS, C. P. 2003. Incentive regulation and efficiency of Portuguese port authorities. *Maritime Economics & Logistics,* 5**,** 55-69.

BARROS, C. P. & ATHANASSIOU, M. 2004. Efficiency in European seaports with DEA: Evidence from Greece and Portugal. *Maritime Economics & Logistics,* 6**,** 122-140.

BECKER, G. S. 1964. *Human capital: A theoretical analysis with special reference to education*, Columbia University Press.

BERESFORD, A. K. C., GARDNER, B. M., PETTIT, S. J., NANIOPOULOS, A. & WOOLDRIDGE, C. F. 2004. The UNCTAD and WORKPORT models of port development: evolution or revolution? *Maritime Policy & Management,* 31**,** 93-107.

BEŠKOVNIK, B. 2008. Measuring and increasing the productivity model on maritime container terminals. *Pomorstvo,* 22**,** 171-183.

BHUTTA, K. S. & HUQ, F. 1999. Benchmarking – best practices: An integrated approach. *Benchmarking: An International Journal,* 6**,** 254-268.

BICHOU, K. 2006. Review of port performance approaches and a supply chain framework to port performance benchmarking. *Research in Transportation Economics,* 17**,** 567-598.

BICHOU, K. & GRAY, R. 2004. A logistics and supply chain management approach to port performance measurement. *Maritime Policy & Management,* 31**,** 47-67.

BOTTANI, E. & RIZZI, A. 2006. A fuzzy TOPSIS methodology to support outsourcing of logistics services. *Supply Chain Management: An International Journal,* 11**,** 294-308.

BOURNE, M., NEELY, A., MILLS, J. & PLATTS, K. 2003. Implementing performance measurement systems: A literature review. *International Journal of Business Performance Management,* 5**,** 1-24.

BRANCH, A. & STOPFORD, M. 2013. *Maritime economics,* Routledge.

BROOKS, M. R. 2006. Issues in measuring port devolution program performance: A managerial perspective. *Research in Transportation Economics,* 17**,** 599-629.

BROOKS, M. R. & PALLIS, A. A. 2008. Assessing port governance models: Process and performance components. *Maritime Policy & Management,* 35**,** 411-432.

BROOKS, M. R. & SCHELLINCK, T. 2013. Measuring port effectiveness in user service delivery: What really determines users' evaluations of port service delivery? *Research in Transportation Business & Management,* 8**,** 87-96.

BROOKS, M. R., SCHELLINCK, T. & PALLIS, A. A. 2011. A systematic approach for evaluating port effectiveness. *Maritime Policy & Management,* 38**,** 315-334.

BROWN, S., MCHARDY, J., MCNABB, R. & TAYLOR, K. 2011. Workplace performance, worker commitment, and loyalty. *Journal of Economics & Management Strategy,* 20**,** 925-955.

BRYMAN, A. & BELL, E. 2007. *Business research methods*, Second ed. Oxford University Press.

BRYMAN, A. & BELL, E. 2011. *Business research methods,* Third ed. Oxford University Press.

BUCHANAN, B. G. & SHORTLIFFE, E. H. 1984. *Rule-based expert systems*, Addison-Wesley Reading.

BÜYÜKÖZKAN, G., ARSENYAN, J. & RUAN, D. 2012. Logistics tool selection with two-phase fuzzy multi criteria decision making: A case study for personal digital assistant selection. *Expert Systems with Applications,* 39**,** 142-153.

BÜYÜKÖZKAN, G. & ÇIFÇI, G. 2012. A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications,* 39**,** 3000-3011.

BÜYÜKÖZKAN, G., FEYZIOĞLU, O. & NEBOL, E. 2008. Selection of the strategic alliance partner in logistics value chain. *International Journal of Production Economics,* 113**,** 148-158.

CAMP, R. C. 1992. Learning from the best leads to superior performance. *Journal of Business Strategy,* 13**,** 3-6.

CARBONE, V. & MARTINO, M. D. 2003. The changing role of ports in supply-chain management: An empirical analysis. *Maritime Policy & Management,* 30**,** 305-320.

CARIOU, P. 2008. Liner shipping strategies: An overview. *International Journal of Ocean Systems Management,* 1**,** 2-13.

CARTER, C. R. & ROGERS, D. S. 2008. A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management,* 38**,** 360-387.

CASSELL, C., NADIN, S. & OLDER GRAY, M. 2001. The use and effectiveness of benchmarking in SMEs. *Benchmarking: An International Journal,* 8**,** 212-222.

CELIK, M., ER, I. D. & OZOK, A. F. 2009. Application of fuzzy extended AHP methodology on shipping registry selection: The case of Turkish maritime industry. *Expert Systems with Applications,* 36**,** 190-198.

CHADWIN, M. L., POPE, J. A. & TALLEY, W. K. 1990. *Ocean container transportation: an operational perspective,* Taylor & Francis.

CHAMODRAKAS, I., ALEXOPOULOU, N. & MARTAKOS, D. 2009. Customer evaluation for order acceptance using a novel class of fuzzy methods based on TOPSIS. *Expert Systems with Applications,* 36**,** 7409-7415.

CHANG, B., CHANG, C.-W. & WU, C.-H. 2011. Fuzzy DEMATEL method for developing supplier selection criteria. *Expert Systems with Applications,* 38**,** 1850-1858.

CHANG, Y.-T., LEE, S.-Y. & TONGZON, J. L. 2008. Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. *Marine Policy,* 32**,** 877-885.

CHARLER, J. J. & RIDOLFI, G. 1994. Intermodel transportation in Europe: Modes, corridors and nodes. *Maritime Policy and Management,* 21**,** 237-250.

CHEN, C.-T. 2000. Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems,* 114**,** 1-9.

CHEN, C.-T., LIN, C.-T. & HUANG, S.-F. 2006. A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics,* 102**,** 289-301.

CHLOMOUDIS, C. & PALLIS, A. 1998. Ports, flexible specialisation, and employment patterns. *8th World Conference on Transport Research.* Antwerp, Belgium.

CHOU, T.-Y. & LIANG, G.-S. 2001. Application of a fuzzy multi-criteria decision-making model for shipping company performance evaluation. *Maritime Policy & Management,* 28**,** 375-392.

COLLIS, J. AND HUSSEY, R. 2009. *Business Research: A Practical Guide for Undergraduate and Postgraduate Students,* Hampshire, Palgrave MacMillan.

Containerisation International Yearbook (2012).

CRESWELL, J.W. & CLARK, V.L.P. 2007. Designing and conducting mixed methods research.

CRESWELL, J.W., PLANO CLARK, V.L., GUTMANN, M.L. AND HANSON, W.E. 2003. Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, 209-240.

CROSS, K. & LYNCH, R. 1991. *Measure up! The essential guide to measuring business performance*, Mandarin.

CRUZ, M. R. P. D., FERREIRA, J. J. & AZEVEDO, S. G. 2013. Key factors of seaport competitiveness based on the stakeholder perspective: An analytic hierarchy process (AHP) model. *Maritime Economics & Logistics,* 15**,** 416-443.

CULLINANE, K., JI, P. & WANG, T.-F. 2005. The relationship between privatization and DEA estimates of efficiency in the container port industry. *Journal of Economics and Business,* 57**,** 433-462.

CULLINANE, K. & KHANNA, M. 2000. Economies of scale in large containerships: Optimal size and geographical implications. *Journal of Transport Geography,* 8**,** 181-195.

CULLINANE, K. & SONG, D.-W. 2003. A stochastic frontier model of the productive efficiency of Korean container terminals. *Applied Economics,* 35**,** 251-267.

CULLINANE, K., SONG, D.-W. & GRAY, R. 2002. A stochastic frontier model of the efficiency of major container terminals in Asia: Assessing the influence of administrative and ownership structures. *Transportation Research Part A: Policy and Practice,* 36**,** 743-762.

CULLINANE, K., SONG, D.-W., JI, P. & WANG, T.-F. 2004. An application of DEA windows analysis to container port production efficiency. *Review of Network Economics,* 3**,** 2194-5993.

CULLINANE, K. & WANG, T.-F. 2006a. Data envelopment analysis (DEA) and improving container port efficiency. *Research in Transportation Economics,* 17**,** 517-566.

CULLINANE, K. & WANG, T.-F. 2006b. The efficiency of European container ports: A cross-sectional data envelopment analysis. *International Journal of Logistics: Research and Applications,* 9**,** 19-31.

CULLINANE, K., WANG, T.-F., SONG, D.-W. & JI, P. 2006. The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A: Policy and Practice,* 40**,** 354-374.

DANIEL, P. & KEEGAN, R. 1989. Are your performance measures obsolete? *Management Accounting,* 70**,** 45-50.

DARBRA, R., PITTAM, N., ROYSTON, K., DARBRA, J. & JOURNEE, H. 2009. Survey on environmental monitoring requirements of European ports. *Journal of Environmental Management,* 90**,** 1396-1403.

DARBRA, R., RONZA, A., STOJANOVIC, T. A., WOOLDRIDGE, C. & CASAL, J. 2005. A procedure for identifying significant environmental aspects in sea ports. *Marine Pollution Bulletin,* 50**,** 866-874.

DE LANGEN, P. W. 2002. Clustering and performance: The case of maritime clustering in The Netherlands. *Maritime Policy & Management,* 29**,** 209-221.

DE LANGEN, P. W. 2004. *The performance of port clusters: An extension of the cluster concept and an application to the port cluster of Rotterdam, Durban and the Lower Mississippi.* PhD Thesis, Erasmus University.

DE LANGEN, P. W., NIJDAM, M. & VAN DER HORST, M. 2007. New indicators to measure port performance. *Journal of Maritime Research: JMR,* 4**,** 23-36.

DE LANGEN, P. W. & PALLIS, A. A. 2006. Analysis of the benefits of intra-port competition. *International Journal of Transport Economics,* 1**,** 69-85.

DE MONIE, G. 1987. *Measuring and evaluating port performance and productivity*, United Nations.

DE TREVILLE, S., SHAPIRO, R. D. & HAMERI, A.-P. 2004. From supply chain to demand chain: The role of lead time reduction in improving demand chain performance. *Journal of Operations Management,* 21**,** 613-627.

DEMPSTER, A. P. 1967. Upper and lower probabilities induced by a multivalued mapping. *The Annals of Mathematical Statistics,* 38**,** 325-339.

DENG, H., YEH, C.-H. & WILLIS, R. J. 2000. Inter-company comparison using modified TOPSIS with objective weights. *Computers & Operations Research,* 27**,** 963-973.

DEWETT, T. & JONES, G. R. 2001. The role of information technology in the organization: A review, model, and assessment. *Journal of Management,* 27**,** 313-346.

DOOMS, M. & VERBEKE, A. 2007. Stakeholder management in ports: A conceptual framework integrating insights from research in strategy, corporate social responsibility and port management. *International Association of Maritime Economists (IAME) Conference.* Athens, Greece.

DREWRY 1998. World container terminals: Global growth and private profit. London: Drewry Shipping Consultants Ltd.

DUCRUET, C., DUMAY, B. & DE LANGEN, P. W. 2007. Average wage level as a new port performance indicator: A method and illustration of US port counties. *International Association of Maritime Economists (IAME) Conference.* Athens, Greece.

DUCRUET, C. & MERK, O. 2013. Examining container vessel turnaround times across the world. *Port Technology International,* 59**,** 18-20.

EASTERBY-SMITH, M., THORPE, R. AND JACKSON, P.R. 2012. *Management Research,* London, SAGE.

ELMUTI, D. & KATHAWALA, Y. 1997. An overview of benchmarking process: A tool for continuous improvement and competitive advantage. *Benchmarking for Quality Management & Technology,* 4**,** 229-243.

ERKAYMAN, B., GUNDOGAR, E. & YILMAZ, A. 2012. An integrated fuzzy approach for strategic alliance partner selection in third-party logistics. *Scientific World Journal,* 2012**,** 1-6.

ESPO 2010. Port performance indicators selection and measurement: Pre-selection of an initial set of indicators. European Seaports Organization.

ESPO 2011. Port performance indicators selection and measurement indicators: Stakeholders' dialogue to evaluate and select a shortlist of indicators. European Seaports Organization.

EYRICH, H. 1991. Benchmarking to become the best of breed. *Manufacturing Systems,* 9**,** 40-47.

FIRMIN, A. 2015. Navigating a future for container Shipping: Assessing the Impact of Consolidation and the Way Forward for the Industry. Hamburg: Hapag-Lloyd.

FITZGERALD, L., BRIGNALL, S., SILVESTRO, R., VOSS, C. & ROBERT, J. 1991. *Performance measurement in service businesses*, Chartered Institute of Management Accountants London.

FLAMHOLTZ, E. 2001. Corporate culture and the bottom line. *European Management Journal,* 19**,** 268-275.

FLEMING, D. K. & BAIRD, A. J. 1999. Comment Some reflections on port competition in the United States and western Europe. *Maritime Policy & Management,* 26**,** 383-394.

FLEMING, D. K. & HAYUTH, Y. 1994. Spatial characteristics of transportation hubs: Centrality and intermediacy. *Journal of Transport Geography,* 2**,** 3-18.

FRY, T. D. & COX, J. F. 1989. Manufacturing performance: Local versus global measures. *Production and Inventory Management Journal,* 30**,** 52-57.

GABUS, A. & FONTELA, E. 1973. Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility. Geneva, Switzerland: Battelle Geneva Research Centre.

GLOBERSON, S. 1985. Issues in developing a performance criteria system for an organization. *International Journal of Production Research,* 23**,** 639-646.

GONZALEZ, M. M. & TRUJILLO, L. 2008. Reforms and infrastructure efficiency in Spain's container ports. *Transportation Research Part A: Policy and Practice,* 42**,** 243-257.

GOODERHAM, P., PARRY, E. & RINGDAL, K. 2008. The impact of bundles of strategic human resource management practices on the performance of European firms. *The International Journal of Human Resource Management,* 19**,** 2041-2056.

GOSS, R. O. 1999. On the distribution of economic rent in seaports. *Maritime Economics & Logistics,* 1**,** 1-9.

GOUSSIATINER, A. 2007. In pursuit of productivity. *Container Management.* Baltic Publishing, Limited.

GREWAL, D. & DARLOW, N. J. 2007. The business paradigm for corporate social reporting in the context of Australian seaports. *Maritime Economics & Logistics,* 9**,** 172-192.

GUEST, D. E. 1997. Human resource management and performance: A review and research agenda. *International Journal of Human Resource Management,* 8**,** 263-276.

GÜNTHER, H.-O. & KIM, K.-H. 2006. Container terminals and terminal operations. *OR Spectrum,* 28**,** 437-445.

HAEZENDONCK, E. & NOTTEBOOM, T. 2002. The competitive advantage of seaports. *In: Huybrechts, M., Meersman, M., Van de Voorde, E., Van Hooydonk, E., Verbeke, A., Winkelmans, W. (Eds.), Port competitiveness: An economic and legal analysis of the factors determining the competitiveness of seaports.* De Boeck, Antwerp.

HANAM CANADA CORPORATION 2008. Pacific coast container terminal competitiveness study. Transport Canada.

HAYES, R. H. & GARVIN, D. A. 1982. Managing as if tomorrow mattered. *Harvard Business Review,* 60**,** 70-79.

HEAVER, T.D. 2002. The evolving roles of shipping lines in international logistics. *International Journal of Maritime Economics*, 4, 210-230.

HEAVER, T., MEERSMAN, H., MOGLIA, F. & VAN DE VOORDE, E. 2000. Do mergers and alliances influence European shipping and port competition? *Maritime Policy & Management,* 27**,** 363-373.

HERAT, A. T., NOOROSSANA, R. & SERKANI, E. S. 2012. Using DEMATEL-analytic network process (ANP) hybrid algorithm approach for selecting improvement projects of Iranian excellence model in healthcare sector. *African Journal of Business Management,* 6**,** 627.

HESKETT, J. L. & SCHLESINGER, L. 1994. Putting the service-profit chain to work. *Harvard Business Review,* 72**,** 164-174.

HON, K. K. B. 2005. Performance and evaluation of manufacturing systems. *CIRP Annals - Manufacturing Technology,* 54**,** 139-154.

HWANG, C.-L. & YOON, K. 1981. *Multiple attribute decision making: methods and applications,* Springer-Verlag.

IMO & ILO 2003. Code of practice on security in ports. Tripartite meeting of experts on security, safety and health in ports. Geneva, Switzerland.

IRANI, Z., BESKESE, A. & LOVE, P. E. D. 2004. Total quality management and corporate culture: Constructs of organisational excellence. *Technovation,* 24**,** 643-650.

JIANG, J., CHEN, Y.-W., CHEN, Y.-W. & YANG, K.-W. 2011. TOPSIS with fuzzy belief structure for group belief multiple criteria decision making. *Expert Systems with Applications,* 38**,** 9400-9406.

JOHN, A., PARASKEVADAKIS, D., BURY, A., YANG, Z., RIAHI, R. & WANG, J. 2014. An integrated fuzzy risk assessment for seaport operations. *Safety Science,* 68**,** 180-194.

JOHNSON, H. T. & KAPLAN, R. S. 1987. The rise and fall of management accounting [2]. *Strategic Finance,* 68**,** 22-30.

KAFETZOPOULOS, D., GOTZAMANI, K. & PSOMAS, E. 2013. Quality systems and competitive performance of food companies. *Benchmarking: An International Journal,* 20**,** 463-483.

KAPLAN, R. S. 1984. The evolution of management accounting. *The Accounting Review,* 59**,** 390-418.

KAPLAN, R. S. 2008. Conceptual foundations of the balanced scorecard. *Handbooks of Management Accounting Research,* 3**,** 1253-1269.

KAPLAN, R. S. & NORTON, D. P. 1992. The balanced scorecard: measures that drive performance. *Harvard Business Review,* 83**,** 172.

KAPLAN, R. S. & NORTON, D. P. 2000. *Having trouble with your strategy?: Then map it,* Harvard Business School Publishing Corporation.

KAPLAN, R. S. & NORTON, D. P. 2004. Measuring the strategic readiness of intangible assets. *Harvard Business Review,* 82**,** 52-63.

KAUFMANN, A. & GUPTA, M. M. 1988. *Fuzzy mathematical models in engineering and management science*, Elsevier Science Inc.

KAUFMANN, A., GUPTA, M. M. & KAUFMANN, A. 1985. *Introduction to fuzzy arithmetic: theory and applications*, Van Nostrand Reinhold Company.

KERAMATI, A. 2007. Assessing the effects of information technology on firm performance using canonical correlation analysis: A survey in Iran car part suppliers sector. *International Conference on Computer, Electrical, and Systems Science, and Engineering (CESSE2007).* Prague, Czech Republic.

KIM, M. & SACHISH, A. 1986. The structure of production, technical change and productivity in a port. *The Journal of Industrial Economics,* 35**,** 209-223.

KUMAR, P. 2008. An integrated model of AHP and TOPSIS for 3PL evaluation. *Asia-Pacific Journal of Management Research and Innovation,* 4**,** 14-21.

KUIPERS, B., 2005. The end of the box. *International Maritime Transport Perspectives, Routledge, London and New York*, 215-229.

LAM, J. S. L. 2015. Designing a sustainable maritime supply chain: A hybrid QFD–ANP approach. *Transportation Research Part E: Logistics and Transportation Review,* 78**,** 70-81.

LEMA, N. M. & PRICE, A. D. 1995. Benchmarking: Performance improvement toward competitive advantage. *Journal of Management in Engineering,* 11**,** 28-37.

LEWIS, P., THORNHILL, A. & SAUNDERS, M. 2007. *Research methods for business students,* Pearson Education.

LEWIS, R. W. 1955. Measuring, reporting and appraising results of operations with reference to goals, plans and budgets. *Planning, managing and measuring the business: A case study of management planning and control at General Electric Company.* New York: Controllership Foundation.

LI, M. K. & YIP, T. L. 2013. Joint planning for yard storage space and home berths in container terminals. *International Journal of Production Research*, 51**,** 3143-3155.

LIN, L.C. & TSENG, C.C. 2007. Operational performance evaluation of major container ports in the Asia-Pacific region. *Maritime Policy & Management, 34,* 535-551.

LIN, C. & WU, W.-W. 2004. A fuzzy extension of the DEMATEL method for group decision making. *European Journal of Operational Research,* 156**,** 445-455.

LIOU, J. J., TZENG, G.-H. & CHANG, H.-C. 2007. Airline safety measurement using a hybrid model. *Journal of Air Transport Management,* 13**,** 243-249.

LIRN, T. C., THANOPOULOU, H. A., BEYNON, M. J. & BERESFORD, A. K. C. 2004. An application of AHP on transhipment port selection: A global perspective. *Maritime Economics & Logistics,* 6**,** 70-91.

LIU, H.-T. & WANG, W.-K. 2009. An integrated fuzzy approach for provider evaluation and selection in third-party logistics. *Expert Systems with Applications,* 36**,** 4387-4398.

LIU, Z. 1995. The comparative performance of public and private enterprises: The case of British ports. *Journal of Transport Economics and Policy,* 29**,** 263-274.

MAHDAVI, I., MAHDAVI-AMIRI, N., HEIDARZADE, A. & NOURIFAR, R. 2008. Designing a model of fuzzy TOPSIS in multiple criteria decision making. *Applied Mathematics and Computation,* 206**,** 607-617.

MANGAN, J., LALWANI, C. & FYNES, B. 2008. Port-centric logistics. *International Journal of Logistics Management,* 19**,** 29-41.

MARLOW, P. B. & PAIXÃO CASACA, A. C. 2003. Measuring lean ports performance. *International Journal of Transport Management,* 1**,** 189-202.

MCNAIR, C. J. & LEIBFRIED, K. H. 1992. *Benchmarking: A tool for continuous improvement*, John Wiley & sons.

MENTZER, J.T. & KAHN, K.B. 1995. A framework of logistics research. *Journal of Business Logistics*, *16*(1), 231-250.

MENTZER, J. T. & KONRAD, B. P. 1991. An efficiency/effectiveness approach to logistics performance analysis. *Journal of Business Logistics,* 12**,** 33-62.

MERK, O., BUSQUET, B. & ARONIETIS, R. 2015. The impact of mega-ships. International transport forum. OECD.

MILLER, J. G. & VOLLMANN, T. E. 1985. The hidden factory. *Harvard Business Review,* 63**,** 142-150.

MIN, H. & PERÇIN, S. 2009. Evaluation of third-party logistics (3PL) providers by using a two-phase AHP and TOPSIS methodology. *Benchmarking: An International Journal,* 16**,** 588-604.

MLTMA. 2013. *Ministry of Land, Transport and Maritime Affairs* [Online]. Seoul.

MOKHTARI, K., REN, J., ROBERTS, C. AND WANG, J. 2012. Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach. *Expert Systems with Applications, 39,* 5087-5103.

MONIOS, J., NOTTEBOOM, T., WILMSMEIER, G., RODRIGUE, J.-P. 2016. Competition and complementarity between seaports and hinterland locations for attracting distribution activities, PortEconomics Discussion Report 04/2016, Chios, Greece.

MONIOS, J. & WILMSMEIER, G. 2012. Giving a direction to port regionalisation. *Transportation Research Part A: Policy and Practice*, *46*, 1551-1561.

MURPHY, P. R., DALEY, J. M. & DALENBERG, D. R. 1992. Port selection criteria: An application of a transportation. *Logistics and Transportation Review,* 28**,** 237.

MWASENGA, H. 2012. Port Performance Indicators: A case of Dar es Salaam port. Ad Hoc expert meeting on assessing port performance. Geneva, Switzerland: UNCTAD.

NAJMI, A. & MAKUI, A. 2010. Providing hierarchical approach for measuring supply chain performance using AHP and DEMATEL methodologies. *International Journal of Industrial Engineering Computations,* 1**,** 199-212.

NAM, H.-S. & SONG, D.-W. 2011. Defining maritime logistics hub and its implication for container port. *Maritime Policy & Management,* 38**,** 269-292.

NEELY, A. & ADAMS, C. 2000. *Perspectives on performance: The performance prism*, Gee Publishing.

NEELY, A., GREGORY, M. & PLATTS, K. 1995. Performance measurement system design: A literature review and research agenda. *International Journal of Operations & Production Management,* 15**,** 80-116.

NEELY, A., MILLS, J., PLATTS, K., RICHARDS, H., GREGORY, M., BOURNE, M. & KENNERLEY, M. 2000. Performance measurement system design: Developing and testing a process-based approach. *International Journal of Operations & Production Management,* 20**,** 1119-1145.

NEELY, A., RICHARDS, H., MILLS, J., PLATTS, K. & BOURNE, M. 1997. Designing performance measures: A structured approach. *International Journal of Operations & Production Management,* 17**,** 1131-1152.

NG, A. K. & LIU, J. 2014. *Port-focal logistics and global supply chains*, Palgrave Macmillan.

NG, K. Y. 2006. Assessing the attractiveness of ports in the North European container transhipment market: An agenda for future research in port competition. *Maritime Economics & Logistics,* 8**,** 234-250.

NOTTEBOOM, T. 2002. Consolidation and contestability in the European container handling industry. *Maritime Policy & Management,* 29**,** 257-269.

NOTTEBOOM, T.E. 2004. Container shipping and ports: an overview. *Review of Network Economics, 3,* 86-106.

NOTTEBOOM, T., COECK, C. & VAN DEN BROECK, J. 2000. Measuring and explaining the relative efficiency of container terminals by means of Bayesian stochastic frontier models. *Maritime Economics & Logistics,* 2**,** 83-106.

NOTTEBOOM, T. & RODRIGUE, J.-P. 2008. Containerisation, box logistics and global supply chains: The integration of ports and liner shipping networks. *Maritime Economics & Logistics,* 10**,** 152-174.

NOTTEBOOM, T. & WINKELMANS, W. 2003. Dealing with stakeholders in the port planning process. *Across the border: building upon a quarter of century of transport research in the Benelux.* Ed. de Boeck, Antwerp.

NOTTEBOOM, T. & RODRIGUE, J.-P. 2005. Port regionalization: Towards a new phase in port development. *Maritime Policy & Management,* 32**,** 297-313.

NOTTEBOOM, T. & WINKELMANS, W. 2001. Structural changes in logistics: How will port authorities face the challenge? *Maritime Policy & Management,* 28**,** 71-89.

NWAOHA, T., YANG, Z., WANG, J. & BONSALL, S. 2011. A new fuzzy evidential reasoning method for risk analysis and control of a liquefied natural gas carrier system. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment,* 230**,** 297-309.

OKOLI, C. & PAWLOWSKI, S. D. 2004. The Delphi method as a research tool: An example, design considerations and applications. *Information & Management,* 42**,** 15-29.

OLSON, D. L. 2004. Comparison of weights in TOPSIS models. *Mathematical and Computer Modelling,* 40**,** 721-727.

PAIXÃO, A. C. & BERNARD MARLOW, P. 2003. Fourth generation ports – a question of agility? *International Journal of Physical Distribution & Logistics Management,* 33**,** 355-376.
PALLIS, A. & VITSOUNIS, T. 2008. Towards an alternative measurement of port performance: Externally generated information and users' satisfaction. *International Forum on Shipping, Ports and Airports (IFSPA)(proceedings: CD-Rom).* Hong Kong.
PALLIS, A. A., VITSOUNIS, T. K., DE LANGEN, P. W. & NOTTEBOOM, T. E. 2011. Port economics, policy and management: Content classification and survey. *Transport Reviews,* 31**,** 445-471.
PANAYIDES, P. M. & SONG, D.-W. 2009. Port integration in global supply chains: Measures and implications for maritime logistics. *International Journal of Logistics: Research and Applications*, 12**,** 133-145.
PANAYIDES, P. M. & WIEDMER, R. 2011. Strategic alliances in container liner shipping. *Research in Transportation Economics,* 32**,** 25-38.
PANTOUVAKIS, A., CHLOMOUDIS, C. & DIMAS, A. 2008. Testing the SERVQUAL scale in the passenger port industry: A confirmatory study. *Maritime Policy & Management,* 35**,** 449-467.
PARK, R.-K. & DE, P. 2004. An alternative approach to efficiency measurement of seaports. *Maritime Economics & Logistics,* 6**,** 53-69.
PARMENTER, D. 2015. *Key performance indicators: developing, implementing, and using winning KPIs*, John Wiley & Sons.
PARTOVI, F. Y. 1994. Determining what to benchmark: An analytic hierarchy process approach. *International Journal of Operations & Production Management,* 14**,** 25-39.
PERIS-MORA, E., OREJAS, J. D., SUBIRATS, A., IBÁÑEZ, S. & ALVAREZ, P. 2005. Development of a system of indicators for sustainable port management. *Marine Pollution Bulletin,* 50**,** 1649-1660.
PILLAY, A. & WANG, J. 2003. Modified failure mode and effects analysis using approximate reasoning. *Reliability Engineering & System Safety,* 79**,** 69-85.
PORTER, M. E. 2008. *Competitive advantage: Creating and sustaining superior performance*, Simon and Schuster.
PULAT, M. 1994. Process improvements through benchmarking. *The TQM Magazine,* 6**,** 37-40.
PWC 2010. Insights into the performance of the global shipping industry: Global shipping benchmarking survey 2010. Price Waterhouse Coopers B.V.
RABINOVICH, E., WINDLE, R., DRESNER, M. AND CORSI, T. 1999. Outsourcing of integrated logistics functions: an examination of industry practices. *International Journal of Physical Distribution & Logistics Management, 29,* 353-374.
RANKINE, G. 2003. Benchmarking container terminal performance. *Container Port Conference.* Rotterdam, the Netherlands
REN, L., ZHANG, Y., WANG, Y. & SUN, Z. 2010. Comparative analysis of a novel M-TOPSIS method and TOPSIS. *Applied Mathematics Research eXpress,* 2007**,** 1-10.
RIAHI, R., BONSALL, S., JENKINSON, I. & WANG, J. 2012. A seafarer's reliability assessment incorporating subjective judgements. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment,* 226**,** 313-334.
ROLL, Y. & HAYUTH, Y. 1993. Port performance comparison applying data envelopment analysis (DEA). *Maritime Policy & Management,* 20**,** 153-161.
SAARI, L. M., JOHNSON, T. R., MCLAUGHLIN, S. D. & ZIMMERLE, D. M. 1988. A survey of management training and education practices in US companies. *Personnel Psychology,* 41**,** 731-743.

SAATY, R. 2012. *The analytic hierarchy process (AHP) for decision making and the analytic network process (ANP) for decision making with dependence and feedback*, Creative Decisions Foundation.

SAATY, T. L. 1980. *The analytic hierarchy process: Planning, priority setting, resources allocation,* New York: McGraw.

SAATY, T. L. 1990. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research,* 48**,** 9-26.

SAATY, T. L. 1996. *Decision making with dependence and feedback: The analytical network process, vol. 9 of Analytic Hierarchy Process*, Pittsburgh: RWS Publications.

SAATY, T. L. 2004. Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of Systems Science and Systems Engineering,* 13**,** 1-35.

SAATY, T. L. & TAKIZAWA, M. 1986. Dependence and independence: From linear hierarchies to nonlinear networks. *European Journal of Operational Research,* 26**,** 229-237.

SAATY, T. L. & VARGAS, L. G. 2013. *Decision making with the analytic network process: economic, political, social and technological applications with benefits, opportunities, costs and risks*, Springer Science & Business Media.

SACHAN, A. & DATTA, S. 2005. Review of supply chain management and logistics research. *International Journal of Physical Distribution & Logistics Management*, *35*, 664-705.

SACHISH, A. 1996. Productivity functions as a managerial tool in Israeli ports. *Maritime Policy & Management,* 23**,** 341-369.

SALTELLI, A., 2002. Sensitivity analysis for importance assessment. *Risk Analysis*, *22*, 579-590.

SÁNCHEZ, R. J., HOFFMANN, J., MICCO, A., PIZZOLITTO, G. V., SGUT, M. & WILMSMEIER, G. 2003. Port efficiency and international trade: Port efficiency as a determinant of maritime transport costs. *Maritime Economics & Logistics,* 5**,** 199-218.

SAUNDERS, M., LEWIS, P. AND THORNHILL, A. 2012. *Research Methods for Business Students*, Essex, Financial Times/Prentice Hall.

SCHELLINCK, T. & BROOKS, M. R. 2014. Improving port effectiveness through determinance/performance gap analysis. *Maritime Policy & Management,* 41**,** 328–345.

SCHMENNER, R. W. 2001. Looking ahead by looking back: Swift, even flow in the history of manufacturing. *Production and Operations Management,* 10**,** 87-96.

SCHMENNER, R. W. 2004. Service businesses and productivity. *Decision Sciences,* 35**,** 333-347.

SEN, P. & YANG, J.-B. 1995. Multiple-criteria decision-making in design selection and synthesis. *Journal of Engeering Design,* 6**,** 207-230.

SHAFER, G. 1976. *A mathematical theory of evidence*, Princeton university press.

SHENG, Y. H. & MYKYTYN JR, P. P. 2002. Information technology investment and firm performance: A perspective of data quality. *Proceedings of the Seventh International Conference on Information Quality (ICIQ-02).* Massachusetts Institute of Technology, US.

SHIEH, J.-I., WU, H.-H. & HUANG, K.-K. 2010. A DEMATEL method in identifying key success factors of hospital service quality. *Knowledge-Based Systems,* 23**,** 277-282.

SHYUR, H.-J. 2006. COTS evaluation using modified TOPSIS and ANP. *Applied Mathematics and Computation,* 177**,** 251-259.

SII, H. S., RUXTON, T. & WANG, J. 2001. A fuzzy-logic-based approach to qualitative safety modelling for marine systems. *Reliability Engineering & System Safety,* 73**,** 19-34.

SLACK, B. 2001. Globalisation in maritime transportation: Competition, uncertainty and implications for port development strategy. Fondazione Eni Enrico Mattei.

SLACK, B., COMTOIS, C. & MCCALLA, R. 2002. Strategic alliances in the container shipping industry: a global perspective. *Maritime Policy & Management,* 29**,** 65-76.
SOBERÓN, A. M. M. 2012. The capacity in container port terminals. Ad Hoc expert meeting on assessing port performance. Geneva, Switzerland: UNCTAD.
SONG, D.-W. 2002. Regional container port competition and co-operation: The case of Hong Kong and South China. *Journal of Transport Geography,* 10**,** 99-110.
SONG, D.-W. & PANAYIDES, P. M. 2008. Global supply chain and port/terminal: Integration and competitiveness. *Maritime Policy & Management,* 35**,** 73-87.
SONG, D.-W. & YEO, K.-T. 2004. A competitive analysis of chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics,* 6**,** 34-52.
SU, Y., LIANG, G.-S., LIU, C.-F. & CHOU, T.-Y. 2003. A study on integrated port performance comparison based on the concept of balanced scorecard. *Journal of the Eastern Asia Society for Transportation Studies,* 5**,** 609-624.
SUYKENS, F. 1983. A few observations on productivity in seaports. *Maritime Policy & Management,* 10**,** 17-40.
TALLEY, W. K. 1988. Optimum throughput and performance evaluation of marine terminals. *Maritime Policy & Management,* 15**,** 327-331.
TALLEY, W. K. 1994. Performance indicators and port performance evaluation. *Logistics and Transportation Review,* 30**,** 339-352.
TALLEY, W. K. 2006. Port performance: An economics perspective. *Research in Transportation Economics,* 17**,** 499-516.
TARDIF, L.-P. 2010. System-wide performance measurements. Transport Canada.
TAVANA, M. & HATAMI-MARBINI, A. 2011. A group AHP-TOPSIS framework for human spaceflight mission planning at NASA. *Expert Systems with Applications,* 38**,** 13588-13603.
THE TIOGA GROUP, I. 2010. Improving marine container terminal productivity: Development of productivity measures, proposed sources of data and initial collection of data from proposed sources.
TOMER, J. F. 1987. *Organizational capital: The path to higher productivity and well-being*, Praeger.
TONGZON, J. 2001. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A: Policy and Practice,* 35**,** 107-122.
TONGZON, J. L. 1995a. Determinants of port performance and efficiency. *Transportation Research Part A: Policy and Practice,* 29**,** 245-252.
TONGZON, J. L. 1995b. Systematizing international benchmarking for ports. *Maritime Policy & Management,* 22**,** 171-177.
TONGZON, J. L. 2009. Port choice and freight forwarders. *Transportation Research Part E: Logistics and Transportation Review,* 45**,** 186-195.
TONGZON, J. L. & GANESALINGAM, S. 1994. An evaluation of ASEAN port performance and efficiency. *Asian Economic Journal,* 8**,** 317-330.
TRUJILLO, L. & NOMBELA, G. 1999. *Privatization and regulation of the seaport industry*, World Bank.
TSAI, M.-C. & SU, C.-H. 2005. Political risk assessment of five East Asian ports—the viewpoints of global carriers. *Marine Policy,* 29**,** 291-298.
UGBOMA, C., IBE, C. & OGWUDE, I. C. 2004. Service quality measurements in ports of a developing economy: Nigerian ports survey. *Managing Service Quality: An International Journal,* 14**,** 487-495.
ULRICH, D. 1997. Measuring human resources: An overview of practice and a prescription for results. *Human Resource Management,* 36**,** 303-320.

UNCTAD. 1976. Port performance indicators. New York, US: UNCTAD.
UNCTAD. 1992. Port marketing and the third generation port. Geneva, Switzerland: UNCTAD.
UNCTAD. 2004. Assessment of a seaport land interface: an analytical framework: UNCTAD.
UNCTAD. 2006. Efficient transport and trade facilitation to improve participation by developing countries in international trade. Geneva, Switzerland: UNCTAD.
VAN DE VOORDE, E. & WINKELMANS, W. 2002. A general introduction to port competition and management. *Huybrechts ea (eds.) port competitiveness.* Ed. de Boeck, Antwerp.
VELDMAN, S. J. & BÜCKMANN, E. H. 2003. A model on container port competition: An application for the west European container hub-ports. *Maritime Economics & Logistics,* 5**,** 3-22.
WANG, J. 1997. A subjective methodology for safety analysis of safety requirements specifications. *IEEE Transactions on Fuzzy Systems,* 5**,** 418-430.
WANG, J. & YANG, J. 2001. A subjective safety and cost based decision model for assessing safety requirements specifications. *International Journal of Reliability, Quality and Safety Engineering,* 8**,** 35-57.
WANG, J., YANG, J. & SEN, P. 1995. Safety analysis and synthesis using fuzzy sets and evidential reasoning. *Reliability Engineering & System Safety,* 47**,** 103-118.
WANG, J., YANG, J. & SEN, P. 1996. Multi-person and multi-attribute design evaluations using evidential reasoning based on subjective safety and cost analyses. *Reliability Engineering & System Safety,* 52**,** 113-128.
WANG, T.-C. & CHANG, T.-H. 2007. Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment. *Expert Systems with Applications,* 33**,** 870-880.
WANG, T.-F. & CULLINANE, K. 2006. The efficiency of European container terminals and implications for supply chain management. *Maritime Economics & Logistics,* 8**,** 82-99.
WEILL, P. 1992. The relationship between investment in information technology and firm performance: A study of the valve manufacturing sector. *Information Systems Research,* 3**,** 307-333.
WILLEM, A. & BUELENS, M. 2009. Knowledge sharing in inter-unit cooperative episodes: The impact of organizational structure dimensions. *International Journal of Information Management,* 29**,** 151-160.
WOLTERS, W.T.M. AND MARESCHAL, B. 1995. Novel types of sensitivity analysis for additive MCDM methods. *European Journal of Operational Research, 81,* 281-290.
WOO, S.-H., PETTIT, S., BERESFORD, A. & KWAK, D.-W. 2012. Seaport research: A decadal analysis of trends and themes since the 1980s. *Transport Reviews,* 32**,** 351-377.
WOO, S.-H., PETTIT, S. & BERESFORD, A. K. 2011a. Port evolution and performance in changing logistics environments. *Maritime Economics & Logistics,* 13**,** 250-277.
WOO, S.-H., PETTIT, S. J. & BERESFORD, A. K. 2013. An assessment of the integration of seaports into supply chains using a structural equation model. *Supply Chain Management: An International Journal,* 18**,** 235-252.
WOO, S.-H., PETTIT, S. J., KWAK, D.-W. & BERESFORD, A. K. C. 2011b. Seaport research: A structured literature review on methodological issues since the 1980s. *Transportation Research Part A: Policy and Practice,* 45**,** 667-685.
WORLD BANK. 2007. World Bank Port Reform Toolkit. Washington, DC, US: World Bank.
WU, H.-H. & TSAI, Y.-N. 2012. An integrated approach of AHP and DEMATEL methods in evaluating the criteria of auto spare parts industry. *International Journal of Systems Science,* 43**,** 2114-2124.

WU, W.-W. 2012. Segmenting critical factors for successful knowledge management implementation using the fuzzy DEMATEL method. *Applied Soft Computing,* 12**,** 527-535.

WU, W.-W. & LEE, Y.-T. 2007. Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications,* 32**,** 499-507.

XU, D.-L. & YANG, J.-B. 2005. Intelligent decision system based on the evidential reasoning approach and its applications. *Journal of Telecommunications and Information Technology,* 3**,** 73-80.

XU, D.-L., YANG, J.-B. & WANG, Y.-M. 2006. The evidential reasoning approach for multi-attribute decision analysis under interval uncertainty. *European Journal of Operational Research,* 174**,** 1914-1943.

YAGER, R. R. 1988. On ordered weighted averaging aggregation operators in multicriteria decisionmaking. *IEEE Transactions on Systems, Man and Cybernetics,* 18**,** 183-190.

YANG, J. 2001. Rule and utility based evidential reasoning approach for multiattribute decision analysis under uncertainties. *European Journal of Operational Research,* 131**,** 31-61.

YANG, J., DALE, B. & SIOW, C. 2001. Self-assessment of excellence: An application of the evidential reasoning approach. *International Journal of Production Research,* 39**,** 3789-3812.

YANG, J. & SEN, P. 1994. A general multi-level evaluation process for hybrid MADM with uncertainty. *IEEE Transactions on Systems, Man and Cybernetics,* 24**,** 1458-1473.

YANG, J. & SINGH, M. 1994. An evidential reasoning approach for multiple-attribute decision making with uncertainty. *IEEE Transactions on Systems, Man and Cybernetics,* 24**,** 1-18.

YANG, J. & XU, D. 1998. Knowledge based executive car evaluation using the evidential reasoning approach, in: Baines, Tleb-Bendiabm, Zhao. (Eds.), Advances in Manufacturing Technology-XII. Professional Engineering Publishing, London, UK.

YANG, J. & XU, D. 2000. An introduction to an intelligent decision system: IDS. *Proceedings of the 42nd Annual Conference of the UK Operational Research Society.* Swansea, UK.

YANG, J. & XU, D. 2002. On the evidential reasoning algorithm for multiple attribute decision analysis under uncertainty. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans,* 32**,** 289-304.

YANG, Z. 2006. *Risk assessment and decision making of container supply chains.* PhD Thesis, Liverpool John Moores University.

YANG, Z., BONSALL, S. & WANG, J. 2009a. Use of hybrid multiple uncertain attribute decision making techniques in safety management. *Expert Systems with Applications,* 36**,** 1569-1586.

YANG, Z., BONSALL, S. & WANG, J. 2011. Approximate TOPSIS for vessel selection under uncertain environment. *Expert Systems with Applications,* 38**,** 14523-14534.

YANG, Z., MASTRALIS, L., BONSALL, S. & WANG, J. 2009b. Incorporating uncertainty and multiple criteria in vessel selection. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment,* 223**,** 177-188.

YANG, Z., WANG, J., BONSALL, S. & FANG, Q. 2009c. Use of fuzzy evidential reasoning in maritime security assessment. *Risk Analysis,* 29**,** 95-120.

YAP, W. Y. & LAM, J. S. L. 2006. Competition dynamics between container ports in East Asia. *Transportation Research Part A: Policy and Practice,* 40**,** 35-51.

YEO, G.-T., NG, A. K., LEE, P. T.-W. & YANG, Z. 2014. Modelling port choice in an uncertain environment. *Maritime Policy & Management,* 41**,** 251-267.

YEO, G.-T., ROE, M. & DINWOODIE, J. 2008. Evaluating the competitiveness of container ports in Korea and China. *Transportation Research Part A: Policy and Practice,* 42**,** 910-921.

YÜKSEL, I. 2012. Developing a multi-criteria decision making model for PESTEL analysis. *International Journal of Business and Management,* 7**,** 52-66.

ZADEH, L. A. 1965. Fuzzy sets. *Information and Control,* 8**,** 338-353.

ZEYDAN, M., ÇOLPAN, C. & ÇOBANOĞLU, C. 2011. A combined methodology for supplier selection and performance evaluation. *Expert Systems with Applications,* 38**,** 2741-2751.

ZHENG, W., YANG, B. & MCLEAN, G. N. 2010. Linking organizational culture, structure, strategy, and organizational effectiveness: Mediating role of knowledge management. *Journal of Business Research,* 63**,** 763-771.

Appendix I Evaluate each port/terminal based on the lowest PPIs

Based on information and previous discussion, different location measurement techniques can be used to transform degrees of belief (DoB) for quantitative PPIs.

- Throughput volume growth

Table I-1 Throughput growth (2012-2013)

Terminal	2012	2013	Growth (‘12-‘13)
T1	2,372,698	1,744,861	-26.46%
T2	1,286,489	1,366,534	6.22%
T3	1,141,941	1,032,732	-9.56%
T4	3,280,016	3,299,457	0.59%
T5	2,442,636	2,375,614	-2.74%
T6	1,988,675	2,391,890	20.28%
T7	662,872	634,916	-4.22%
T8	680,329	747,445	9.87%
T9	805,021	902,077	12.06%
T10	601,706	592,662	-1.50%
T11	369,150	402,473	9.03%
T12	149,181	237,800	59.40%

Table I-2 Throughput growth sets

Terminal	Throughput growth set
T1	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T2	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0.756), (10\%, 0.244), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T3	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T4	$H^{throughput} = \{(\text{leq } 0\%, 0.882), (5\%, 0.118), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T5	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T6	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.944), (geq\ 25\%, 0.056)\}$
T7	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T8	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0.026), (10\%, 0.974), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T9	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0.588), (15\%, 0.412), (20\%, 0), (geq\ 25\%, 0)\}$
T10	$H^{throughput} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T11	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0.194), (10\%, 0.806), (15\%, 0), (20\%, 0), (geq\ 25\%, 0)\}$
T12	$H^{throughput} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (geq\ 25\%, 1)\}$

- Vessel call capacity growth

Vessel call capacity growth in T6

The quantitative assessment grades of the vessel call capacity growth is defined as *{leq 0%, 5%, 10%, 15%, geq 20%}* in section 5.3.1.

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), geq\ 20\%(H_5)\}$$

The vessel call capacity growth in T6 is 18.04%, this value can be transformed to DoB.

$$h_{j-1,i} = 15\%(H_4), \qquad h_{j,i} = 18.04\%, \qquad h_{j+1,i} = geq\ 20\%(H_5)$$

Thus, $B_{j+1,i} = \frac{18.04-15}{20-15} = 0.608$ DoB with $geq\ 20\%(H_5)$ and $B_{j-1,i} = 1 - 0.608 = 0.392$ DoB with $15\%(H_4)$. Therefore, the vessel capacity growth set in T6 is assessed as follows:

$$H^{V\ capacity} = \{(leq\ 0\%, 0), (5\%, 0), (10\%, 0), (15\%, 0.392), (geq\ 20\%, 0.608)\}$$

Table I-3 Vessel capacity growth (2012-2013)

Terminal	2012			2013			Growth (‘12-‘13)
	No.Vessel	Total G/T	Ave. Capacity	No.Vessel	Total G/T	Ave. Capacity	
T1	1,981	54,362,646	27,442	1,816	35,433,654	19,512	-28.90%
T2	1,793	20,091,761	11,206	2,038	20,741,024	10,177	-9.18%

T3	1,302	25,752,362	19,779	1,154	25,362,340	21,978	11.12%
T4	1,921	105,401,114	54,868	2,051	112,842,775	55,018	0.27%
T5	1,683	65,301,443	38,801	1,624	66,216,616	40,774	5.09%
T6	1,075	43,696,846	40,648	1,070	51,339,161	47,981	18.04%
T7	3,006	77,396,480	25,747	2,816	85,263,878	30,278	17.60%
T8	2,928	79,448,056	27,134	3,107	89,492,516	28,804	6.15%
T9	2,564	85,776,486	33,454	2,335	86,755,301	37,154	11.06%
T10	1,212	22,421,683	18,500	1,137	23,237,577	20,438	-1.50%
T11	1,139	9,373,625	8,230	1,115	9,654,695	8,659	9.03%
T12	460	4,281,966	9,309	630	5,899,253	9,364	59.40%

Table I-4 Vessel capacity growth sets

Terminal	Vessel call size growth
T1	$H^{V\ capacity}=\{(\text{leq }0\%,1),(5\%,0),(10\%,0),(15\%,0),(geq\ 20\%,0)\}$
T2	$H^{V\ capacity}=\{(\text{leq }0\%,1),(5\%,0),(10\%,0),(15\%,0),(geq\ 20\%,0)\}$
T3	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0),(10\%,0.776),(15\%,0.224),(geq\ 20\%,0)\}$
T4	$H^{V\ capacity}=\{(\text{leq }0\%,0.946),(5\%,0.054),(10\%,0),(15\%,0),(geq\ 20\%,0)\}$
T5	$H^{V\ capacity}=\{(\text{leq }0\%,0.982),(5\%,0.018),(10\%,0),(15\%,0),(geq\ 20\%,0)\}$
T6	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0),(10\%,0),(15\%,0.392),(geq\ 20\%,0.608)\}$
T7	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0),(10\%,0),(15\%,0.48),(geq\ 20\%,0.52)\}$
T8	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0.77),(10\%,0.23),(15\%,0),(geq\ 20\%,0)\}$
T9	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0),(10\%,0.788),(15\%,0.212),(geq\ 20\%,0)\}$
T10	$H^{V\ capacity}=\{(\text{leq }0\%,1),(5\%,0),(10\%,0),(15\%,0),(geq\ 20\%,0)\}$
T11	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0.194),(10\%,0.806),(15\%,0),(geq\ 20\%,0)\}$
T12	$H^{V\ capacity}=\{(\text{leq }0\%,0),(5\%,0),(10\%,0),(15\%,0),(geq\ 20\%,1)\}$

- Ship load rate

<u>*Ship load rate in T6*</u>

A set of quantitative grades *{leq 25TEU, 40TEU, 55TEU, 70TEU, 85TEU, geq 100TEU}* for ship load rate is defined in section 5.3.1.

$$H=\{\text{leq 25TEU}(H_1),40TEU(H_2),55TEU(H_3),\text{70TEU}(H_4),85TEU(H_5),\text{geq 100TEU}(H_6)\}$$

The ship load rate in T6 is 49.85TEU/GT, this value can be transformed to DoB.

$$h_{j-1,i}=\ 40TEU(H_2),\qquad h_{j,i}=49.85TEU,\qquad h_{j+1,i}=\ 55TEU(H_3)$$

Thus, $B_{j+1,i}=\frac{49.85-40}{55-40}=0.657$ DoB with $55TEU(H_3)$ and $B_{j-1,i}=1-0.657=0.343$ DoB with $40TEU(H_2)$. Therefore, the ship load rate (SLR) set in T6 is assessed as follows:

$$H^{SLR}=\{(leq\ 25TEU,0),(40TEU,0.343),(55TEU,0.657),(70TEU,0),(85TEU,0),(geq\ 100TEU,0)\}$$

Table I-5 Ship load rate (2013)

Terminal	Throughput (TEU)	Aver. Capacity (GT)	Load rate (TEU/GT)
T1	1,744,861	19,512	89.43
T2	1,366,534	10,177	134.27
T3	1,032,732	21,978	46.99
T4	3,299,457	55,018	59.97
T5	2,375,614	40,774	58.26
T6	2,391,890	47,981	49.85
T7	634,916	30,278	20.97
T8	747,445	28,804	25.95
T9	902,077	37,154	24.28
T10	592,662	20,438	29.00
T11	402,473	8,659	46.48
T12	237,800	9,364	25.40

Table I-6 Ship load rate sets

Terminal	Ship load rate
T1	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0.705), (geq 100TEU, 0.295)}
T2	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 1)}
T3	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0.534), (55TEU, 0.466), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T4	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0.669), (70TEU, 0.331), (85TEU, 0), (geq 100TEU, 0)}
T5	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0.783), (70TEU, 0.217), (85TEU, 0), (geq 100TEU, 0)}
T6	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0.343), (55TEU, 0.657), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T7	$H^{loadrate}$ = {(leq 25TEU, 1), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T8	$H^{loadrate}$ = {(leq 25TEU, 0.937), (40TEU, 0.063), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T9	$H^{loadrate}$ = {(leq 25TEU, 1), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T10	$H^{loadrate}$ = {(leq 25TEU, 0.733), (40TEU, 0.267), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T11	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0.568), (55TEU, 0.432), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
T12	$H^{loadrate}$ = {(leq 25TEU, 0.973), (40TEU, 0.027), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}

- Berth utilisation

Berth utilisation in T6

A set of quantitative grades *{leq 300TEU, 600TEU, 900TEU, 1200TEU, 1500TEU, geq 1800TEU}* for berth utilization is defined in section 5.3.1.

$$H = \{leq\ 300TEU(H_1), 600TEU(H_2), 900TEU(H_3), 1200TEU(H_4), 1500TEU(H_5), geq\ 1800TEU(H_6)\}$$

The berth utilization in T6 is 2080TEU/m, this value can be directly transformed to DoB set as follow:

$$H^{berth\ U} = \{(less\ than\ 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0), (more\ than\ 1800TEU, 1)\}$$

Table I-7 Berth utilization

Terminal	Throughput (TEU)	Berth length (m)	Utilization
T1	1,744,861	1,500	1163
T2	1,366,534	1,447	944
T3	1,032,732	826	1250
T4	3,299,457	2,000	1650
T5	2,375,614	1,100	2160
T6	2,391,890	1,150	2080
T7	634,916	1,150	552
T8	747,445	1,150	650
T9	902,077	1,400	644
T10	592,662	600	988
T11	402,473	407	989
T12	237,800	260	915

Table I-8 Berth utilization sets

Terminal	Berth utilization
T1	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.123), (1200TEU, 0.877), (1500TEU, 0), (geq 1800TEU, 0)}
T2	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.853), (1200TEU, 0.147), (1500TEU, 0), (geq 1800TEU, 0)}
T3	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0.833), (1500TEU, 0.167), (geq 1800TEU, 0)}
T4	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0.25), (geq 1800TEU, 0.75)}
T5	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 1)}
T6	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 1)}
T7	$H^{berth\ U}$ = {(leq 300TEU, 0.16), (600TEU, 0.84), (900TEU, 0), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 0)}
T8	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0.833), (900TEU, 0.167), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 0)}
T9	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0.853), (900TEU, 0.147), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 0)}
T10	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.707), (1200TEU, 0.293), (1500TEU, 0), (geq 1800TEU, 0)}
T11	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.703), (1200TEU, 0.297), (1500TEU, 0), (geq 1800TEU, 0)}
T12	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.95), (1200TEU, 0.05), (1500TEU, 0), (geq 1800TEU, 0)}

- Berth occupancy rate

Berth occupancy rate in T6

A set of quantitative grades *{leq 45%, 50%, 55%, 60-80%, geq 80%}* for berth occupancy rate is already defined in section 5.3.1.

$$H = \{leq\ 45\%(H_1), 50\%(H_2), 55\%(H_3), 60 - 80\%(H_4), geq\ 80\%(H_5)\}$$

The berth occupancy rate in T6 is 69%, this value can be directly transformed to DoB set as follows:

$$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (geq\ 80\%, 0)\}$$

Table I-9 Berth occupancy rate

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
Berth occupancy (%)	47	51	72	27	54	69	41	40	48	55	42	53

Table I-10. Berth occupancy rate sets

Terminal	Berth occupancy
T1	$H^{berth\ O} = \{(leq\ 45\%, 0.6), (50\%, 0.4), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T2	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0.8), (55\%, 0.2), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T3	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (geq\ 80\%, 0)\}$
T4	$H^{berth\ O} = \{(leq\ 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T5	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0.2), (55\%, 0.8), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T6	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 0), (60 - 80\%, 1), (geq\ 80\%, 0)\}$
T7	$H^{berth\ O} = \{(leq\ 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T8	$H^{berth\ O} = \{(leq\ 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T9	$H^{berth\ O} = \{(leq\ 45\%, 0.4), (50\%, 0.6), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T10	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0), (55\%, 1), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T11	$H^{berth\ O} = \{(leq\ 45\%, 1), (50\%, 0), (55\%, 0), (60 - 80\%, 0), (geq\ 80\%, 0)\}$
T12	$H^{berth\ O} = \{(leq\ 45\%, 0), (50\%, 0.4), (55\%, 0.6), (60 - 80\%, 0), (geq\ 80\%, 0)\}$

- Crane efficiency

Crane efficiency in T6

A set of quantitative grades *{leq 20moves, 25moves, 30moves, 35moves, 40moves, geq 45moves}* for crane efficiency is already defined in section 5.3.1.

$$H = \{leq\ 20moves(H_1), 25moves(H_2), 30moves(H_3), 35moves(H_4), 40moves(H_5), geq\ 45moves(H_6)\}$$

The crane efficiency in T6 is 31 moves/h, this value can be transformed to DoB.

$$h_{j-1,i} = \ 30moves(H_3), \qquad h_{j,i} = 31moves, \qquad h_{j+1,i} = \ 35moves(H_4)$$

Thus, $B_{j+1,i} = \frac{31-30}{35-30} = 0.2$ DoB with $35moves(H_4)$ and $B_{j-1,i} = 1 - 0.2 = 0.8$ DoB with $30moves(H_3)$. Therefore, the crane efficiency set in T6 is assessed as follows:

$$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.8), (35moves, 0.2), (40moves, 0), (geq\ 45mvoes, 0)\}$$

Table I-11 Crane efficiency

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
Crane efficiency (moves/h)	34	34	35	39	33	31	33	30	35	31	32	36

Table I-12 Crane efficiency sets

Terminal	Crane efficiency
T1	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.2), (35moves, 0.8), (40moves, 0), (geq\ 45moves, 0)\}$
T2	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.2), (35moves, 0.8), (40moves, 0), (geq\ 45moves, 0)\}$
T3	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 1), (40moves, 0), (geq\ 45moves, 0)\}$
T4	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 0.2), (40moves, 0.8), (geq\ 45moves, 0)\}$
T5	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.4), (35moves, 0.6), (40moves, 0), (geq\ 45moves, 0)\}$
T6	$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0.8), (35moves, 0.2), (40moves, 0), (geq\ 45moves, 0)\}$

T7	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 0.4), (35moves, 0.6), (40moves, 0), (geq 45moves, 0)}
T8	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 1), (35moves, 0), (40moves, 0), (geq 45moves, 0)}
T9	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 1), (40moves, 0), (geq 45moves, 0)}
T10	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 0.8), (35moves, 0.2), (40moves, 0), (geq 45moves, 0)}
T11	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 0.6), (35moves, 0.4), (40moves, 0), (geq 45moves, 0)}
T12	H^{crane} = {(leq 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 0.8), (40moves, 0.2), (geq 45moves, 0)}

- Yard utilisation

Yard utilisation in T6

A set of quantitative grades *{less than 2TEU, 4TEU, 6TEU, 8TEU, more than 10TEU*} for yard utilization is already defined in section 5.3.1.

$$H = \{leq\ 2TEU(H_1), 4TEU(H_2), 6TEU(H_3), 8TEU(H_4), geq10TEU(H_5)\}$$

The yard utilization in T6 is 11.2 TEU/㎡, this value can be directly transformed to DoB set as follow:

$$H^{yard} = \{(leq\ 2TEU, 0), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 1)\}$$

Table I-13 Yard utilization

Terminal	Throughput (TEU)	CY area (㎡)	Utilization
T1	1,744,861	806,000	2.2
T2	1,366,534	394,000	3.5
T3	1,032,732	153,000	6.7
T4	3,299,457	525,000	6.3
T5	2,375,614	346,000	6.9
T6	2,391,890	213,000	11.2
T7	634,916	259,000	2.5
T8	747,445	259,000	2.9
T9	902,077	515,000	1.8
T10	592,662	270,000	2.2
T11	402,473	225,000	1.8
T12	237,800	102,000	2.3

Table I-14 Yard utilization sets

Terminal	Yard utilization
T1	H^{yard} = {(leq 2TEU, 0.9), (4TEU, 0.1), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T2	H^{yard} = {(leq 2TEU, 0.25), (4TEU, 0.75), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T3	H^{yard} = {(leq 2TEU, 0), (4TEU, 0), (6TEU, 0.65), (8TEU, 0.35), (geq 10TEU, 0)}
T4	H^{yard} = {(leq 2TEU, 0), (4TEU, 0), (6TEU, 0.85), (8TEU, 0.15), (geq 10TEU, 0)}
T5	H^{yard} = {(leq 2TEU, 0), (4TEU, 0), (6TEU, 0.55), (8TEU, 0.45), (geq 10TEU, 0)}
T6	H^{yard} = {(leq 2TEU, 0), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq 10TEU, 1)}
T7	H^{yard} = {(leq 2TEU, 0.75), (4TEU, 0.25), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T8	H^{yard} = {(leq 2TEU, 0.55), (4TEU, 0.45), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T9	H^{yard} = {(leq 2TEU, 1), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T10	H^{yard} = {(leq 2TEU, 0.9), (4TEU, 0.1), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T11	H^{yard} = {(leq 2TEU, 1), (4TEU, 0), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}
T12	H^{yard} = {(leq 2TEU, 0.85), (4TEU, 0.15), (6TEU, 0), (8TEU, 0), (geq 10TEU, 0)}

- Labour utilisation

Labour utilisation in T6

A set of quantitative grades *{leq 1000TEU, 2000TEU, 3000TEU, 4000TEU, 5000TEU, geq 6000TEU}* for labour utilization is already defined in section 5.3.1.

$$H = \{leq\ 1000TEU(H_1), 2000TEU(H_2), 3000TEU(H_3), 4000TEU(H_4), 5000TEU(H_5), geq\ 6000TEU(H_6)\}$$

The labour utilisation in T6 is 5,144TEU/man, this value can be transformed to DoB.

$$h_{j-1,i} = 5000TEU(H_5),\ \ h_{j,i} = 5{,}144\ TEU, \qquad h_{j+1,i} = geq\ 6000TEU(H_6)$$

Thus, $B_{j+1,i} = \frac{5144-5000}{6000-5000} = 0.144$ DoB with $geq\ 6000TEU(H_6)$ and $B_{j-1,i} = 1 - 0.144 = 0.856$ DoB with $5000TEU(H_5)$. Therefore, the labour utilization set in T6 is assessed as follows:

$$H^{labour} = \{(leq\ 1000TEU, 0), (2000TEU, 0), (3000TEU, 0), (4000TEU, 0), (5000TEU, 0.856), (geq\ 6000TEU, 0.144)\}$$

Table I-15 Labour utilisation

Terminal	Throughput (TEU)	Employee	Utilization
T1	1,744,861	527	3311
T2	1,366,534	406	3366
T3	1,032,732	368	2806
T4	3,299,457	1117	2954
T5	2,375,614	490	4848
T6	2,391,890	465	5144
T7*	634,916	-	-
T8	747,445	-	-
T9	902,077	-	-
T10	592,662	-	-
T11	402,473	-	-
T12	237,800	-	-

Note: *No applicable data in T7-T12 (the numbers of employees in T7-T12 were collected using questionnaire survey but the data was not applicable for analysis due to huge variances between responses).

Table I-16 Labour utilisation sets

Terminal	Labour utilization
T1	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.689), (4000TEU, 0.311), (5000TEU, 0), (geq 6000TEU, 0)}
T2	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.634), (4000TEU, 0.366), (5000TEU, 0), (geq 6000TEU, 0)}
T3	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0.194), (3000TEU, 0.806), (4000TEU, 0), (5000TEU, 0), (geq 6000TEU, 0)}
T4	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0.046), (3000TEU, 0.954), (4000TEU, 0), (5000TEU, 0), (geq 6000TEU, 0)}
T5	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0), (4000TEU, 0.152), (5000TEU, 0.848), (geq 6000TEU, 0)}
T6	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0), (4000TEU, 0), (5000TEU, 0.856), (geq 6000TEU, 0.144)}
T7	-
T8	-
T9	-
T10	-
T11	-
T12	-

- Vessel turnaround time

Vessel turnaround time in T6

A set of quantitative grades {geq 5 days, 4 days, 3days, 2days, leq 1day} for vessel turnaround time is already defined in section 5.3.1.

$$H = \{geq\ 5days(H_1), 4days(H_2), 3days(H_3), 2days(H_4), leq\ 1day(H_5)\}$$

The vessel turnaround time in T6 is 18.6 hours which can be directly transformed to DoB set as follow:

$$H^{vessel\ T} = \{(more\ than\ 5days, 0), (4days, 0), (3days, 0), (2days, 0), (less\ than\ 1day, 1)\}$$

Table I-17 Vessel turnaround time

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7*	T 8*	T 9*	T 10*	T 11*	T 12*
Turnaround time (hour)	14.5	16.1	19.4	16.1	16.5	18.6	≤24	≤24	≤24	≤24	≤24	≤24

Note: *The data in T7-T12 was collected using questionnaire survey.

Table I-18 Vessel turnaround time sets

Terminal	Vessel turnaround time

T1	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T2	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T3	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T4	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T5	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T6	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T7	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T8	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T9	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T10	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T11	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
T12	$H^{vessel\,T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}

- Truck turnaround time

<u>*Truck turnaround time in T6*</u>

A set of quantitative grades *{geq 40 minutes, 35minutes, 30minutes, 25minutes, 20minutes, leq15minutes}* for truck turnaround time is already defined in section 5.3.1.

$$H = \{geq\ 40\ mins(H_1), 35mins(H_2), 30mins(H_3), 25mins(H_4), 20mins(H_5), leq\ 15mins(H_6)\}$$

The truck turnaround time in T6 is 16.7 minutes, which can be transformed to DoB.

$$h_{j-1,i} = 20mins(H_5),\quad h_{j,i} = 16.7,\qquad h_{j+1,i} = leq\ 15mins(H_6)$$

Thus, $B_{j+1,i} = \frac{16.7-20}{15-20} = 0.66$ DoB with $leq\ 15mins(H_6)$ and $B_{j-1,i} = 1 - 0.66 = 0.34$ DoB with $20mins(H_5)$. Therefore, the truck turnaround time set in T6 is assessed as follows:

$$H^{truck\,T} = \{(geq\ 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.34), (leq\ 15mins, 0.66)\}$$

Table I-19 Truck turnaround time

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7*	T 8	T 9	T 10	T 11	T 12
Turnaround time (minute)	18.4	18.8	23.1	14.4	14.1	16.7	20.3	21.5	23.5	34.8	38.4	24.3

Note: *The data was collected using questionnaire survey.

Table I-20 Truck turnaround time sets

Terminal	Truck turnaround time
T1	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.68), (leq 15mins, 0.32)}
T2	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.76), (leq 15mins, 0.24)}
T3	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.62), (20mins, 0.38), (leq 15mins, 0)}
T4	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0), (leq 15mins, 1)}
T5	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0), (leq 15mins, 1)}
T6	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.34), (leq 15mins, 0.66)}
T7	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.94), (20mins, 0.06), (leq 15mins, 0)}
T8	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.3), (20mins, 0.7), (leq 15mins, 0)}
T9	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.7), (20mins, 0.3), (leq 15mins, 0)}
T10	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0.96), (30mins, 0.04), (25mins, 0), (20mins, 0), (leq 15mins, 0)}
T11	$H^{truck\,T}$ = {(geq 40mins, 0.68), (35mins, 0.32), (30mins, 0), (25mins, 0), (20mins, 0), (leq 15mins, 0)}
T12	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.86), (20mins, 0.14), (leq 15mins, 0)}

- Container dwell time

<u>*Container dwell time in T6*</u>

A set of quantitative grades *{geq 4 weeks, 3 weeks, 10 days, 7 days, 5 days, leq 3 days}* for container dwell time is already defined in section 5.3.1.

$$H = \{geq\ 4weeks(H_1), 3weeks(H_2), 10days(H_3), 7days(H_4), 5days(H_5), leq\ 3days(H_6)\}$$

The container dwell time in T6 is 3.7 days, which can be transformed to DoB.

$$h_{j-1,i} = 5days(H_5), \qquad h_{j,i} = 3.7days, \qquad h_{j+1,i} = leq\ 3days(H_6)$$

Thus, $B_{j+1,i} = \frac{3.7-5}{3-5} = 0.65$ DoB with $leq\ 3days(H_6)$ and $B_{j-1,i} = 1 - 0.65 = 0.35$ DoB with $5days(H_5)$. Therefore, container dwell time set in T6 is assessed as follows:

$H^{dwell} = \{(geq\ 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.35), (leq\ 3days, 0.65)\}$

Table I-21 Container dwell time

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
Container dwell time (hour)	4.2	4.7	3.6	4.1	4	3.7	5.9	5.8	5.8	4.3	5.2	5.1

Table I-22 Container dwell time sets

Terminal	Container dwell time
T1	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.6), (leq 3days, 0.4)}
T2	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.85), (leq 3days, 0.15)}
T3	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.3), (leq 3days, 0.7)}
T4	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.55), (leq 3days, 0.45)}
T5	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.5), (leq 3days, 0.5)}
T6	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.35), (leq 3days, 0.65)}
T7	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.45), (5days, 0.55), (leq 3days, 0)}
T8	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.4), (5days, 0.6), (leq 3days, 0)}
T9	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.4), (5days, 0.6), (leq 3days, 0)}
T10	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.65), (leq 3days, 0.35)}
T11	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.1), (5days, 0.9), (leq 3days, 0)}
T12	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.05), (5days, 0.95), (leq 3days, 0)}

- Revenue growth

<u>*Revenue growth in T6*</u>

A set of quantitative grades *{leq 0 %, 2 %, 4 %, 6 %, 8 %, geq 10 %}* for revenue growth is already defined in section 5.3.1.

$$H = \{leq\ 0\%(H_1), 2\%(H_2), 4\%(H_3), 6\%(H_4), 8\%(H_5), geq\ 10\%(H_6)\}$$

The revenue growth in T6 is 35.63%, which can be directly transformed to DoB set as follows:

$$H^{revenue} = \{(leq\ 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (geq\ 10\%, 1)\}$$

Table I-23 Revenue growth (2012-2013)

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11*	T 12
Revenue growth (%)	-29	-2.22	-3.21	-1.23	-9.74	35.63	-5.89	16.42	8.75	2.8	0.03	49.68

Note: *The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-24 Revenue growth sets

Terminal	Revenue growth
T1	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T2	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T3	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T4	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T5	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T6	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 1)}
T7	$H^{revenue}$ = {(leq 0%, 1), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T8	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 1)}
T9	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0.625), (geq 10%, 0.375)}
T10	$H^{revenue}$ = {(leq 0%, 0), (2%, 0.6), (4%, 0.4), (6%, 0), (8%, 0), (geq 10%, 0)}
T11	$H^{revenue}$ = {(leq 0%, 0.985), (2%, 0.015), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 0)}
T12	$H^{revenue}$ = {(leq 0%, 0), (2%, 0), (4%, 0), (6%, 0), (8%, 0), (geq 10%, 1)}

- Operating profit margin

Operating profit margin in T6

A set of quantitative grades *{leq 0%, 10%, 15%, 20%, 25%, geq 30%}* for operating profit margin is already defined in section 5.3.1.

$$H = \{leq\ 0\%(H_1), 10\%(H_2), 15\%(H_3), 20\%(H_4), 25\%(H_5), geq\ 30\%(H_6)\}$$

The operating profit margin in T6 is 29.72%, this value can be transformed to DoB.

$$h_{j-1,i} = 25\%(\mathrm{H}_5), \qquad h_{j,i} = 20.94\%, \qquad h_{j+1,i} = \mathrm{geq}\ 30\%(\mathrm{H}_6)$$

Thus, $B_{j+1,i} = \frac{29.72-25}{30-25} = 0.944$ DoB with $\mathrm{geq}\ 30\%(\mathrm{H}_6)$ and $B_{j-1,i} = 1 - 0.944 = 0.056$ DoB with $25\%(\mathrm{H}_5)$. Therefore, operating profit margin set in T6 is assessed as follows:

$$H^{operating\ M} = \{(leq\ 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.056), (geq\ 30\%, 0.944)\}$$

Table I-25 Operating profit margin (2013)

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9*	T 10	T 11**	T 12
Operating profit margin (%)	-55.6	-19	4.35	26.09	25.08	29.72	-0.95	-1.01	-	29.9	17.55	4.29

Note: *No available data.
**The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-26 Operating profit margin sets

Terminal	Operating profit margin
T1	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T2	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T3	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0.565), (10\%, 0.435), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T4	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.782), (\mathrm{geq}\ 30\%, 0.218)\}$
T5	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.984), (\mathrm{geq}\ 30\%, 0.016)\}$
T6	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.056), (\mathrm{geq}\ 30\%, 0.944)\}$
T7	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T8	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T9	-
T10	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.02), (\mathrm{geq}\ 30\%, 0.98)\}$
T11	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0), (10\%, 0), (15\%, 0.49), (20\%, 0.51), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$
T12	$H^{operating\ M} = \{(\mathrm{leq}\ 0\%, 0.571), (10\%, 0.429), (15\%, 0), (20\%, 0), (25\%, 0), (\mathrm{geq}\ 30\%, 0)\}$

- Net profit margin

Net profit margin in T6

A set of quantitative grades {leq 0 %, 5 %, 10 %, 15 %, 20 %, geq 25 %} for net profit margin is already defined in section 5.3.1.

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), geq\ 25\%(H_6)\}$$

The net profit margin in T6 is 13.18%, this value can be transformed to DoB.

$$h_{j-1,i} = 10\%(H_3), \qquad h_{j,i} = 13.18\%, \qquad h_{j+1,i} = 15\%(H_4)$$

Thus, $B_{j+1,i} = \frac{13.18-10}{15-10} = 0.636$ DoB with $15\%(H_4)$ and $B_{j-1,i} = 1 - 0.636 = 0.364$ DoB with $10\%(H_3)$. Therefore, net profit margin set in T6 is assessed as follows:

$$H^{net\ M} = \{(\mathrm{leq}\ 0\%, 0), (5\%, 0), (10\%, 0.364), (15\%, 0.636), (20\%, 0), (\mathrm{geq}\ 25\%, 0)\}$$

Table I-27 Net profit margin (2013)

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11*	T 12
Net profit margin (%)	-59.3	-15.3	5.24	22.33	15.88	13.18	-0.11	1.04	9.09	19.2	13.98	0.9

Note: *The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-28 Net profit margin sets

Terminal	Net profit margin
T1	$H^{net\ M}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
T2	$H^{net\ M}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
T3	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0.952), (10%, 0.048), (15%, 0), (20%, 0), (geq 25%, 0)}
T4	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0), (20%, 0.534), (geq 25%, 0.466)}
T5	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0.824), (20%, 0.176), (geq 25%, 0)}
T6	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.364), (15%, 0.636), (20%, 0), (geq 25%, 0)}
T7	$H^{net\ M}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
T8	$H^{net\ M}$ = {(leq 0%, 0.792), (5%, 0.208), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
T9	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0.182), (10%, 0.818), (15%, 0), (20%, 0), (geq 25%, 0)}
T10	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0), (15%, 0.16), (20%, 0.84), (geq 25%, 0)}
T11	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.204), (15%, 0.796), (20%, 0), (geq 25%, 0)}
T12	$H^{net\ M}$ = {(leq 0%, 0.82), (5%, 0.18), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}

- Current ratio

Current ratio in T6

A set of quantitative grades {leq 1, between 1 and 2, geq 2} for current ratio is already defined.

$$H = \{leq\ 1(H_1), between\ 1\ and\ 2(H_2), geq\ 2(H_3)\}$$

The current ratio in T6 is 0.91 (91%), this value can be directly transformed to DoB set as follows:

$$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$$

Table I-29 Current ratio

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9*	T 10	T 11**	T 12
Current ratio	0.61	1.82	4.94	4.89	2.55	0.91	1.49	0.46	-	1.89	1.26	5.22

Note: *No available data.
**The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-30 Current ratio sets

Terminal	Current ratio
T1	$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
T2	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 1), (geq\ 2, 0)\}$
T3	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
T4	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
T5	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
T6	$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
T7	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 1), (geq\ 2, 0)\}$
T8	$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
T9	-
T10	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 1), (geq\ 2, 0)\}$
T11	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 1), (geq\ 2, 0)\}$
T12	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$

- Debt to total assets

Debt to total assets in T6

A set of quantitative grades {geq 0.5, leq 0.5} for debt to total assets is already defined in section 5.3.1.

$$H = \{geq\ 0.5(H_1), leq\ 0.5(H_2)\}$$

The debt to total assets in T6 is 0.84 (84%), this value can be directly transformed to DoB set as follows:

$$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$$

Table I-31 Debt to total assets

Terminal	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9*	T 10	T 11**	T 12
Debt to total assets	0.57	5.34	0.27	0.24	0.84	0.84	0.40	1.55	-	0.62	0.28	0.32

Note: *No available data.
**The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-32 Debt to total assets sets

Terminal	Debt to total assets sets
T1	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T2	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T3	$H^{DA} = \{(geq\ 0.5,0), (leq\ 0.5, 1)\}$
T4	$H^{DA} = \{(geq\ 0.5,0), (leq\ 0.5, 1)\}$
T5	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T6	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T7	$H^{DA} = \{(geq\ 0.5,0), (leq\ 0.5, 1)\}$
T8	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T9	-
T10	$H^{DA} = \{(geq\ 0.5,1), (leq\ 0.5, 0)\}$
T11	$H^{DA} = \{(geq\ 0.5,0), (leq\ 0.5, 1)\}$
T12	$H^{DA} = \{(geq\ 0.5,0), (leq\ 0.5, 1)\}$

- Debt to owner's equity

Debt to owner's equity in T6

A set of quantitative grades {geq 2, 1.8, 1.6, 1.4, 1.2, leq 1} for debt to owner's equity is already defined in section 5.3.1.

$$H = \{geq\ 2(H_1), 1.8(H_2), 1.6(H_3), 1.4(H_4), 1.2(H_5), leq\ 1(H_6)\}$$

The debt to owner's equity in T6 is 5.13 (513%), this value can be directly transformed to DoB as follows:

$$H^{DE} = \{(geq\ 2,1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$$

Table I-33 Debt to owner's equity (2013)

Terminal	T 1	T 2*	T 3	T 4	T 5	T 6	T 7	T 8*	T 9**	T 10	T 11***	T 12
Debt to owner's equity	1.33	-1.23	0.36	0.31	5.06	5.13	0.68	-2.82	-	1.63	0.39	0.46

Note: *Impairment of capital in T2 and T8, which means they are in a perilous financial condition.
**No available data.
***The data in T11 is based on the consolidated financial statement but others are based on their individual financial statement.

Table I-34 Debt to owner's equity sets

Terminal	Debt to owner's equity
T1	$H^{DE} = \{(geq\ 2,0), (1.8, 0), (1.6, 0), (1.4, 0.65), (1.2, 0.35), (leq\ 1, 0)\}$
T2	-
T3	$H^{DE} = \{(geq\ 2,0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
T4	$H^{DE} = \{(geq\ 2,0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
T5	$H^{DE} = \{(geq\ 2,1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$
T6	$H^{DE} = \{(geq\ 2,1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$
T7	$H^{DE} = \{(geq\ 2,0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
T8	-
T9	-
T10	$H^{DE} = \{(geq\ 2,0), (1.8, 0.15), (1.6, 0.85), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$
T11	$H^{DE} = \{(geq\ 2,0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$

T12	$H^{DE} = \{(geq\ 2{,}0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$

- Qualitative PPIs (T1)

The DoB with respect to linguistic terms for qualitative PPIs are straightforwardly obtained by assessors' judgements. 11 assessors from T1 evaluated on the SA, TSCI, SSS and EVS. 43 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-35 Response details for T1

	Terminal operator	User		Administrator	
	T1	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	17 (13)	21 (18)	0	0
Online received	12 (11)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(11)	(18)	(25)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Based on Eq. (5.34), the judgement results by a number of assessors can be represented as follows. Total 11 assessors from T1 took part in the judgements on supporting activities. Then, the measurement can be presented by DoB belonging to linguistic terms based on Eq. (5.35).

Table I-36 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0*	0	0	11	0	11
Capability	0	1	4	6	0	11
Training and education opportunity	1	3	3	3	1	11
Commitment and Loyalty	0	2	3	5	1	11
Organisation Capital (OCS)						
Culture	0	1	3	5	2	11
Leadership	0	1	3	4	3	11
Alignment	1	1	3	5	1	11
Teamwork	0	1	3	7	0	11
Information Capital (ICS)						
IT systems	0	0	2	6	3	11
Databases	0	0	6	4	1	11
Networks	0	2	1	6	2	11

Note: * The data represents the number of assessors who judge on the associated linguistic term.

Table I-37 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.00	1.00	0.00	1.00
Capability	0.00	0.09	0.36	0.55	0.00	1.00
Training and education opportunity	0.09	0.27	0.27	0.27	0.09	1.00
Commitment and Loyalty	0.00	0.18	0.27	0.45	0.09	1.00
Organisation Capital (OCS)						
Culture	0.00	0.09	0.27	0.45	0.18	1.00
Leadership	0.00	0.09	0.27	0.36	0.27	1.00
Alignment	0.09	0.09	0.27	0.45	0.09	1.00
Teamwork	0.00	0.09	0.27	0.64	0.00	1.00
Information Capital (ICS)						
IT systems	0.00	0.00	0.18	0.55	0.27	1.00
Databases	0.00	0.00	0.55	0.36	0.09	1.00

Networks	0.00	0.18	0.09	0.55	0.18	1.00

Users' Satisfaction

Total 42-43 assessors from port users took part in the judgements on users' satisfaction. Then, the measurement can be presented by degrees of belief belonged to linguistic terms based on based on Eq. (5.35).

Table I-38 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	1	10	24	8	43
Responsiveness to special requests	1	2	15	17	7	42
Accuracy of document & information	0	4	14	19	6	43
Incidence of cargo damage	0	2	16	16	9	43
Incidence of service delay	1	3	26	10	3	43
Service Costs (SCU)						
Overall service costs	0	4	20	14	5	43
Cargo handling charges	0	4	22	14	3	43
Cost of terminal ancillary services	0	5	22	13	3	43

Note: S. dissatisfied: Strongly Dissatisfied; S. satisfied: Strongly Satisfied

Table I-39 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.02	0.23	0.56	0.19	1.00
Responsiveness to special requests	0.02	0.05	0.36	0.40	0.17	1.00
Accuracy of document & information	0.00	0.09	0.33	0.44	0.14	1.00
Incidence of cargo damage	0.00	0.05	0.37	0.37	0.21	1.00
Incidence of service delay	0.02	0.07	0.60	0.23	0.07	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.09	0.47	0.33	0.12	1.00
Cargo handling charges	0.00	0.09	0.51	0.33	0.07	1.00
Cost of terminal ancillary services	0.00	0.12	0.51	0.30	0.07	1.00

Terminal Supply Chain Integration

Total 51 assessors T1 and port users took part in the judgements on terminal supply chain integration. Then, the measurement can be presented by DoB belonging to linguistic terms.

Table I-40 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	7	14	22	8	51
Land side connectivity	1	3	15	24	8	51
Reliability for multimodal operations	0	2	24	16	9	51
Efficiency of multimodal operations	0	2	22	21	6	51
Value-Added Services (VAST)						
Facilities for adding value to cargoes	4	7	16	21	3	51
Capacity to handle different types of cargo	1	5	21	15	9	51
Service adaptation to customers	2	6	14	19	10	51
Tailored services to customers	0	7	22	15	7	51
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	1	16	25	9	51
Integrated IT to share data	0	4	15	24	8	51
Collaborate with channel members	0	3	22	19	7	51
Latest IT in the industry	0	6	22	18	5	51

Table I-41 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum

Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.14	0.27	0.43	0.16	1.00
Land side connectivity	0.02	0.06	0.29	0.47	0.16	1.00
Reliability for multimodal operations	0.00	0.04	0.47	0.31	0.18	1.00
Efficiency of multimodal operations	0.00	0.04	0.43	0.41	0.12	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.08	0.14	0.31	0.41	0.06	1.00
Capacity to handle different types of cargo	0.02	0.10	0.41	0.29	0.18	1.00
Service adaptation to customers	0.04	0.12	0.27	0.37	0.20	1.00
Tailored services to customers	0.00	0.14	0.43	0.29	0.14	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.02	0.31	0.49	0.18	1.00
Integrated IT to share data	0.00	0.08	0.29	0.47	0.16	1.00
Collaborate with channel members	0.00	0.06	0.43	0.37	0.14	1.00
Latest IT in the industry	0.00	0.12	0.43	0.35	0.10	1.00

Sustainable Growth

Total 6-16 assessors from T 1 (10 assessors) and port administration (6 assessors) took part in the judgements on sustainable growth. Then, the measurement can be presented by DoB belonging to linguistic terms.

Table I-42 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	1	6	9	16
Formal safety and security training practices	0	0	2	7	7	16
Adequate monitoring and threat awareness	0	0	1	10	5	16
Safety and security officers and facilities	0	0	1	6	9	16
Environment (EVS)						
Carbon footprint	2	4	6	2	2	16
Total water consumption	1	0	7	5	3	16
Total energy consumption	0	0	4	9	3	16
Waste recycling	1	0	6	7	2	16
Environment management programs	0	1	9	4	2	16
Social Engagement (SES)						
Employment	0	0	2	3	1	6
Regional GDP	0	0	1	3	2	6
Disclose of information	0	1	3	2	0	6

Table I-43 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.06	0.38	0.56	1.00
Formal safety and security training practices	0.00	0.00	0.13	0.44	0.44	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.06	0.63	0.31	1.00
Safety and security officers and facilities	0.00	0.00	0.06	0.38	0.56	1.00
Environment (EVS)						
Carbon footprint	0.13	0.25	0.38	0.13	0.13	1.00
Total water consumption	0.06	0.00	0.44	0.31	0.19	1.00
Total energy consumption	0.00	0.00	0.25	0.56	0.19	1.00
Waste recycling	0.06	0.00	0.38	0.44	0.13	1.00
Environment management programs	0.00	0.06	0.56	0.25	0.13	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.33	0.50	0.17	1.00
Regional GDP	0.00	0.00	0.17	0.50	0.33	1.00
Disclose of information	0.00	0.17	0.50	0.33	0.00	1.00

- Qualitative PPIs (T2)

8 assessors from T2 evaluated on the SA, TSCI, SSS and EVS. 42 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-44 Response details for T2

	Terminal operator	User		Administrator	
	T2	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	17 (13)	21 (17)	0	0
Online received	9 (8)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(8)	(18)	(24)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-45 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	1	2	5	0	8
Capability	0	2	4	2	0	8
Training and education opportunity	2	0	5	1	0	8
Commitment and Loyalty	1	1	5	1	0	8
Organisation Capital (OCS)						
Culture	1	3	2	2	0	8
Leadership	0	4	0	4	0	8
Alignment	0	3	1	4	0	8
Teamwork	1	3	1	2	1	8
Information Capital (ICS)						
IT systems	0	1	3	4	0	8
Databases	0	2	3	3	0	8
Networks	1	1	3	3	0	8

Table I-46 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.13	0.25	0.63	0.00	1.00
Capability	0.00	0.25	0.50	0.25	0.00	1.00
Training and education opportunity	0.25	0.00	0.63	0.13	0.00	1.00
Commitment and Loyalty	0.13	0.13	0.63	0.13	0.00	1.00
Organisation Capital (OCS)						
Culture	0.13	0.38	0.25	0.25	0.00	1.00
Leadership	0.00	0.50	0.00	0.50	0.00	1.00
Alignment	0.00	0.38	0.13	0.50	0.00	1.00
Teamwork	0.13	0.38	0.13	0.25	0.13	1.00
Information Capital (ICS)						
IT systems	0.00	0.13	0.38	0.50	0.00	1.00
Databases	0.00	0.25	0.38	0.38	0.00	1.00
Networks	0.13	0.13	0.38	0.38	0.00	1.00

Users' Satisfaction

Table I-47 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	1	23	12	6	42

Responsiveness to special requests	1	4	23	11	3	42
Accuracy of document & information	0	4	19	16	3	42
Incidence of cargo damage	0	2	17	15	8	42
Incidence of service delay	0	7	22	11	2	42
Service Costs (SCU)						
Overall service costs	0	5	21	14	2	42
Cargo handling charges	0	5	23	12	2	42
Cost of terminal ancillary services	0	10	16	15	1	42

Table I-48 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.02	0.55	0.29	0.14	1.00
Responsiveness to special requests	0.02	0.10	0.55	0.26	0.07	1.00
Accuracy of document & information	0.00	0.10	0.45	0.38	0.07	1.00
Incidence of cargo damage	0.00	0.05	0.40	0.36	0.19	1.00
Incidence of service delay	0.00	0.17	0.52	0.26	0.05	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.12	0.50	0.33	0.05	1.00
Cargo handling charges	0.00	0.12	0.55	0.29	0.05	1.00
Cost of terminal ancillary services	0.00	0.24	0.38	0.36	0.02	1.00

Terminal Supply Chain Integration

Table I-49 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	6	21	17	4	48
Land side connectivity	0	6	15	16	11	48
Reliability for multimodal operations	0	2	22	18	6	48
Efficiency of multimodal operations	1	2	23	19	3	48
Value-Added Services (VAST)						
Facilities for adding value to cargoes	4	7	20	13	4	48
Capacity to handle different types of cargo	1	6	22	13	6	48
Service adaptation to customers	1	10	18	13	6	48
Tailored services to customers	1	9	18	17	3	48
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	1	24	19	4	48
Integrated IT to share data	0	3	24	16	5	48
Collaborate with channel members	0	3	26	17	2	48
Latest IT in the industry	0	8	23	14	3	48

Table I-50 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.13	0.44	0.35	0.08	1.00
Land side connectivity	0.00	0.13	0.31	0.33	0.23	1.00
Reliability for multimodal operations	0.00	0.04	0.46	0.38	0.13	1.00
Efficiency of multimodal operations	0.02	0.04	0.48	0.40	0.06	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.08	0.15	0.42	0.27	0.08	1.00
Capacity to handle different types of cargo	0.02	0.13	0.46	0.27	0.13	1.00
Service adaptation to customers	0.02	0.21	0.38	0.27	0.13	1.00
Tailored services to customers	0.02	0.19	0.38	0.35	0.06	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.02	0.50	0.40	0.08	1.00
Integrated IT to share data	0.00	0.06	0.50	0.33	0.10	1.00
Collaborate with channel members	0.00	0.06	0.54	0.35	0.04	1.00
Latest IT in the industry	0.00	0.17	0.48	0.29	0.06	1.00

Sustainable Growth

Table I-51 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	2	2	5	5	14
Formal safety and security training practices	0	3	1	6	4	14
Adequate monitoring and threat awareness	0	2	2	6	4	14
Safety and security officers and facilities	0	2	2	3	7	14
Environment (EVS)						
Carbon footprint	2	3	6	2	1	14
Total water consumption	2	3	3	3	3	14
Total energy consumption	1	2	2	7	2	14
Waste recycling	1	2	3	6	2	14
Environment management programs	1	2	7	3	1	14
Social Engagement (SES)						
Employment	0	0	4	2	0	6
Regional GDP	0	0	4	2	0	6
Disclose of information	0	2	2	2	0	6

Table I-52 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.14	0.14	0.36	0.36	1.00
Formal safety and security training practices	0.00	0.21	0.07	0.43	0.29	1.00
Adequate monitoring and threat awareness	0.00	0.14	0.14	0.43	0.29	1.00
Safety and security officers and facilities	0.00	0.14	0.14	0.21	0.50	1.00
Environment (EVS)						
Carbon footprint	0.14	0.21	0.43	0.14	0.07	1.00
Total water consumption	0.14	0.21	0.21	0.21	0.21	1.00
Total energy consumption	0.07	0.14	0.14	0.50	0.14	1.00
Waste recycling	0.07	0.14	0.21	0.43	0.14	1.00
Environment management programs	0.07	0.14	0.50	0.21	0.07	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.67	0.33	0.00	1.00
Regional GDP	0.00	0.00	0.67	0.33	0.00	1.00
Disclose of information	0.00	0.33	0.33	0.33	0.00	1.00

- Qualitative PPIs (T3)

12 assessors from T3 evaluated on the SA, TSCI, SSS and EVS. 42 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-53 Response details for T3

	Terminal operator	User		Administrator	
	T3	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	2 (2)	17 (13)	21 (17)	0	0
Online received	12 (10)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(12)	(18)	(24)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-54 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum

Human Capital (HCS)						
Knowledge and skills	0	0	2	8	2	12
Capability	0	0	5	6	1	12
Training and education opportunity	0	2	4	4	2	12
Commitment and Loyalty	0	0	3	5	4	12
Organisation Capital (OCS)						
Culture	0	1	2	8	1	12
Leadership	0	0	2	6	4	12
Alignment	0	0	2	6	4	12
Teamwork	0	0	2	6	4	12
Information Capital (ICS)						
IT systems	0	1	1	10	0	12
Databases	0	1	2	9	0	12
Networks	0	2	1	9	0	12

Table I-55 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.17	0.67	0.17	1.00
Capability	0.00	0.00	0.42	0.50	0.08	1.00
Training and education opportunity	0.00	0.17	0.33	0.33	0.17	1.00
Commitment and Loyalty	0.00	0.00	0.25	0.42	0.33	1.00
Organisation Capital (OCS)						
Culture	0.00	0.08	0.17	0.67	0.08	1.00
Leadership	0.00	0.00	0.17	0.50	0.33	1.00
Alignment	0.00	0.00	0.17	0.50	0.33	1.00
Teamwork	0.00	0.00	0.17	0.50	0.33	1.00
Information Capital (ICS)						
IT systems	0.00	0.08	0.08	0.83	0.00	1.00
Databases	0.00	0.08	0.17	0.75	0.00	1.00
Networks	0.00	0.17	0.08	0.75	0.00	1.00

Users' Satisfaction

Table I-56 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	1	3	24	12	2	42
Responsiveness to special requests	2	4	22	12	2	42
Accuracy of document & information	0	5	13	22	2	42
Incidence of cargo damage	1	4	13	18	6	42
Incidence of service delay	0	6	25	10	1	42
Service Costs (SCU)						
Overall service costs	0	7	21	12	2	42
Cargo handling charges	0	8	24	10	0	42
Cost of terminal ancillary services	0	11	16	15	0	42

Table I-57 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.02	0.07	0.57	0.29	0.05	1.00
Responsiveness to special requests	0.05	0.10	0.52	0.29	0.05	1.00
Accuracy of document & information	0.00	0.12	0.31	0.52	0.05	1.00
Incidence of cargo damage	0.02	0.10	0.31	0.43	0.14	1.00
Incidence of service delay	0.00	0.14	0.60	0.24	0.02	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.17	0.50	0.29	0.05	1.00
Cargo handling charges	0.00	0.19	0.57	0.24	0.00	1.00
Cost of terminal ancillary services	0.00	0.26	0.38	0.36	0.00	1.00

Terminal Supply Chain Integration

Table I-58 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	1	6	21	20	4	52
Land side connectivity	1	8	20	18	5	52
Reliability for multimodal operations	1	2	22	21	6	52
Efficiency of multimodal operations	1	5	24	19	3	52
Value-Added Services (VAST)						
Facilities for adding value to cargoes	3	7	24	16	2	52
Capacity to handle different types of cargo	1	7	25	15	4	52
Service adaptation to customers	0	10	17	20	5	52
Tailored services to customers	1	8	24	16	3	52
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	4	18	23	6	52
Integrated IT to share data	1	4	21	19	7	52
Collaborate with channel members	1	3	23	21	4	52
Latest IT in the industry	1	7	22	20	2	52

Table I-59 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.02	0.12	0.40	0.38	0.08	1.00
Land side connectivity	0.02	0.15	0.38	0.35	0.10	1.00
Reliability for multimodal operations	0.02	0.04	0.42	0.40	0.12	1.00
Efficiency of multimodal operations	0.02	0.10	0.46	0.37	0.06	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.06	0.13	0.46	0.31	0.04	1.00
Capacity to handle different types of cargo	0.02	0.13	0.48	0.29	0.08	1.00
Service adaptation to customers	0.00	0.19	0.33	0.38	0.10	1.00
Tailored services to customers	0.02	0.15	0.46	0.31	0.06	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.02	0.08	0.35	0.44	0.12	1.00
Integrated IT to share data	0.02	0.08	0.40	0.37	0.13	1.00
Collaborate with channel members	0.02	0.06	0.44	0.40	0.08	1.00
Latest IT in the industry	0.02	0.13	0.42	0.38	0.04	1.00

Sustainable Growth

Table I-60 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	1	7	10	18
Formal safety and security training practices	0	0	2	9	7	18
Adequate monitoring and threat awareness	0	0	3	7	8	18
Safety and security officers and facilities	0	0	1	6	11	18
Environment (EVS)						
Carbon footprint	1	7	7	2	1	18
Total water consumption	0	0	4	7	7	18
Total energy consumption	0	0	2	10	6	18
Waste recycling	0	1	4	9	4	18
Environment management programs	0	6	7	3	2	18
Social Engagement (SES)						
Employment	0	1	3	2	0	6
Regional GDP	0	1	3	1	1	6
Disclose of information	0	1	3	2	0	6

Table I-61 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.06	0.39	0.56	1.00
Formal safety and security training practices	0.00	0.00	0.11	0.50	0.39	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.17	0.39	0.44	1.00
Safety and security officers and facilities	0.00	0.00	0.06	0.33	0.61	1.00
Environment (EVS)						
Carbon footprint	0.06	0.39	0.39	0.11	0.06	1.00
Total water consumption	0.00	0.00	0.22	0.39	0.39	1.00
Total energy consumption	0.00	0.00	0.11	0.56	0.33	1.00
Waste recycling	0.00	0.06	0.22	0.50	0.22	1.00
Environment management programs	0.00	0.33	0.39	0.17	0.11	1.00
Social Engagement (SES)						
Employment	0.00	0.17	0.50	0.33	0.00	1.00
Regional GDP	0.00	0.17	0.50	0.17	0.17	1.00
Disclose of information	0.00	0.17	0.50	0.33	0.00	1.00

- Qualitative PPIs (T4)

7 assessors from T4 evaluated on the SA, TSCI, SSS and EVS. 42 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-62 Response details for T4

	Terminal operator	User		Administrator	
	T4	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	1 (1)	17 (13)	21 (17)	0	0
Online received	6 (6)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(7)	(18)	(24)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-63 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	0	4	3	7
Capability	0	0	3	4	0	7
Training and education opportunity	0	1	2	4	0	7
Commitment and Loyalty	0	0	2	3	2	7
Organisation Capital (OCS)						
Culture	0	0	3	3	1	7
Leadership	0	0	2	1	4	7
Alignment	0	0	2	5	0	7
Teamwork	0	0	2	3	2	7
Information Capital (ICS)						
IT systems	0	0	2	5	0	7
Databases	0	0	2	5	0	7
Networks	0	0	4	2	1	7

Table I-64 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.00	0.57	0.43	1.00

Capability	0.00	0.00	0.43	0.57	0.00	1.00
Training and education opportunity	0.00	0.14	0.29	0.57	0.00	1.00
Commitment and Loyalty	0.00	0.00	0.29	0.43	0.29	1.00
Organisation Capital (OCS)						
Culture	0.00	0.00	0.43	0.43	0.14	1.00
Leadership	0.00	0.00	0.29	0.14	0.57	1.00
Alignment	0.00	0.00	0.29	0.71	0.00	1.00
Teamwork	0.00	0.00	0.29	0.43	0.29	1.00
Information Capital (ICS)						
IT systems	0.00	0.00	0.29	0.71	0.00	1.00
Databases	0.00	0.00	0.29	0.71	0.00	1.00
Networks	0.00	0.00	0.57	0.29	0.14	1.00

Users' Satisfaction

Table I-65 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	1	2	15	18	6	42
Responsiveness to special requests	2	2	22	13	3	42
Accuracy of document & information	1	1	16	19	5	42
Incidence of cargo damage	1	2	10	19	10	42
Incidence of service delay	0	3	17	19	3	42
Service Costs (SCU)						
Overall service costs	1	7	15	15	4	42
Cargo handling charges	2	7	18	12	3	42
Cost of terminal ancillary services	2	10	14	14	2	42

Table I-66 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.02	0.05	0.36	0.43	0.14	1.00
Responsiveness to special requests	0.05	0.05	0.52	0.31	0.07	1.00
Accuracy of document & information	0.02	0.02	0.38	0.45	0.12	1.00
Incidence of cargo damage	0.02	0.05	0.24	0.45	0.24	1.00
Incidence of service delay	0.00	0.07	0.40	0.45	0.07	1.00
Service Costs (SCU)						
Overall service costs	0.02	0.17	0.36	0.36	0.10	1.00
Cargo handling charges	0.05	0.17	0.43	0.29	0.07	1.00
Cost of terminal ancillary services	0.05	0.24	0.33	0.33	0.05	1.00

Terminal Supply Chain Integration

Table I-67 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	5	12	22	7	46
Land side connectivity	1	4	11	22	8	46
Reliability for multimodal operations	1	1	13	22	9	46
Efficiency of multimodal operations	1	1	17	22	5	46
Value-Added Services (VAST)						
Facilities for adding value to cargoes	3	4	18	18	3	46
Capacity to handle different types of cargo	1	4	15	17	9	46
Service adaptation to customers	1	6	10	21	8	46
Tailored services to customers	1	5	14	21	5	46
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	1	17	17	11	46
Integrated IT to share data	0	4	13	20	9	46

Collaborate with channel members	0	3	16	22	5	46
Latest IT in the industry	0	5	13	22	6	46

Table I-68 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.11	0.26	0.48	0.15	1.00
Land side connectivity	0.02	0.09	0.24	0.48	0.17	1.00
Reliability for multimodal operations	0.02	0.02	0.28	0.48	0.20	1.00
Efficiency of multimodal operations	0.02	0.02	0.37	0.48	0.11	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.07	0.09	0.39	0.39	0.07	1.00
Capacity to handle different types of cargo	0.02	0.09	0.33	0.37	0.20	1.00
Service adaptation to customers	0.02	0.13	0.22	0.46	0.17	1.00
Tailored services to customers	0.02	0.11	0.30	0.46	0.11	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.02	0.37	0.37	0.24	1.00
Integrated IT to share data	0.00	0.09	0.28	0.43	0.20	1.00
Collaborate with channel members	0.00	0.07	0.35	0.48	0.11	1.00
Latest IT in the industry	0.00	0.11	0.28	0.48	0.13	1.00

Sustainable Growth

Table I-69 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	0	3	9	12
Formal safety and security training practices	0	0	0	4	8	12
Adequate monitoring and threat awareness	0	0	0	2	10	12
Safety and security officers and facilities	0	0	0	0	12	12
Environment (EVS)						
Carbon footprint	1	0	4	3	4	12
Total water consumption	0	1	2	6	3	12
Total energy consumption	0	0	0	9	3	12
Waste recycling	0	1	4	5	2	12
Environment management programs	0	1	5	3	3	12
Social Engagement (SES)						
Employment	0	0	0	2	4	6
Regional GDP	0	0	0	3	3	6
Disclose of information	0	0	5	1	0	6

Table I-70 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.00	0.25	0.75	1.00
Formal safety and security training practices	0.00	0.00	0.00	0.33	0.67	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.00	0.17	0.83	1.00
Safety and security officers and facilities	0.00	0.00	0.00	0.00	1.00	1.00
Environment (EVS)						
Carbon footprint	0.08	0.00	0.33	0.25	0.33	1.00
Total water consumption	0.00	0.08	0.17	0.50	0.25	1.00
Total energy consumption	0.00	0.00	0.00	0.75	0.25	1.00
Waste recycling	0.00	0.08	0.33	0.42	0.17	1.00
Environment management programs	0.00	0.08	0.42	0.25	0.25	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.00	0.33	0.67	1.00
Regional GDP	0.00	0.00	0.00	0.50	0.50	1.00
Disclose of information	0.00	0.00	0.83	0.17	0.00	1.00

- Qualitative PPIs (T5)

14 assessors from T5 evaluated on the SA, TSCI, SSS and EVS. 42-43 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-71 Response details for T5

	Terminal operator	User		Administrator	
	T5	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	4 (4)	17 (13)	21 (17)	0	0
Online received	13 (10)	9 (5)	11 (7)	4 (2)	5 (4)
Usable response	(14)	(18)	(24)	(2)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-72 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	3	11	0	14
Capability	0	1	5	8	0	14
Training and education opportunity	0	3	5	6	0	14
Commitment and Loyalty	0	0	7	6	1	14
Organisation Capital (OCS)						
Culture	0	0	4	10	0	14
Leadership	0	0	5	8	1	14
Alignment	0	0	8	6	0	14
Teamwork	0	2	4	8	0	14
Information Capital (ICS)						
IT systems	0	2	3	8	1	14
Databases	0	3	5	6	0	14
Networks	0	1	9	4	0	14

Table I-73 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.21	0.79	0.00	1.00
Capability	0.00	0.07	0.36	0.57	0.00	1.00
Training and education opportunity	0.00	0.21	0.36	0.43	0.00	1.00
Commitment and Loyalty	0.00	0.00	0.50	0.43	0.07	1.00
Organisation Capital (OCS)						
Culture	0.00	0.00	0.29	0.71	0.00	1.00
Leadership	0.00	0.00	0.36	0.57	0.07	1.00
Alignment	0.00	0.00	0.57	0.43	0.00	1.00
Teamwork	0.00	0.14	0.29	0.57	0.00	1.00
Information Capital (ICS)						
IT systems	0.00	0.14	0.21	0.57	0.07	1.00
Databases	0.00	0.21	0.36	0.43	0.00	1.00
Networks	0.00	0.07	0.64	0.29	0.00	1.00

Users' Satisfaction

Table I-74 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum

Service Fulfilment (SFU)						
Overall service reliability	1	3	14	17	8	43
Responsiveness to special requests	1	3	21	11	6	42
Accuracy of document & information	0	1	12	22	8	43
Incidence of cargo damage	1	3	8	21	10	43
Incidence of service delay	1	1	20	15	6	43
Service Costs (SCU)						
Overall service costs	2	6	16	16	3	43
Cargo handling charges	2	7	19	12	3	43
Cost of terminal ancillary services	3	12	13	11	4	43

Table I-75 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.02	0.07	0.33	0.40	0.19	1.00
Responsiveness to special requests	0.02	0.07	0.50	0.26	0.14	1.00
Accuracy of document & information	0.00	0.02	0.28	0.51	0.19	1.00
Incidence of cargo damage	0.02	0.07	0.19	0.49	0.23	1.00
Incidence of service delay	0.02	0.02	0.47	0.35	0.14	1.00
Service Costs (SCU)						
Overall service costs	0.05	0.14	0.37	0.37	0.07	1.00
Cargo handling charges	0.05	0.16	0.44	0.28	0.07	1.00
Cost of terminal ancillary services	0.07	0.28	0.30	0.26	0.09	1.00

Terminal Supply Chain Integration

Table I-76 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	2	4	14	27	8	55
Land side connectivity	1	4	16	27	7	55
Reliability for multimodal operations	0	3	16	27	9	55
Efficiency of multimodal operations	1	2	17	25	10	55
Value-Added Services (VAST)						
Facilities for adding value to cargoes	2	3	19	27	4	55
Capacity to handle different types of cargo	0	3	13	26	13	55
Service adaptation to customers	0	5	12	27	11	55
Tailored services to customers	1	4	15	28	7	55
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	2	14	25	13	55
Integrated IT to share data	0	3	17	26	9	55
Collaborate with channel members	0	4	22	21	8	55
Latest IT in the industry	0	4	19	22	10	55

Table I-77 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.04	0.07	0.25	0.49	0.15	1.00
Land side connectivity	0.02	0.07	0.29	0.49	0.13	1.00
Reliability for multimodal operations	0.00	0.05	0.29	0.49	0.16	1.00
Efficiency of multimodal operations	0.02	0.04	0.31	0.45	0.18	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.04	0.05	0.35	0.49	0.07	1.00
Capacity to handle different types of cargo	0.00	0.05	0.24	0.47	0.24	1.00
Service adaptation to customers	0.00	0.09	0.22	0.49	0.20	1.00
Tailored services to customers	0.02	0.07	0.27	0.51	0.13	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.02	0.04	0.25	0.45	0.24	1.00
Integrated IT to share data	0.00	0.05	0.31	0.47	0.16	1.00

Collaborate with channel members	0.00	0.07	0.40	0.38	0.15	1.00
Latest IT in the industry	0.00	0.07	0.35	0.40	0.18	1.00

Sustainable Growth

Table I-78 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	2	9	8	19
Formal safety and security training practices	0	1	2	12	4	19
Adequate monitoring and threat awareness	0	1	2	10	6	19
Safety and security officers and facilities	0	0	1	9	9	19
Environment (EVS)						
Carbon footprint	0	4	6	7	2	19
Total water consumption	0	1	4	9	5	19
Total energy consumption	0	0	2	13	4	19
Waste recycling	0	1	6	8	4	19
Environment management programs	0	4	10	3	2	19
Social Engagement (SES)						
Employment	0	0	3	2	1	6
Regional GDP	0	0	0	3	3	6
Disclose of information	0	1	3	2	0	6

Table I-79 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.11	0.47	0.42	1.00
Formal safety and security training practices	0.00	0.05	0.11	0.63	0.21	1.00
Adequate monitoring and threat awareness	0.00	0.05	0.11	0.53	0.32	1.00
Safety and security officers and facilities	0.00	0.00	0.05	0.47	0.47	1.00
Environment (EVS)						
Carbon footprint	0.00	0.21	0.32	0.37	0.11	1.00
Total water consumption	0.00	0.05	0.21	0.47	0.26	1.00
Total energy consumption	0.00	0.00	0.11	0.68	0.21	1.00
Waste recycling	0.00	0.05	0.32	0.42	0.21	1.00
Environment management programs	0.00	0.21	0.53	0.16	0.11	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.50	0.33	0.17	1.00
Regional GDP	0.00	0.00	0.00	0.50	0.50	1.00
Disclose of information	0.00	0.17	0.50	0.33	0.00	1.00

- Qualitative PPIs (T7)

14 assessors from T7 evaluated on the SA, TSCI, SSS and EVS. 28 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 10 from port authority and government participated in the judgements on SG.

Table I-80 Response details for T7

	Terminal operator	User		Administrator	
	T7	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	14 (14)	10 (10)	14 (14)	0	0
Online received	0	4 (4)	2 (0)	6 (6)	4 (4)
Usable response	(14)	(14)	(14)	(6)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-81 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	1	10	2	1	14
Capability	0	8	4	2	0	14
Training and education opportunity	2	8	4	0	0	14
Commitment and Loyalty	0	4	6	4	0	14
Organisation Capital (OCS)						
Culture	0	4	10	0	0	14
Leadership	1	2	7	4	0	14
Alignment	1	1	8	4	0	14
Teamwork	0	7	1	6	0	14
Information Capital (ICS)						
IT systems	1	7	5	1	0	14
Databases	1	6	6	1	0	14
Networks	0	2	9	3	0	14

Table I-82 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.07	0.71	0.14	0.07	1.00
Capability	0.00	0.57	0.29	0.14	0.00	1.00
Training and education opportunity	0.14	0.57	0.29	0.00	0.00	1.00
Commitment and Loyalty	0.00	0.29	0.43	0.29	0.00	1.00
Organisation Capital (OCS)						
Culture	0.00	0.29	0.71	0.00	0.00	1.00
Leadership	0.07	0.14	0.50	0.29	0.00	1.00
Alignment	0.07	0.07	0.57	0.29	0.00	1.00
Teamwork	0.00	0.50	0.07	0.43	0.00	1.00
Information Capital (ICS)						
IT systems	0.07	0.50	0.36	0.07	0.00	1.00
Databases	0.07	0.43	0.43	0.07	0.00	1.00
Networks	0.00	0.14	0.64	0.21	0.00	1.00

Users' Satisfaction

Table I-83 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	1	7	14	6	28
Responsiveness to special requests	0	2	4	15	7	28
Accuracy of document & information	0	2	9	11	6	28
Incidence of cargo damage	0	3	7	10	8	28
Incidence of service delay	1	0	8	11	8	28
Service Costs (SCU)						
Overall service costs	0	5	9	12	2	28
Cargo handling charges	0	2	14	10	2	28
Cost of terminal ancillary services	0	4	10	13	1	28

Table I-84 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.04	0.25	0.50	0.21	1.00
Responsiveness to special requests	0.00	0.07	0.14	0.54	0.25	1.00
Accuracy of document & information	0.00	0.07	0.32	0.39	0.21	1.00
Incidence of cargo damage	0.00	0.11	0.25	0.36	0.29	1.00

Incidence of service delay	0.04	0.00	0.29	0.39	0.29	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.18	0.32	0.43	0.07	1.00
Cargo handling charges	0.00	0.07	0.50	0.36	0.07	1.00
Cost of terminal ancillary services	0.00	0.14	0.36	0.46	0.04	1.00

Terminal Supply Chain Integration

Table I-85 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	7	15	16	4	42
Land side connectivity	1	7	15	16	3	42
Reliability for multimodal operations	0	5	17	18	2	42
Efficiency of multimodal operations	0	7	17	16	2	42
Value-Added Services (VAST)						
Facilities for adding value to cargoes	3	9	13	15	2	42
Capacity to handle different types of cargo	1	5	17	17	2	42
Service adaptation to customers	0	5	14	19	4	42
Tailored services to customers	1	3	18	18	2	42
Information/Communication Integration (ICIT)						
Integrated EDI for communication	2	2	16	18	4	42
Integrated IT to share data	2	2	18	15	5	42
Collaborate with channel members	2	4	19	13	4	42
Latest IT in the industry	1	6	17	15	3	42

Table I-86 Degree of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.17	0.36	0.38	0.10	1.00
Land side connectivity	0.02	0.17	0.36	0.38	0.07	1.00
Reliability for multimodal operations	0.00	0.12	0.40	0.43	0.05	1.00
Efficiency of multimodal operations	0.00	0.17	0.40	0.38	0.05	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.07	0.21	0.31	0.36	0.05	1.00
Capacity to handle different types of cargo	0.02	0.12	0.40	0.40	0.05	1.00
Service adaptation to customers	0.00	0.12	0.33	0.45	0.10	1.00
Tailored services to customers	0.02	0.07	0.43	0.43	0.05	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.05	0.05	0.38	0.43	0.10	1.00
Integrated IT to share data	0.05	0.05	0.43	0.36	0.12	1.00
Collaborate with channel members	0.05	0.10	0.45	0.31	0.10	1.00
Latest IT in the industry	0.02	0.14	0.40	0.36	0.07	1.00

Sustainable Growth

Table I-87 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	1	5	7	11	24
Formal safety and security training practices	1	2	3	9	9	24
Adequate monitoring and threat awareness	0	3	4	8	9	24
Safety and security officers and facilities	0	0	3	12	9	24
Environment (EVS)						
Carbon footprint	2	15	5	2	0	24
Total water consumption	0	14	6	2	2	24
Total energy consumption	0	13	8	3	0	24
Waste recycling	0	11	5	7	1	24
Environment management programs	0	16	5	3	0	24

Social Engagement (SES)						
Employment	0	5	5	0	0	10
Regional GDP	0	4	5	1	0	10
Disclose of information	0	0	7	2	1	10

Table I-88 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.04	0.21	0.29	0.46	1.00
Formal safety and security training practices	0.04	0.08	0.13	0.38	0.38	1.00
Adequate monitoring and threat awareness	0.00	0.13	0.17	0.33	0.38	1.00
Safety and security officers and facilities	0.00	0.00	0.13	0.50	0.38	1.00
Environment (EVS)						
Carbon footprint	0.08	0.63	0.21	0.08	0.00	1.00
Total water consumption	0.00	0.58	0.25	0.08	0.08	1.00
Total energy consumption	0.00	0.54	0.33	0.13	0.00	1.00
Waste recycling	0.00	0.46	0.21	0.29	0.04	1.00
Environment management programs	0.00	0.67	0.21	0.13	0.00	1.00
Social Engagement (SES)						
Employment	0.00	0.50	0.50	0.00	0.00	1.00
Regional GDP	0.00	0.40	0.50	0.10	0.00	1.00
Disclose of information	0.00	0.00	0.70	0.20	0.10	1.00

- Qualitative PPIs (T8)

15 assessors from T8 evaluated on the SA, TSCI, SSS and EVS. 29 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 10 from port authority and government participated in the judgements on SG.

Table I-89 Response details for T8

	Terminal operator	User		Administrator	
	T8	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	15 (15)	11 (11)	14 (14)	0	0
Online received	0	4 (4)	2 (0)	6 (6)	4 (4)
Usable response	(15)	(15)	(14)	(6)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-90 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	3	11	1	15
Capability	0	0	6	8	1	15
Training and education opportunity	0	1	6	8	0	15
Commitment and Loyalty	0	0	11	3	1	15
Organisation Capital (OCS)						
Culture	0	1	5	8	1	15
Leadership	0	0	5	10	0	15
Alignment	0	0	5	9	1	15
Teamwork	0	0	7	7	1	15
Information Capital (ICS)						
IT systems	0	0	6	9	0	15
Databases	0	0	10	5	0	15
Networks	0	0	7	7	1	15

Table I-91 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.20	0.73	0.07	1.00
Capability	0.00	0.00	0.40	0.53	0.07	1.00
Training and education opportunity	0.00	0.07	0.40	0.53	0.00	1.00
Commitment and Loyalty	0.00	0.00	0.73	0.20	0.07	1.00
Organisation Capital (OCS)						
Culture	0.00	0.07	0.33	0.53	0.07	1.00
Leadership	0.00	0.00	0.33	0.67	0.00	1.00
Alignment	0.00	0.00	0.33	0.60	0.07	1.00
Teamwork	0.00	0.00	0.47	0.47	0.07	1.00
Information Capital (ICS)						
IT systems	0.00	0.00	0.40	0.60	0.00	1.00
Databases	0.00	0.00	0.67	0.33	0.00	1.00
Networks	0.00	0.00	0.47	0.47	0.07	1.00

Users' Satisfaction

Table I-92 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	1	9	15	4	29
Responsiveness to special requests	0	3	5	16	5	29
Accuracy of document & information	0	2	10	11	6	29
Incidence of cargo damage	0	3	6	13	7	29
Incidence of service delay	1	1	12	11	4	29
Service Costs (SCU)						
Overall service costs	0	5	12	9	3	29
Cargo handling charges	0	4	12	10	3	29
Cost of terminal ancillary services	0	5	12	10	2	29

Table I-93 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.03	0.31	0.52	0.14	1.00
Responsiveness to special requests	0.00	0.10	0.17	0.55	0.17	1.00
Accuracy of document & information	0.00	0.07	0.34	0.38	0.21	1.00
Incidence of cargo damage	0.00	0.10	0.21	0.45	0.24	1.00
Incidence of service delay	0.03	0.03	0.41	0.38	0.14	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.17	0.41	0.31	0.10	1.00
Cargo handling charges	0.00	0.14	0.41	0.34	0.10	1.00
Cost of terminal ancillary services	0.00	0.17	0.41	0.34	0.07	1.00

Terminal Supply Chain Integration

Table I-94 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	6	12	20	6	44
Land side connectivity	1	7	15	17	4	44
Reliability for multimodal operations	0	4	11	23	6	44
Efficiency of multimodal operations	0	4	19	15	6	44
Value-Added Services (VAST)						
Facilities for adding value to cargoes	1	6	16	20	1	44
Capacity to handle different types of cargo	0	6	13	19	6	44

Service adaptation to customers	1	4	13	19	7	44
Tailored services to customers	1	3	14	21	5	44
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	2	15	17	9	44
Integrated IT to share data	1	5	15	15	8	44
Collaborate with channel members	2	3	21	15	3	44
Latest IT in the industry	0	4	18	15	7	44

Table I-95 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.14	0.27	0.45	0.14	1.00
Land side connectivity	0.02	0.16	0.34	0.39	0.09	1.00
Reliability for multimodal operations	0.00	0.09	0.25	0.52	0.14	1.00
Efficiency of multimodal operations	0.00	0.09	0.43	0.34	0.14	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.02	0.14	0.36	0.45	0.02	1.00
Capacity to handle different types of cargo	0.00	0.14	0.30	0.43	0.14	1.00
Service adaptation to customers	0.02	0.09	0.30	0.43	0.16	1.00
Tailored services to customers	0.02	0.07	0.32	0.48	0.11	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.02	0.05	0.34	0.39	0.20	1.00
Integrated IT to share data	0.02	0.11	0.34	0.34	0.18	1.00
Collaborate with channel members	0.05	0.07	0.48	0.34	0.07	1.00
Latest IT in the industry	0.00	0.09	0.41	0.34	0.16	1.00

Sustainable Growth

Table I-96 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	1	1	11	12	25
Formal safety and security training practices	0	0	2	9	14	25
Adequate monitoring and threat awareness	0	0	4	10	11	25
Safety and security officers and facilities	0	0	2	9	14	25
Environment (EVS)						
Carbon footprint	0	10	6	9	0	25
Total water consumption	0	11	5	6	3	25
Total energy consumption	0	8	6	7	4	25
Waste recycling	0	8	4	11	2	25
Environment management programs	0	8	2	11	4	25
Social Engagement (SES)						
Employment	0	3	6	1	0	10
Regional GDP	0	0	5	5	0	10
Disclose of information	0	1	4	4	1	10

Table I-97 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.04	0.04	0.44	0.48	1.00
Formal safety and security training practices	0.00	0.00	0.08	0.36	0.56	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.16	0.40	0.44	1.00
Safety and security officers and facilities	0.00	0.00	0.08	0.36	0.56	1.00
Environment (EVS)						
Carbon footprint	0.00	0.40	0.24	0.36	0.00	1.00
Total water consumption	0.00	0.44	0.20	0.24	0.12	1.00
Total energy consumption	0.00	0.32	0.24	0.28	0.16	1.00
Waste recycling	0.00	0.32	0.16	0.44	0.08	1.00

Environment management programs	0.00	0.32	0.08	0.44	0.16	1.00
Social Engagement (SES)						
Employment	0.00	0.30	0.60	0.10	0.00	1.00
Regional GDP	0.00	0.00	0.50	0.50	0.00	1.00
Disclose of information	0.00	0.10	0.40	0.40	0.10	1.00

- Qualitative PPIs (T9)

11 assessors from T9 evaluated on the SA, TSCI, SSS and EVS. 28 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 10 from port authority and government participated in the judgements on SG.

Table I-98 Response details for T9

	Terminal operator	User		Administrator	
	T9	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	11 (11)	10 (10)	14 (14)	0	0
Online received	0	4 (4)	2 (0)	6 (6)	4 (4)
Usable response	(11)	(14)	(14)	(6)	(4)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-99 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	1	9	1	11
Capability	0	0	2	8	1	11
Training and education opportunity	0	0	4	3	4	11
Commitment and Loyalty	0	0	3	8	0	11
Organisation Capital (OCS)						
Culture	0	0	3	7	1	11
Leadership	0	0	2	7	2	11
Alignment	0	0	3	4	4	11
Teamwork	0	0	4	5	2	11
Information Capital (ICS)						
IT systems	0	0	0	10	1	11
Databases	0	0	0	9	2	11
Networks	0	0	2	7	2	11

Table I-100 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.09	0.82	0.09	1.00
Capability	0.00	0.00	0.18	0.73	0.09	1.00
Training and education opportunity	0.00	0.00	0.36	0.27	0.36	1.00
Commitment and Loyalty	0.00	0.00	0.27	0.73	0.00	1.00
Organisation Capital (OCS)						
Culture	0.00	0.00	0.27	0.64	0.09	1.00
Leadership	0.00	0.00	0.18	0.64	0.18	1.00
Alignment	0.00	0.00	0.27	0.36	0.36	1.00
Teamwork	0.00	0.00	0.36	0.45	0.18	1.00
Information Capital (ICS)						
IT systems	0.00	0.00	0.00	0.91	0.09	1.00
Databases	0.00	0.00	0.00	0.82	0.18	1.00
Networks	0.00	0.00	0.18	0.64	0.18	1.00

Users' Satisfaction

Table I-101 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	2	11	11	4	28
Responsiveness to special requests	0	4	8	10	6	28
Accuracy of document & information	0	1	14	9	4	28
Incidence of cargo damage	0	4	7	12	5	28
Incidence of service delay	1	0	11	11	5	28
Service Costs (SCU)						
Overall service costs	0	5	14	6	3	28
Cargo handling charges	0	2	14	10	2	28
Cost of terminal ancillary services	0	4	12	8	4	28

Table I-102 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.07	0.39	0.39	0.14	1.00
Responsiveness to special requests	0.00	0.14	0.29	0.36	0.21	1.00
Accuracy of document & information	0.00	0.04	0.50	0.32	0.14	1.00
Incidence of cargo damage	0.00	0.14	0.25	0.43	0.18	1.00
Incidence of service delay	0.04	0.00	0.39	0.39	0.18	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.18	0.50	0.21	0.11	1.00
Cargo handling charges	0.00	0.07	0.50	0.36	0.07	1.00
Cost of terminal ancillary services	0.00	0.14	0.43	0.29	0.14	1.00

Terminal Supply Chain Integration

Table I-103 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	2	15	17	5	39
Land side connectivity	1	2	15	16	5	39
Reliability for multimodal operations	0	3	10	22	4	39
Efficiency of multimodal operations	0	2	16	16	5	39
Value-Added Services (VAST)						
Facilities for adding value to cargoes	1	4	16	18	0	39
Capacity to handle different types of cargo	0	2	13	21	3	39
Service adaptation to customers	0	2	14	17	6	39
Tailored services to customers	1	1	11	19	7	39
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	0	13	19	6	39
Integrated IT to share data	1	3	13	16	6	39
Collaborate with channel members	1	1	14	19	4	39
Latest IT in the industry	0	3	16	15	5	39

Table I-104 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.05	0.38	0.44	0.13	1.00
Land side connectivity	0.03	0.05	0.38	0.41	0.13	1.00
Reliability for multimodal operations	0.00	0.08	0.26	0.56	0.10	1.00
Efficiency of multimodal operations	0.00	0.05	0.41	0.41	0.13	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.03	0.10	0.41	0.46	0.00	1.00
Capacity to handle different types of cargo	0.00	0.05	0.33	0.54	0.08	1.00
Service adaptation to customers	0.00	0.05	0.36	0.44	0.15	1.00
Tailored services to customers	0.03	0.03	0.28	0.49	0.18	1.00

Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.03	0.00	0.33	0.49	0.15	1.00
Integrated IT to share data	0.03	0.08	0.33	0.41	0.15	1.00
Collaborate with channel members	0.03	0.03	0.36	0.49	0.10	1.00
Latest IT in the industry	0.00	0.08	0.41	0.38	0.13	1.00

Sustainable Growth

Table I-105. Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	0	10	11	21
Formal safety and security training practices	0	0	1	8	12	21
Adequate monitoring and threat awareness	0	0	1	8	12	21
Safety and security officers and facilities	0	1	0	7	13	21
Environment (EVS)						
Carbon footprint	0	10	3	8	0	21
Total water consumption	0	9	5	5	2	21
Total energy consumption	0	7	8	4	2	21
Waste recycling	0	8	2	7	3	20
Environment management programs	0	8	4	6	3	21
Social Engagement (SES)						
Employment	0	2	5	3	0	10
Regional GDP	0	1	7	2	0	10
Disclose of information	0	3	4	3	0	10

Table I-106 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.00	0.48	0.52	1.00
Formal safety and security training practices	0.00	0.00	0.05	0.38	0.57	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.05	0.38	0.57	1.00
Safety and security officers and facilities	0.00	0.05	0.00	0.33	0.62	1.00
Environment (EVS)						
Carbon footprint	0.00	0.48	0.14	0.38	0.00	1.00
Total water consumption	0.00	0.43	0.24	0.24	0.10	1.00
Total energy consumption	0.00	0.33	0.38	0.19	0.10	1.00
Waste recycling	0.00	0.40	0.10	0.35	0.15	1.00
Environment management programs	0.00	0.38	0.19	0.29	0.14	1.00
Social Engagement (SES)						
Employment	0.00	0.20	0.50	0.30	0.00	1.00
Regional GDP	0.00	0.10	0.70	0.20	0.00	1.00
Disclose of information	0.00	0.30	0.40	0.30	0.00	1.00

- Qualitative PPIs (T10)

14 assessors from T10 evaluated on the SA, TSCI, SSS and EVS. 28 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-107 Response details for T10

	Terminal operator	User		Administrator	
	T10	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	9 (9)	7 (7)	0	0
Online received	14 (14)	0	13 (12)	3 (3)	3 (3)

Usable response	(14)	(9)	(19)	(3)	(3)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-108 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	2	7	5	14
Capability	1	0	4	5	4	14
Training and education opportunity	0	1	6	4	3	14
Commitment and Loyalty	0	1	4	6	3	14
Organisation Capital (OCS)						
Culture	0	1	2	9	2	14
Leadership	1	0	4	6	3	14
Alignment	0	0	5	6	3	14
Teamwork	0	0	5	6	3	14
Information Capital (ICS)						
IT systems	2	0	4	6	2	14
Databases	2	0	5	5	2	14
Networks	2	0	6	5	1	14

Table I-109 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.14	0.50	0.36	1.00
Capability	0.07	0.00	0.29	0.36	0.29	1.00
Training and education opportunity	0.00	0.07	0.43	0.29	0.21	1.00
Commitment and Loyalty	0.00	0.07	0.29	0.43	0.21	1.00
Organisation Capital (OCS)						
Culture	0.00	0.07	0.14	0.64	0.14	1.00
Leadership	0.07	0.00	0.29	0.43	0.21	1.00
Alignment	0.00	0.00	0.36	0.43	0.21	1.00
Teamwork	0.00	0.00	0.36	0.43	0.21	1.00
Information Capital (ICS)						
IT systems	0.14	0.00	0.29	0.43	0.14	1.00
Databases	0.14	0.00	0.36	0.36	0.14	1.00
Networks	0.14	0.00	0.43	0.36	0.07	1.00

Users' Satisfaction

Table I-110 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	4	9	13	2	28
Responsiveness to special requests	1	2	11	9	5	28
Accuracy of document & information	0	5	8	11	4	28
Incidence of cargo damage	0	5	13	10	0	28
Incidence of service delay	1	5	12	7	3	28
Service Costs (SCU)						
Overall service costs	0	5	14	6	3	28
Cargo handling charges	0	4	12	9	3	28
Cost of terminal ancillary services	0	7	10	7	4	28

Note: S. dissatisfied: Strongly Dissatisfied; S. satisfied: Strongly Satisfied

Table I-111 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						

Overall service reliability	0.00	0.14	0.32	0.46	0.07	1.00
Responsiveness to special requests	0.04	0.07	0.39	0.32	0.18	1.00
Accuracy of document & information	0.00	0.18	0.29	0.39	0.14	1.00
Incidence of cargo damage	0.00	0.18	0.46	0.36	0.00	1.00
Incidence of service delay	0.04	0.18	0.43	0.25	0.11	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.18	0.50	0.21	0.11	1.00
Cargo handling charges	0.00	0.14	0.43	0.32	0.11	1.00
Cost of terminal ancillary services	0.00	0.25	0.36	0.25	0.14	1.00

Terminal Supply Chain Integration

Table I-112 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	7	15	19	1	42
Land side connectivity	1	7	15	16	3	42
Reliability for multimodal operations	2	3	11	24	2	42
Efficiency of multimodal operations	2	5	16	17	2	42
Value-Added Services (VAST)						
Facilities for adding value to cargoes	2	9	14	11	4	40
Capacity to handle different types of cargo	1	7	20	7	5	40
Service adaptation to customers	2	4	18	10	6	40
Tailored services to customers	2	5	16	15	2	40
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	5	11	18	7	42
Integrated IT to share data	2	4	13	21	2	42
Collaborate with channel members	2	4	12	19	5	42
Latest IT in the industry	2	4	16	17	3	42

Table I-113 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.17	0.36	0.45	0.02	1.00
Land side connectivity	0.02	0.17	0.36	0.38	0.07	1.00
Reliability for multimodal operations	0.05	0.07	0.26	0.57	0.05	1.00
Efficiency of multimodal operations	0.05	0.12	0.38	0.40	0.05	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.05	0.23	0.35	0.28	0.10	1.00
Capacity to handle different types of cargo	0.03	0.18	0.50	0.18	0.13	1.00
Service adaptation to customers	0.05	0.10	0.45	0.25	0.15	1.00
Tailored services to customers	0.05	0.13	0.40	0.38	0.05	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.02	0.12	0.26	0.43	0.17	1.00
Integrated IT to share data	0.05	0.10	0.31	0.50	0.05	1.00
Collaborate with channel members	0.05	0.10	0.29	0.45	0.12	1.00
Latest IT in the industry	0.05	0.10	0.38	0.40	0.07	1.00

Sustainable Growth

Table I-114 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	1	10	10	21
Formal safety and security training practices	0	1	6	8	6	21
Adequate monitoring and threat awareness	0	0	5	9	7	21
Safety and security officers and facilities	0	0	1	11	9	21
Environment (EVS)						
Carbon footprint	3	8	4	1	5	21

Total water consumption	2	7	4	4	4	21
Total energy consumption	2	5	5	4	5	21
Waste recycling	1	4	6	7	3	21
Environment management programs	1	7	6	4	3	21
Social Engagement (SES)						
Employment	0	0	5	1	0	6
Regional GDP	0	0	4	2	0	6
Disclose of information	0	0	2	3	1	6

Table I-115 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.05	0.48	0.48	1.00
Formal safety and security training practices	0.00	0.05	0.29	0.38	0.29	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.24	0.43	0.33	1.00
Safety and security officers and facilities	0.00	0.00	0.05	0.52	0.43	1.00
Environment (EVS)						
Carbon footprint	0.14	0.38	0.19	0.05	0.24	1.00
Total water consumption	0.10	0.33	0.19	0.19	0.19	1.00
Total energy consumption	0.10	0.24	0.24	0.19	0.24	1.00
Waste recycling	0.05	0.19	0.29	0.33	0.14	1.00
Environment management programs	0.05	0.33	0.29	0.19	0.14	1.00
Social Engagement (SES)						
Employment	0.00	0.00	0.83	0.17	0.00	1.00
Regional GDP	0.00	0.00	0.67	0.33	0.00	1.00
Disclose of information	0.00	0.00	0.33	0.50	0.17	1.00

- Qualitative PPIs (T11)

11 assessors from T10 evaluated on the SA, TSCI, SSS and EVS. 28 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-116 Response details for T11

	Terminal operator	User		Administrator	
	T11	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	9 (9)	7 (7)	0	0
Online received	11 (11)	0	13 (12)	3 (3)	3 (3)
Usable response	(11)	(9)	(19)	(3)	(3)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-117 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	0	1	7	3	11
Capability	0	0	4	5	2	11
Training and education opportunity	0	0	2	6	3	11
Commitment and Loyalty	0	0	2	6	3	11
Organisation Capital (OCS)						
Culture	0	0	5	4	2	11
Leadership	0	0	3	5	3	11
Alignment	0	2	2	5	2	11
Teamwork	0	1	3	5	2	11

Information Capital (ICS)						
IT systems	0	0	2	8	1	11
Databases	0	0	3	5	3	11
Networks	0	1	3	5	2	11

Table I-118 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.00	0.09	0.64	0.27	1.00
Capability	0.00	0.00	0.36	0.45	0.18	1.00
Training and education opportunity	0.00	0.00	0.18	0.55	0.27	1.00
Commitment and Loyalty	0.00	0.00	0.18	0.55	0.27	1.00
Organisation Capital (OCS)						
Culture	0.00	0.00	0.45	0.36	0.18	1.00
Leadership	0.00	0.00	0.27	0.45	0.27	1.00
Alignment	0.00	0.18	0.18	0.45	0.18	1.00
Teamwork	0.00	0.09	0.27	0.45	0.18	1.00
Information Capital (ICS)						
IT systems	0.00	0.00	0.18	0.73	0.09	1.00
Databases	0.00	0.00	0.27	0.45	0.27	1.00
Networks	0.00	0.09	0.27	0.45	0.18	1.00

Users' Satisfaction

Table I-119 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	2	12	11	3	28
Responsiveness to special requests	0	4	11	13	0	28
Accuracy of document & information	0	4	11	9	4	28
Incidence of cargo damage	0	3	10	13	2	28
Incidence of service delay	0	4	10	8	6	28
Service Costs (SCU)						
Overall service costs	0	3	18	4	3	28
Cargo handling charges	0	3	13	11	1	28
Cost of terminal ancillary services	0	7	12	7	2	28

Note: S. dissatisfied: Strongly Dissatisfied; S. satisfied: Strongly Satisfied

Table I-120 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.07	0.43	0.39	0.11	1.00
Responsiveness to special requests	0.00	0.14	0.39	0.46	0.00	1.00
Accuracy of document & information	0.00	0.14	0.39	0.32	0.14	1.00
Incidence of cargo damage	0.00	0.11	0.36	0.46	0.07	1.00
Incidence of service delay	0.00	0.14	0.36	0.29	0.21	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.11	0.64	0.14	0.11	1.00
Cargo handling charges	0.00	0.11	0.46	0.39	0.04	1.00
Cost of terminal ancillary services	0.00	0.25	0.43	0.25	0.07	1.00

Terminal Supply Chain Integration

Table I-121 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	4	8	22	5	39
Land side connectivity	1	7	12	17	2	39

Reliability for multimodal operations	1	4	15	15	4	39
Efficiency of multimodal operations	1	6	13	16	3	39
Value-Added Services (VAST)						
Facilities for adding value to cargoes	3	10	13	11	0	37
Capacity to handle different types of cargo	2	7	17	8	3	37
Service adaptation to customers	0	6	14	13	4	37
Tailored services to customers	1	2	17	15	2	37
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	4	14	18	3	39
Integrated IT to share data	0	4	13	20	2	39
Collaborate with channel members	0	2	13	19	5	39
Latest IT in the industry	0	3	17	17	2	39

Table I-122 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.10	0.21	0.56	0.13	1.00
Land side connectivity	0.03	0.18	0.31	0.44	0.05	1.00
Reliability for multimodal operations	0.03	0.10	0.38	0.38	0.10	1.00
Efficiency of multimodal operations	0.03	0.15	0.33	0.41	0.08	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.08	0.27	0.35	0.30	0.00	1.00
Capacity to handle different types of cargo	0.05	0.19	0.46	0.22	0.08	1.00
Service adaptation to customers	0.00	0.16	0.38	0.35	0.11	1.00
Tailored services to customers	0.03	0.05	0.46	0.41	0.05	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.10	0.36	0.46	0.08	1.00
Integrated IT to share data	0.00	0.10	0.33	0.51	0.05	1.00
Collaborate with channel members	0.00	0.05	0.33	0.49	0.13	1.00
Latest IT in the industry	0.00	0.08	0.44	0.44	0.05	1.00

Sustainable Growth

Table I-123 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	0	9	9	18
Formal safety and security training practices	0	1	5	9	3	18
Adequate monitoring and threat awareness	0	0	3	10	5	18
Safety and security officers and facilities	0	0	3	10	5	18
Environment (EVS)						
Carbon footprint	3	8	4	2	1	18
Total water consumption	1	7	5	4	1	18
Total energy consumption	1	4	7	4	2	18
Waste recycling	0	1	10	5	2	18
Environment management programs	0	7	7	2	2	18
Social Engagement (SES)						
Employment	0	2	3	1	0	6
Regional GDP	0	2	3	1	0	6
Disclose of information	0	2	3	1	0	6

Table I-124 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.00	0.50	0.50	1.00
Formal safety and security training practices	0.00	0.06	0.28	0.50	0.17	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.17	0.56	0.28	1.00
Safety and security officers and facilities	0.00	0.00	0.17	0.56	0.28	1.00
Environment (EVS)						

Carbon footprint	0.17	0.44	0.22	0.11	0.06	1.00
Total water consumption	0.06	0.39	0.28	0.22	0.06	1.00
Total energy consumption	0.06	0.22	0.39	0.22	0.11	1.00
Waste recycling	0.00	0.06	0.56	0.28	0.11	1.00
Environment management programs	0.00	0.39	0.39	0.11	0.11	1.00
Social Engagement (SES)						
Employment	0.00	0.33	0.50	0.17	0.00	1.00
Regional GDP	0.00	0.33	0.50	0.17	0.00	1.00
Disclose of information	0.00	0.33	0.50	0.17	0.00	1.00

- Qualitative PPIs (T12)

14 assessors from T12 evaluated on the SA, TSCI, SSS and EVS. 28 assessors from shipping lines and freight forwarders who have experience in using the terminal services provided by T1 took part in assessing the US and TSCI and 6 from port authority and government participated in the judgements on SG.

Table I-125 Response details for T12

	Terminal operator	User		Administrator	
	T12	SL	FF	PA	GOV
Total distributed	25	100	100	20	20
Total received	0	9 (9)	7 (7)	0	0
Online received	14 (14)	0	13 (12)	3 (3)	3 (3)
Usable response	(14)	(9)	(19)	(3)	(3)
Judgement on:	SA, TSCI, SSS, EVS	US, TSCI		SG	

Supporting Activities

Table I-126 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	1	0	1	8	4	14
Capability	1	0	2	7	4	14
Training and education opportunity	1	1	4	5	3	14
Commitment and Loyalty	1	0	3	6	4	14
Organisation Capital (OCS)						
Culture	1	0	4	7	2	14
Leadership	1	0	4	7	2	14
Alignment	1	0	4	7	2	14
Teamwork	0	2	3	6	3	14
Information Capital (ICS)						
IT systems	0	0	5	4	5	14
Databases	0	0	5	4	5	14
Networks	0	0	4	7	3	14

Table I-127 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.07	0.00	0.07	0.57	0.29	1.00
Capability	0.07	0.00	0.14	0.50	0.29	1.00
Training and education opportunity	0.07	0.07	0.29	0.36	0.21	1.00
Commitment and Loyalty	0.07	0.00	0.21	0.43	0.29	1.00
Organisation Capital (OCS)						
Culture	0.07	0.00	0.29	0.50	0.14	1.00
Leadership	0.07	0.00	0.29	0.50	0.14	1.00
Alignment	0.07	0.00	0.29	0.50	0.14	1.00
Teamwork	0.00	0.14	0.21	0.43	0.21	1.00

Information Capital (ICS)						
IT systems	0.00	0.00	0.36	0.29	0.36	1.00
Databases	0.00	0.00	0.36	0.29	0.36	1.00
Networks	0.00	0.00	0.29	0.50	0.21	1.00

Users' Satisfaction

Table I-128 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	4	10	11	3	28
Responsiveness to special requests	0	2	16	10	0	28
Accuracy of document & information	0	5	9	11	3	28
Incidence of cargo damage	0	6	9	12	1	28
Incidence of service delay	0	5	11	10	2	28
Service Costs (SCU)						
Overall service costs	0	3	14	7	4	28
Cargo handling charges	1	3	14	8	2	28
Cost of terminal ancillary services	0	6	9	11	2	28

Note: S. dissatisfied: Strongly Dissatisfied; S. satisfied: Strongly Satisfied

Table I-129 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.14	0.36	0.39	0.11	1.00
Responsiveness to special requests	0.00	0.07	0.57	0.36	0.00	1.00
Accuracy of document & information	0.00	0.18	0.32	0.39	0.11	1.00
Incidence of cargo damage	0.00	0.21	0.32	0.43	0.04	1.00
Incidence of service delay	0.00	0.18	0.39	0.36	0.07	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.11	0.50	0.25	0.14	1.00
Cargo handling charges	0.04	0.11	0.50	0.29	0.07	1.00
Cost of terminal ancillary services	0.00	0.21	0.32	0.39	0.07	1.00

Terminal Supply Chain Integration

Table I-130 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	4	13	19	6	42
Land side connectivity	1	6	10	21	4	42
Reliability for multimodal operations	1	1	15	23	2	42
Efficiency of multimodal operations	1	3	15	19	4	42
Value-Added Services (VAST)						
Facilities for adding value to cargoes	2	4	14	17	3	40
Capacity to handle different types of cargo	1	3	20	11	5	40
Service adaptation to customers	0	6	15	15	4	40
Tailored services to customers	1	6	13	15	5	40
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0	3	16	20	3	42
Integrated IT to share data	0	4	18	15	5	42
Collaborate with channel members	0	2	11	23	6	42
Latest IT in the industry	1	1	19	17	4	42

Table I-131 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.10	0.31	0.45	0.14	1.00
Land side connectivity	0.02	0.14	0.24	0.50	0.10	1.00

Reliability for multimodal operations	0.02	0.02	0.36	0.55	0.05	1.00
Efficiency of multimodal operations	0.02	0.07	0.36	0.45	0.10	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.05	0.10	0.35	0.43	0.08	1.00
Capacity to handle different types of cargo	0.03	0.08	0.50	0.28	0.13	1.00
Service adaptation to customers	0.00	0.15	0.38	0.38	0.10	1.00
Tailored services to customers	0.03	0.15	0.33	0.38	0.13	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.00	0.07	0.38	0.48	0.07	1.00
Integrated IT to share data	0.00	0.10	0.43	0.36	0.12	1.00
Collaborate with channel members	0.00	0.05	0.26	0.55	0.14	1.00
Latest IT in the industry	0.02	0.02	0.45	0.40	0.10	1.00

Sustainable Growth

Table I-132 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	1	10	10	21
Formal safety and security training practices	0	1	8	6	6	21
Adequate monitoring and threat awareness	0	0	4	10	7	21
Safety and security officers and facilities	0	0	2	11	8	21
Environment (EVS)						
Carbon footprint	2	9	4	6	0	21
Total water consumption	1	4	6	6	4	21
Total energy consumption	1	3	5	7	5	21
Waste recycling	0	1	10	4	6	21
Environment management programs	0	7	10	4	0	21
Social Engagement (SES)						
Employment	0	3	3	0	0	6
Regional GDP	0	2	4	0	0	6
Disclose of information	0	0	2	3	1	6

Table I-133 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.05	0.48	0.48	1.00
Formal safety and security training practices	0.00	0.05	0.38	0.29	0.29	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.19	0.48	0.33	1.00
Safety and security officers and facilities	0.00	0.00	0.10	0.52	0.38	1.00
Environment (EVS)						
Carbon footprint	0.10	0.43	0.19	0.29	0.00	1.00
Total water consumption	0.05	0.19	0.29	0.29	0.19	1.00
Total energy consumption	0.05	0.14	0.24	0.33	0.24	1.00
Waste recycling	0.00	0.05	0.48	0.19	0.29	1.00
Environment management programs	0.00	0.33	0.48	0.19	0.00	1.00
Social Engagement (SES)						
Employment	0.00	0.50	0.50	0.00	0.00	1.00
Regional GDP	0.00	0.33	0.67	0.00	0.00	1.00
Disclose of information	0.00	0.00	0.33	0.50	0.17	1.00

Appendix II Mapping process –Transform the evaluation from the lowest level PPIs to top level PPI

- Revenue growth to profitability

The numerical grades used to assess the "revenue growth (RG)" are "leq 0 % (RG1)", "2 % (RG2)", "4 % (RG3), "6 % (RG4)", "8 % (RG5) and "geq 10 % (RG6)". The linguistic terms of principle-PPI, "profitability (PFF)", are "very low (PFF1)", "low (PFF2)", "medium (PFF3)", "high (PFF4)" and "very high (PFF5)". The mapping from revenue growth to profitability can be conducted using following fuzzy rule.

Table II-1 Fuzzy rule base belief structure

<u>*Revenue growth (RG) to profitability (PFF)*</u>	R^1: *If "RG" is "RG6", then "PFF" is "100% PFF5"* R^2: *If "RG" is "RG5", then "PFF" is "25% PFF5"and "75% PFF4"* R^3: *If "RG" is "RG4", then "PFF" is "50% PFF4" and "50% PFF3"* R^4: *If "RG" is "RG3", then "PFF" is "50% PFF3" and "50% PFF2"* R^5: *If "RG" is "RG2", then "PFF" is "75% PFF2"and "25% PFF1"* R^6: *If "RG" is "RG1", then "PFF" is "100% PFF1"*

<u>*Revenue growth to profitability in T6*</u>

According to Table I-24, the revenue growth set in T6 is assessed as follows.

$$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 1)\}$$

Based on R^1, it can be directly transformed into <u>100% PFF5</u> $(O^5 = 1 \times 1)$. The RG profitability set in T6 is assessed as follows.

$$H^{RG\ PFF} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0), (very\ high, 1)\}$$

- Operating profit margin to profitability

The numerical grades used to assess the "operating profit margin (OP)" are "leq 0 % (OP1)", "10 % (OP2)", "15 % (OP3), "20 % (OP4)", "25 % (OP5) and "geq 30 % (OP6)". The mapping from operating profit margin to profitability can be conducted using following fuzzy rule.

Table II-2. Fuzzy rule base belief structure

<u>*Operating profit margin (OP) to profitability (PFF)*</u>	R^1: *If "OP" is "OP6", then "PFF" is "100% PFF5"* R^2: *If "OP" is "OP5", then "PFF" is "25% PFF5"and "75% PFF4"* R^3: *If "OP" is "OP4", then "PFF" is "50% PFF4" and "50% PFF3"* R^4: *If "OP" is "OP3", then "PFF" is "50% PFF3" and "50% PFF2"* R^5: *If "OP" is "OP2", then "PFF" is "75% PFF2"and "25% PFF1"* R^6: *If "OP" is "OP1", then "PFF" is "100% PFF1"*

<u>*Operating profit margin to profitability in T6*</u>

According to Table I-26, the operating profit margin set in T6 is assessed as follows.

$$H^{operating\ M} = \{(\text{leq } 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0.056), (\text{geq } 30\%, 0.944)\}$$

Based on $R^1$and R^2, it can be transformed into <u>4.2% PFF4</u> $(O^4 = 0.056 \times 0.75)$ and <u>95.8% PFF5</u> $(O^5 = (0.056 \times 0.25) + (0.944 \times 1))$ respectively. The OP profitability set in T6 is assessed as follows.

$$H^{OP\ PFF} = \{(\text{very low}, 0), (low, 0), (medium, 0), (high, 0.042), (very\ high, 0.958)\}$$

- Net profit margin to profitability

The numerical grades used to assess the "net profit margin (OP)" are "leq 0 % (NP1)", "5 % (NP2)", "10 % (NP3), "15 % (NP4)", "20 % (NP5) and "geq 25 % (NP6)".

The mapping from net profit margin to profitability can be conducted using following fuzzy rule.

Table II-3. Fuzzy rule base belief structure

Net profit margin (NP) to profitability (PFF)	R^1: *If "NP" is "NP6", then "PFF" is "100% PFF5"* R^2: *If "NP" is "NP5", then "PFF" is "25% PFF5"and "75% PFF4"* R^3: *If "NP" is "NP4", then "PFF" is "50% PFF4" and "50% PFF3"* R^4: *If "NP" is "NP3", then "PFF" is "50% PFF3" and "50% PFF2"* R^5: *If "NP" is "NP2", then "PFF" is "75% PFF2"and "25% PFF1"* R^6: *If "NP" is "NP1", then "PFF" is "100% PFF1"*

Net profit margin to profitability in T6

According to Table I-28, the net profit margin set in T6 is assessed as follows.

$$H^{net\ M} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0.364), (15\%, 0.636), (20\%, 0), (\text{geq } 25\%, 0)\}$$

Based on R^3 and R^4, it can be directly transformed into 18.2% PFF2 ($O^2 = 0.364 \times 0.5$) and 50% PFF3 ($O^3 = (0.364 \times 0.5) + (0.636 \times 0.5)$ and 31.8% PFF4 ($O^4 = 0.636 \times 0.5$), respectively. The NP profitability set in T6 is assessed as follows.

$$H^{NP\ PFF} = \{(\text{very low}, 0), (low, 0.182), (medium, 0.5), (high, 0.318), (very\ high, 0)\}$$

- Current ratio to liquidity and solvency

The numerical grades used to assess the "current ratio (CR)" are "leq 1 (CR1)", "between 1 and 2 (CR2)" and "geq 2 (CR3)". The linguistic terms of principle-PPI, "liquidity and solvency (LSF)", are "very poor (LSF1)", "poor (LSF2)", "medium (LSF3)", "good (LSF4)" and "very good (LSF5)". The mapping from current ratio to liquidity and solvency can be conducted using following fuzzy rule.

Table II-4. Fuzzy rule base belief structure

Current ratio (CR) to liquidity and solvency (LSF)	R^1: *If "CR" is "CR2", then "LSF" is "100% LSF5"* R^2: *If "CR" is "CR3", then "LSF" is "25% LSF3" and "50% LSF4" and "25% LSF5"* R^3: *If "CR" is "CR1", then "LSF" is "25% LSF1" and "50% LSF2" and "25% LSF3"*

Current ratio to liquidity and solvency in T6

According to Table I-30, the current ratio set in T6 is assessed as follows.

$$H^{CR} = \{(\text{leq } 1,1)(\text{between 1 and } 2, 0), (\text{geq } 2, 0)\}$$

Based on R^3, it can be directly transformed into 25% LSF1 ($O^1 = 1 \times 0.25$) and 50% LSF2 ($O^2 = 1 \times 0.5$) and 25% LSF3 ($O^3 = 1 \times 0.25$). The CR liquidity and solvency set in T6 is assessed as follows.

$$H^{CR\ LSF} = \{(\text{very poor}, 0.25), (poor, 0.5), (medium, 0.25), (good, 0), (very\ good, 0)\}$$

- Debt to total assets to liquidity and solvency

The numerical grades used to assess the "debt to total assets (DA)" are "geq 0.5 (DA1)" and "leq 0.5 (DA2)". The mapping from debt to total assets to liquidity and solvency can be conducted using following fuzzy rule.

Table II-5. Fuzzy rule base belief structure

Debt to total assets (DA) to liquidity and solvency (LSF)	R^1: *If "DA" is "DA2", then "LSF" is "25% LSF3" and "25% LSF4" and "50% LSF5"* R^2: *If "CR" is "DA1", then "LSF" is "25% LSF1" and "50% LSF2" and "25% LSF3"*

Debt to total assets to liquidity and solvency in T6

According to Table I-32, the debt to total assets set in T6 is assessed as follows.

$$H^{DA} = \{(\text{geq } 0.5,1), (\text{leq } 0.5, 0)\}$$

Based on R^2, it can be directly transformed into 25% LSF1 ($O^1 = 1 \times 0.25$) and 50% LSF2 ($O^2 = 1 \times 0.5$) and 25% LSF3 ($O^3 = 1 \times 0.25$). The DA liquidity and solvency set in T6 is assessed as follows.

$$H^{DA\ LSF} = \{(\text{very poor}, 0.25), (poor, 0.5), (medium, 0.25), (good, 0), (very\ good, 0)\}$$

- Debt to owner's equity to liquidity and solvency

The numerical grades used to assess the "debt to owner's equity (DE)" are "geq 2 (DE1)", "1.8 (DE2)", "1.6 (DE3), "1.4 (DE4)", "1.2 (DE5) and "leq1 (DE6)". The mapping from debt to owner's equity to liquidity and solvency can be conducted using following fuzzy rule.

Table II-6. Fuzzy rule base belief structure

Debt to owner's (DE) to liquidity and solvency (LSF)	R^1: *If "DE" is "DE6", then "LSF" is "100% LSF5"* R^2: *If "DE" is "DE5", then "LSF" is "25% LSF5"and "75% LSF4"* R^3: *If "DE" is "DE4", then "LSF" is "50% LSF4" and "50% LSF3"* R^4: *If "DE" is "DE3", then "LSF" is "50% LSF3" and "50% LSF2"* R^5: *If "DE" is "DE2", then "LSF" is "75% LSF2"and "25% LSF1"* R^6: *If "DE" is "DE1", then "LSF" is "100% LSF1"*

Debt to owner's equity to liquidity and solvency in T6

According to Table I-34, the debt to owner's equity set in T6 is assessed as follows.

$$H^{DE} = \{(\text{geq } 2,1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (\text{leq } 1, 0)\}$$

Based on R^6, it can be directly transformed into 100% LSF1 ($O^1 = 1 \times 1$). The DE liquidity and solvency set in T6 is assessed as follows.

$$H^{DE\ LSF} = \{(\text{very poor}, 1), (poor, 0), (medium, 0), (good, 0), (very\ good, 0)\}$$

- Mapping of the qualitative PPIs

The linguistic terms are used to assess the qualitative PPIs (see section 5.3.1). The example of fuzzy rule for mapping from knowledge and skills to human capital is shown in Table II-7.

Table II-7. Fuzzy rule base belief structure

Knowledge and skills (KS) to human capital (HCS)	R^1: *If "KS" is "KS5", then "HCS" is "100% HCS5"* R^2: *If "KS" is "KS4", then "HCS" is "25% HCS5"and "75% HCS4"* R^3: *If "KS" is "KS3", then "HCS" is "25% HCS4", "50% HCS3" and "25% HCS2".* R^4: *If "KS" is "KS2", then "HCS" is "75% HCS2"and "25% HCS1"* R^5: *If "KS" is "KS1", then "HCS" is "100% HCS1"*

Knowledge and skills to human capital in T6

The knowledge and skill set in T6 is assessed as follows (see Table 5.30).

$$H^{KN} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.71), (very\ good, 0.29)\}$$

Based on $R^1$and R^2, it can be transformed into 53.25% HCS4 ($O^4 = 0.71 \times 0.75$) and 46.75% HCS5 ($O^5 = (0.71 \times 0.25) + (0.29 \times 1)$) respectively. The KN human capital set in T6 is assessed as follows.

$$H^{KN\ HCS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.533), (very\ good, 0.468)\}$$

Capability to human capital in T6

The capability set in T6 is assessed as follows (see Table 5.30).

$$H^{CP} = \{(\text{very poor}, 0), (poor, 0.14), (medium, 0.29), (good, 0.57), (very\ good, 0)\}$$

Based on R^2, $R^3$and R^4, it can be transformed into 3.5% HCS1 ($O^1 = 0.14 \times 0.25$), 17.75% HCS2 ($O^2 = (0.14 \times 0.75) + (0.29 \times 0.25)$), 14.5% HCS3 ($O^3 = 0.29 \times 0.5$), 50% HCS4 ($O^4 = (0.29 \times 0.25) + (0.57 \times 0.75)$) and 14.25% HCS5 ($O^5 = 0.57 \times 0.25$) respectively. The CP human capital set in T6 is assessed as follows.

$$H^{CP\ HCS} = \{(\text{very poor}, 0.035), (poor, 0.178), (medium, 0.145), (good, 0.5), (very\ good, 0.143)\}$$

Training and education to human capital in T6

According to Table 5.30, the training and education set in T6 is assessed as follows.

$$H^{TE} = \{(\text{very poor}, 0), (poor, 0.14), (medium, 0.43), (good, 0.29), (very\ good, 0.14)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 3.5% HCS1 ($O^1 = 0.14 \times 0.25$), 21.25% HCS2 ($O^2 = (0.14 \times 0.75) + (0.43 \times 0.25)$), 21.5% HCS3 ($O^3 = 0.43 \times 0.5$), 32.5% HCS4 ($O^4 = (0.43 \times 0.25) + (0.29 \times 0.75)$) and 21.25% HCS5 ($O^5 = (0.29 \times 0.25) + (0.14 \times 1)$) respectively. The TE human capital set in T6 is assessed as follows.

$$H^{TE\ HCS} = \{(\text{very poor}, 0.035), (poor, 0.213), (medium, 0.215), (good, 0.325), (very\ good, 0.213)\}$$

Commitment and loyalty to human capital in T6

According to Table 5.30, the commitment and loyalty set in T6 is assessed as follows.

$$H^{CL} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.43), (good, 0.57), (very\ good, 0)\}$$

Based on R^2 and R^3, it can be transformed into 10.75% HCS2 ($O^2 = 0.43 \times 0.25$), 21.5% HCS3 ($O^3 = 0.43 \times 0.5$), 53.5% HCS4 ($O^4 = (0.43 \times 0.25) + (0.57 \times 0.75)$) and 14.25% HCS5 ($O^5 = 0.57 \times 0.25$) respectively. The CL human capital set in T6 is assessed as follows.

$$H^{CL\ HCS} = \{(\text{very poor}, 0), (poor, 0.108), (medium, 0.215), (good, 0.535), (very\ good, 0.143)\}$$

Culture to organisational capital in T6

According to Table 5.30, the culture set in T6 is assessed as follows.

$$H^{CU} = \{(\text{very poor}, 0), (poor, 0.14), (medium, 0.14), (good, 0.72), (very\ good, 0)\}$$

Based on R^2, $R^3$and R^4, it can be transformed into 3.5% OCS1 ($O^1 = 0.14 \times 0.25$), 14% OCS2 ($O^2 = (0.14 \times 0.75) + (0.14 \times 0.25)$), 7% OCS3 ($O^3 = 0.14 \times 0.5$), 57.5% OCS4 ($O^4 = (0.14 \times 0.25) + (0.72 \times 0.75)$) and 18% OCS5 ($O^5 = 0.72 \times 0.25$) respectively. The CU organisational capital set in T6 is assessed as follows.

$$H^{CU\ OCS} = \{(\text{very poor}, 0.035), (poor, 0.14), (medium, 0.07), (good, 0.575), (very\ good, 0.18)\}$$

Leadership to organisational capital in T6

According to Table 5.30Table 5.31, the leadership set in T6 is assessed as follows.

$$H^{LE} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.43), (good, 0.43), (very\ good, 0.14)\}$$

Based on R^1, R^2 and R^3, it can be transformed into 10.75% OCS2 ($O^2 = 0.43 \times 0.25$), 21.5% OCS3 ($O^3 = 0.43 \times 0.5$), 43% OCS4 ($O^4 = (0.43 \times 0.25) + (0.43 \times 0.75)$) and 24.75% OCS5 ($O^5 = (0.43 \times 0.25) + (0.14 \times 1)$) respectively. The LE organisational capital set in T6 is assessed as follows.

$$H^{LE\ OCS} = \{(\text{very poor}, 0), (poor, 0.108), (medium, 0.215), (good, 0.43), (very\ good, 0.248)\}$$

Alignment to organisational capital in T6

According to Table 5.30, the alignment set in T6 is assessed as follows.

$$H^{AL} = \{(\text{very poor}, 0), (poor, 0.14), (medium, 0.29), (good, 0.43), (very\ good, 0.14)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 3.5% OCS1 ($O^1 = 0.14 \times 0.25$), 17.75% OCS2 ($O^2 = (0.14 \times 0.75) + (0.29 \times 0.25)$), 14.5% OCS3 ($O^3 = 0.29 \times 0.5$), 39.5% OCS4 ($O^4 = (0.29 \times 0.25) + (0.43 \times 0.75)$) and 24.75% OCS5 ($O^5 = (0.43 \times 0.25) + (0.14 \times 1)$) respectively. The AL organisational capital set in T6 is assessed as follows.

$$H^{AL\ OCS} = \{(\text{very poor}, 0.035), (poor, 0.178), (medium, 0.145), (good, 0.395), (very\ good, 0.248)\}$$

Teamwork to organisational capital in T6

According to Table 5.30, the teamwork set in T6 is assessed as follows.

$$H^{TW} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.43), (good, 0.29), (very\ good, 0.29)\}$$

Based on R^1, R^2 and R^3, it can be transformed into 10.75% OCS2 ($O^2 = 0.43 \times 0.25$), 21.5% OCS3 ($O^3 = 0.43 \times 0.5$), 32.5% OCS4 ($O^4 = (0.29 \times 0.25) + (0.29 \times 0.75)$) and 36.25% OCS5 ($O^5 = (0.29 \times 0.25) + (0.29 \times 1)$) respectively. The TW organisational capital set in T6 is assessed as follows.

$$H^{TW\ OCS} = \{(\text{very poor}, 0), (poor, 0.108), (medium, 0.215), (good, 0.325), (very\ good, 0.362)\}$$

IT systems to information capital in T6

According to Table 5.30, the IT systems set in T6 is assessed as follows.

$$H^{IT} = \{(\text{very poor}, 0.14), (poor, 0), (medium, 0.14), (good, 0.57), (very\ good, 0.14)\}$$

Based on R^1, R^2, $R^3$and R^5, it can be transformed into 14% ICS1 ($O^1 = 0.14 \times 1$), 3.5% ICS2 ($O^2 = 0.14 \times 0.25$), 7% ICS3 ($O^3 = 0.14 \times 0.5$), 46.3% ICS4 ($O^4 = (0.14 \times 0.25) + (0.57 \times 0.75)$) and 28.25% ICS5 ($O^5 = (0.57 \times 0.25) + (0.14 \times 1)$) respectively. The IT information capital set in T6 is assessed as follows.

$$H^{IT\ ICS} = \{(\text{very poor}, 0.14), (poor, 0.035), (medium, 0.007), (good, 0.463), (very\ good, 0.283)\}$$

Database to information capital in T6

According to Table 5.30, the database set in T6 is assessed as follows.

$$H^{DB} = \{(\text{very poor}, 0), (poor, 0.14), (medium, 0.29), (good, 0.43), (very\ good, 0.14)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 3.5% ICS1 ($O^1 = 0.14 \times 0.25$), 17.75% ICS2 ($O^2 = (0.14 \times 0.75) + (0.29 \times 0.25)$), 14.5% ICS3 ($O^3 = 0.29 \times 0.5$), 39.5% ICS4 ($O^4 = (0.29 \times 0.25) + (0.43 \times 0.75)$) and 24.75% ICS5 ($O^5 = (0.43 \times 0.25) + (0.14 \times 1)$) respectively. The DB information capital set in T6 is assessed as follows.

$$H^{DB\ ICS} = \{(\text{very poor}, 0.035), (poor, 0.178), (medium, 0.145), (good, 0.395), (very\ good, 0.248)\}$$

Networks to information capital in T6

According to Table 5.30, the networks set in T6 is assessed as follows.

$$H^{NT} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.29), (good, 0.71), (very\ good, 0)\}$$

Based on R^2 and R^3, it can be transformed into 7.25% ICS2 ($O^2 = 0.29 \times 0.25$), 14.5% ICS3 ($O^3 = 0.29 \times 0.5$), 60.5% ICS4 ($O^4 = (0.29 \times 0.25) + (0.71 \times 0.75)$) and 17.75% ICS5 ($O^5 = 0.71 \times 0.25$) respectively. The DB information capital set in T6 is assessed as follows.

$$H^{DB\ ICS} = \{(\text{very poor}, 0), (poor, 0.073), (medium, 0.145), (good, 0.605), (very\ good, 0.178)\}$$

Overall service reliability to service fulfilment in T6

According to Table 5.32, the overall service reliability set in T6 is assessed as follows.

$$H^{SR} = \{(\text{very poor}, 0), (poor, 0.19), (medium, 0.26), (good, 0.42), (very\ good, 0.14)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into <u>4.75% SFU1</u> ($O^1 = 0.19 \times 0.25$), <u>20.75% SFU2</u> ($O^2 = (0.19 \times 0.75) + (0.26 \times 0.25)$), <u>13% SFU3</u> ($O^3 = 0.26 \times 0.5$), <u>38% SFU4</u> ($O^4 = (0.26 \times 0.25) + (0.42 \times 0.75\ )$) and <u>24.5% SFU5</u> ($O^5 = (0.42 \times 0.25) + (0.14 \times 1)$) respectively. The SR service fulfilment set in T6 is assessed as follows.

$$H^{SR\ SFU} = \{(\text{very poor}, 0.048), (poor, 0.208), (medium, 0.13), (good, 0.38), (very\ good, 0.245)\}$$

<u>*Responsiveness to special requests to service fulfilment in T6*</u>

According to Table 5.32, the responsiveness to special requests set in T6 is assessed as follows.

$$H^{RR} = \{(\text{very poor}, 0.07), (poor, 0.1), (medium, 0.43), (good, 0.31), (very\ good, 0.1)\}$$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into <u>9.5% SFU1</u> ($O^1 = (0.07 \times 1) + (0.1 \times 0.25)$), <u>18.25% SFU2</u> ($O^2 = 0.1 \times 0.75) + (0.43 \times 0.25)$), <u>21.5% SFU3</u> ($O^3 = 0.43 \times 0.5$), <u>34% SFU4</u> ($O^4 = (0.43 \times 0.25) + (0.31 \times 0.75)$) and <u>17.75% SFU5</u> ($O^5 = (0.31 \times 0.25) + (0.1 \times 1)$) respectively. The RR service fulfilment set in T6 is assessed as follows.

$$H^{RR\ SFU} = \{(\text{very poor}, 0.095), (poor, 0.183), (medium, 0.215), (good, 0.34), (very\ good, 0.178)\}$$

<u>*Accuracy of documents and information to service fulfilment in T6*</u>

According to Table 5.32, the accuracy of documents and information set in T6 is assessed as follows.

$$H^{ADI} = \{(\text{very poor}, 0.02), (poor, 0.05), (medium, 0.3), (good, 0.42), (very\ good, 0.21)\}$$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into <u>33% SFU1</u> ($O^1 = (0.02 \times 1) + (0.05 \times 0.25)$), <u>11.3% SFU2</u> ($O^2 = 0.05 \times 0.75) + (0.3 \times 0.25)$), <u>15% SFU3</u> ($O^3 = 0.3 \times 0.5$), <u>39% SFU4</u> ($O^4 = (0.3 \times 0.25) + (0.42 \times 0.75)$) and <u>31.5% SFU5</u> ($O^5 = (0.42 \times 0.25) + (0.21 \times 1)$) respectively. The DI service fulfilment set in T6 is assessed as follows.

$$H^{ADI\ SFU} = \{(\text{very poor}, 0.033), (poor, 0.113), (medium, 0.15), (good, 0.39), (very\ good, 0.315)\}$$

<u>*Incidence of cargo damage to service fulfilment in T6*</u>

According to Table 5.32, the incidence of cargo damage set in T6 is assessed as follows.

$$H^{ICD} = \{(\text{very poor}, 0), (poor, 0.12), (medium, 0.21), (good, 0.47), (very\ good, 0.21)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into <u>3% SFU1</u> ($O^1 = 0.12 \times 0.25$), <u>14.25% SFU2</u> ($O^2 = (0.12 \times 0.75) + (0.21 \times 0.25)$), <u>10.5% SFU3</u> ($O^3 = 0.21 \times 0.5$), <u>40.5% SFU4</u> ($O^4 = (0.21 \times 0.25) + (0.47 \times 0.75)$) and <u>32.75% SFU5</u> ($O^5 = (0.47 \times 0.25) + (0.21 \times 1)$) respectively. The ICD service fulfilment set in T6 is assessed as follows.

$$H^{ICD\ SFU} = \{(\text{very poor}, 0.03), (poor, 0.143), (medium, 0.105), (good, 0.405), (very\ good, 0.328)\}$$

<u>*Incidence of service delay to service fulfilment in T6*</u>

According to Table 5.32, the incidence of service delay set in T6 is assessed as follows.

$$H^{ISD} = \{(\text{very poor}, 0.07), (poor, 0.07), (medium, 0.40), (good, 0.37), (very\ good, 0.09)\}$$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into <u>8.75% SFU1</u> ($O^1 = (0.07 \times 1) + (0.07 \times 0.25)$), <u>15.25% SFU2</u> ($O^2 = 0.07 \times 0.75) + (0.4 \times 0.25)$), <u>20% SFU3</u> ($O^3 = 0.4 \times 0.5$) , <u>37.75% SFU4</u> ($O^4 = (0.4 \times 0.25) + (0.37 \times 0.75\ )$) and <u>18.25% SFU5</u> ($O^5 = (0.37 \times 0.25) + (0.09 \times 1)$) respectively. The ISD service fulfilment set in T6 is assessed as follows.

$H^{ISD\ SFU} = \{(\text{very poor}, 0.088), (poor, 0.153), (medium, 0.2), (good, 0.378), (very\ good, 0.183)\}$

Overall service costs to service costs in T6

According to Table 5.32, the overall service costs set in T6 is assessed as follows.

$H^{OSC} = \{(\text{very poor}, 0.09), (poor, 0.16), (medium, 0.35), (good, 0.35), (very\ good, 0.05)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 13% SCU1 ($O^1 = (0.09 \times 1) + (0.16 \times 0.25)$), 20.75% SCU2 ($O^2 = 0.16 \times 0.75) + (0.35 \times 0.25)$), 17.5% SCU3 ($O^3 = 0.35 \times 0.5$), 35% SCU4 ($O^4 = (0.35 \times 0.25) + (0.35 \times 0.75)$) and 13.75% SCU5 ($O^5 = (0.35 \times 0.25) + (0.05 \times 1)$) respectively. The OSC service costs set in T6 is assessed as follows.

$H^{OSC\ SFU} = \{(\text{very poor}, 0.13), (poor, 0.208), (medium, 0.175), (good, 0.35), (very\ good, 0.138)\}$

Cargo handling charges to service costs in T6

According to Table 5.32, the cargo handling charges set in T6 is assessed as follows.

$H^{CHC} = \{(\text{very poor}, 0.07), (poor, 0.19), (medium, 0.42), (good, 0.28), (very\ good, 0.05)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 11.75% SCU1 ($O^1 = (0.07 \times 1) + (0.19 \times 0.25)$), 24.75% SCU2 ($O^2 = 0.19 \times 0.75) + (0.42 \times 0.25)$), 21% SCU3 ($O^3 = 0.42 \times 0.5$), 31.5% SCU4 ($O^4 = (0.42 \times 0.25) + (0.28 \times 0.75)$) and 12% SCU5 ($O^5 = (0.28 \times 0.25) + (0.05 \times 1)$) respectively. The CHC service costs set in T6 is assessed as follows.

$H^{CHC\ SFU} = \{(\text{very poor}, 0.118), (poor, 0.248), (medium, 0.21), (good, 0.315), (very\ good, 0.12)\}$

Costs of terminal ancillary services to service costs in T6

According to Table 5.32, the costs of terminal ancillary services set in T6 is assessed as follows.

$H^{CTA} = \{(\text{very poor}, 0.07), (poor, 0.28), (medium, 0.37), (good, 0.23), (very\ good, 0.05)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 14% SCU1 ($O^1 = (0.07 \times 1) + (0.28 \times 0.25)$), 30.25% SCU2 ($O^2 = 0.28 \times 0.75) + (0.37 \times 0.25)$), 18.5% SCU3 ($O^3 = 0.37 \times 0.5$), 26.5% SCU4 ($O^4 = (0.37 \times 0.25) + (0.23 \times 0.75)$) and 10.75% SCU5 ($O^5 = (0.23 \times 0.25) + (0.05 \times 1)$) respectively. The CTA service costs set in T6 is assessed as follows.

$H^{CTA\ SFU} = \{(\text{very poor}, 0.14), (poor, 0.303), (medium, 0.185), (good, 0.265), (very\ good, 0.108)\}$

Sea side connectivity to intermodal transport systems in T6

According to Table 5.34, the sea side connectivity set in T6 is assessed as follows.

$H^{SSC} = \{(\text{very poor}, 0.02), (poor, 0.08), (medium, 0.25), (good, 0.44), (very\ good, 0.21)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 4% ITST1 ($O^1 = (0.02 \times 1) + (0.28 \times 0.25)$), 12.25% ITST2 ($O^2 = 0.08 \times 0.75) + (0.25 \times 0.25)$), 12.5% ITST3 ($O^3 = 0.25 \times 0.5$), 39.25% ITST4 ($O^4 = (0.25 \times 0.25) + (0.44 \times 0.75)$) and 32% ITST5 ($O^5 = (0.44 \times 0.25) + (0.21 \times 1)$) respectively. The SSC intermodal transport systems set in T6 is assessed as follows.

$H^{SSC\ ITST} = \{(\text{very poor}, 0.04), (poor, 0.123), (medium, 0.125), (good, 0.393), (very\ good, 0.32)\}$

Land side connectivity to intermodal transport systems in T6

According to Table 5.34, the land side connectivity set in T6 is assessed as follows.

$H^{LSC} = \{(\text{very poor}, 0.02), (poor, 0.1), (medium, 0.27), (good, 0.46), (very\ good, 0.15)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 4.5% ITST1 ($O^1 = (0.02 \times 1) + (0.1 \times 0.25)$), 14.25% ITST2 ($O^2 = 0.1 \times 0.75) + (0.27 \times 0.25)$), 13.5% ITST3 ($O^3 = 0.27 \times 0.5$), 41.25% ITST4 ($O^4 = (0.27 \times 0.25) + (0.46 \times 0.75)$) and 26.5% ITST5 ($O^5 = (0.46 \times 0.25) + (0.15 \times 1)$) respectively. The LSC intermodal transport systems set in T6 is assessed as follows.

$H^{LSC\ ITST} = \{(\text{very poor}, 0.045), (poor, 0.143), (medium, 0.135), (good, 0.413), (very\ good, 0.265)\}$

Reliability for multimodal operations to intermodal transport systems in T6

According to Table 5.34, the reliability for multimodal operations set in T6 is assessed as follows.

$H^{RMO} = \{(\text{very poor}, 0.04), (poor, 0.04), (medium, 0.31), (good, 0.4), (very\ good, 0.21)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 5% ITST1 ($O^1 = (0.04 \times 1) + (0.04 \times 0.25)$), 10.75% ITST2 ($O^2 = 0.04 \times 0.75) + (0.31 \times 0.25)$), 15.5% ITST3 ($O^3 = 0.31 \times 0.5$), 37.75% ITST4 ($O^4 = (0.31 \times 0.25) + (0.4 \times 0.75)$) and 31% ITST5 ($O^5 = (0.4 \times 0.25) + (0.21 \times 1)$) respectively. The RMO intermodal transport systems set in T6 is assessed as follows.

$H^{RMO\ ITST} = \{(\text{very poor}, 0.05), (poor, 0.108), (medium, 0.155), (good, 0.378), (very\ good, 0.31)\}$

Efficiency of multimodal operations to intermodal transport systems in T6

According to Table 5.34, the efficiency of multimodal operations set in T6 is assessed as follows.

$H^{EMO} = \{(\text{very poor}, 0.04), (poor, 0.08), (medium, 0.27), (good, 0.4), (very\ good, 0.21)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 5% ITST1 ($O^1 = (0.04 \times 1) + (0.08 \times 0.25)$), 12.75% ITST2 ($O^2 = 0.08 \times 0.75) + (0.27 \times 0.25)$), 13.5% ITST3 ($O^3 = 0.27 \times 0.5$), 36.75% ITST4 ($O^4 = (0.27 \times 0.25) + (0.4 \times 0.75)$) and 31% ITST5 ($O^5 = (0.4 \times 0.25) + (0.21 \times 1)$) respectively. The EMO intermodal transport systems set in T6 is assessed as follows.

$H^{EMO\ ITST} = \{(\text{very poor}, 0.06), (poor, 0.128), (medium, 0.135), (good, 0.368), (very\ good, 0.31)\}$

Facilities for adding value to cargoes to value-added services in T6

According to Table 5.34, the facilities for adding value to cargoes set in T6 is assessed as follows.

$H^{FAV} = \{(\text{very poor}, 0.06), (poor, 0.1), (medium, 0.29), (good, 0.46), (very\ good, 0.08)\}$

Based on R^1, R^2, R^3, $R^4$and R^5, it can be transformed into 8.5% VAST1 ($O^1 = (0.06 \times 1) + (0.1 \times 0.25)$), 14.75% VAST2 ($O^2 = 0.1 \times 0.75) + (0.29 \times 0.25)$), 14.5% VAST3 ($O^3 = 0.29 \times 0.5$), 41.75% VAST4 ($O^4 = (0.29 \times 0.25) + (0.46 \times 0.75)$) and 19.5% VAST5 ($O^5 = (0.46 \times 0.25) + (0.08 \times 1)$) respectively. The FAV value-added services set in T6 is assessed as follows.

$H^{FAV\ VAST} = \{(\text{very poor}, 0.085), (poor, 0.148), (medium, 0.145), (good, 0.418), (very\ good, 0.195)\}$

Capacity to handle different types of cargo to value-added services in T6

According to Table 5.34, the capacity to handle different types of cargo set in T6 is assessed as follows.

$H^{HDC} = \{(\text{very poor}, 0), (poor, 0.1), (medium, 0.31), (good, 0.46), (very\ good, 0.13)\}$

Based on R^1, R^2, R^3 and R^4, it can be transformed into 2.5% VAST1 ($O^1 = 0.1 \times 0.25$), 15.25% VAST2 ($O^2 = (0.1 \times 0.75) + (0.31 \times 0.25)$), 15.5% VAST3 ($O^3 = 0.31 \times 0.5$), 42.25% VAST4 ($O^4 = (0.31 \times 0.25) + (0.46 \times 0.75)$) and 24.5% VAST5 ($O^5 = (0.46 \times 0.25) + (0.13 \times 1)$) respectively. The HDC value-added services set in T6 is assessed as follows.

$H^{HDC\ VAST} = \{(\text{very poor}, 0.025), (poor, 0.153), (medium, 0.155), (good, 0.423), (very\ good, 0.245)\}$

Service adaptation to customers to value-added services in T6

According to Table 5.34, the service adaptation to customers set in T6 is assessed as follows.

$H^{SAC} = \{(\text{very poor}, 0.08), (poor, 0.17), (medium, 0.19), (good, 0.44), (very\ good, 0.13)\}$

Based on R^1, R^2, R^3, R^4 and R^5, it can be transformed into 12.25% VAST1 ($O^1 = (0.08 \times 1) + (0.17 \times 0.25)$), 17.5% VAST2 ($O^2 = 0.17 \times 0.75) + (0.19 \times 0.25)$), 9.5% VAST3 ($O^3 = 0.19 \times 0.5$), 37.75% VAST4 ($O^4 = (0.19 \times 0.25) + (0.44 \times 0.75)$) and 24% VAST5 ($O^5 = (0.44 \times 0.25) + (0.13 \times 1)$) respectively. The SAC value-added services set in T6 is assessed as follows.

$H^{SAC\ VAST} = \{(\text{very poor}, 0.123), (poor, 0.175), (medium, 0.095), (good, 0.378), (very\ good, 0.24)\}$

Tailored services to customers to value-added services in T6

According to Table 5.34, the tailored services to customers set in T6 is assessed as follows.

$H^{TSC} = \{(\text{very poor}, 0.08), (poor, 0.08), (medium, 0.27), (good, 0.46), (very\ good, 0.1)\}$

Based on R^1, R^2, R^3, R^4 and R^5, it can be transformed into 10% VAST1 ($O^1 = (0.08 \times 1) + (0.08 \times 0.25)$), 12.75% VAST2 ($O^2 = 0.08 \times 0.75) + (0.27 \times 0.25)$), 13.5% VAST3 ($O^3 = 0.27 \times 0.5$), 41.25% VAST4 ($O^4 = (0.27 \times 0.25) + (0.46 \times 0.75)$) and 21.5% VAST5 ($O^5 = (0.46 \times 0.25) + (0.1 \times 1)$) respectively. The TSC value-added services set in T6 is assessed as follows.

$H^{TSC\ VAST} = \{(\text{very poor}, 0.1), (poor, 0.128), (medium, 0.135), (good, 0.413), (very\ good, 0.215)\}$

Integrated EDI for communication to information/communication integration in T6

According to Table 5.34, the integrated EDI for communication set in T6 is assessed as follows.

$H^{EDI} = \{(\text{very poor}, 0), (poor, 0.02), (medium, 0.33), (good, 0.46), (very\ good, 0.19)\}$

Based on R^1, R^2, R^3 and R^4, it can be transformed into 0.5% ICIT1 ($O^1 = 0.02 \times 0.25$), 9.75% ICIT2 ($O^2 = (0.02 \times 0.75) + (0.33 \times 0.25)$), 16.5% ICIT3 ($O^3 = 0.33 \times 0.5$), 42.75% ICIT4 ($O^4 = (0.33 \times 0.25) + (0.46 \times 0.75)$) and 30.5% ICIT5 ($O^5 = (0.46 \times 0.25) + (0.19 \times 1)$) respectively. The EDI information/communication integration set in T6 is assessed as follows.

$H^{EDI\ ICIT} = \{(\text{very poor}, 0.005), (poor, 0.098), (medium, 0.165), (good, 0.428), (very\ good, 0.305)\}$

Integrated IT to share data to information/communication integration in T6

According to Table 5.34, the integrated IT to share data set in T6 is assessed as follows.

$H^{IIT} = \{(\text{very poor}, 0), (poor, 0.06), (medium, 0.31), (good, 0.46), (very\ good, 0.17)\}$

Based on R^1, R^2, R^3 and R^4, it can be transformed into 1.5% ICIT1 ($O^1 = 0.06 \times 0.25$), 12.25% ICIT2 ($O^2 = (0.06 \times 0.75) + (0.31 \times 0.25)$), 15.5% ICIT3 ($O^3 = 0.31 \times 0.5$), 42.25% ICIT4 ($O^4 = (0.31 \times 0.25) + (0.46 \times 0.75)$) and 28.5% ICIT5 ($O^5 = (0.46 \times 0.25) +$

$(0.17 \times 1))$ respectively. The IIT information/communication integration set in T6 is assessed as follows.

$$H^{IIT\ ICIT} = \{(\text{very poor}, 0.015), (poor, 0.123), (medium, 0.155), (good, 0.423), (very\ good, 0.285)\}$$

Collaboration with channel members to information/communication integration in T6

According to Table 5.34, the collaboration with channel members set in T6 is assessed as follows.

$$H^{CCM} = \{(\text{very poor}, 0), (poor, 0.08), (medium, 0.35), (good, 0.44), (very\ good, 0.13)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 2% ICIT1 ($O^1 = 0.08 \times 0.25$), 14.75% ICIT2 ($O^2 = (0.08 \times 0.75) + (0.35 \times 0.25)$), 17.5% ICIT3 ($O^3 = 0.35 \times 0.5$), 41.75% ICIT4 ($O^4 = (0.35 \times 0.25) + (0.44 \times 0.75)$) and 24% ICIT5 ($O^5 = (0.44 \times 0.25) + (0.13 \times 1)$) respectively. The CCM information/communication integration set in T6 is assessed as follows.

$$H^{CCM\ ICIT} = \{(\text{very poor}, 0.02), (poor, 0.148), (medium, 0.175), (good, 0.418), (very\ good, 0.24)\}$$

Latest port IT systems to information/communication integration in T6

According to Table 5.34, the latest port IT systems set in T6 is assessed as follows.

$$H^{LIT} = \{(\text{very poor}, 0), (poor, 0.13), (medium, 0.29), (good, 0.44), (very\ good, 0.15)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 3.25% ICIT1 ($O^1 = 0.13 \times 0.25$), 17% ICIT2 ($O^2 = (0.13 \times 0.75) + (0.29 \times 0.25)$), 14.5% ICIT3 ($O^3 = 0.29 \times 0.5$), 40.25% ICIT4 ($O^4 = (0.29 \times 0.25) + (0.44 \times 0.75)$) and 26% ICIT5 ($O^5 = (0.44 \times 0.25) + (0.15 \times 1)$) respectively. The LIT information/communication integration set in T6 is assessed as follows.

$$H^{LIT\ ICIT} = \{(\text{very poor}, 0.033), (poor, 0.17), (medium, 0.145), (good, 0.403), (very\ good, 0.26)\}$$

Identifying restricted areas and access control to safety and security in T6

According to Table 5.36, the identifying restricted areas and access control in T6 is assessed as follows.

$$H^{RAC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.23), (very\ good, 0.77)\}$$

Based on R^1 and R^2, it can be transformed into 17.25% SSS4 ($O^4 = (0.23 \times 0.25) + (0.77 \times 0.75)$) and 82.75% SSS5 ($O^5 = (0.23 \times 0.25) + (0.77 \times 1)$) respectively. The RAC safety and security set in T6 is assessed as follows.

$$H^{RAC\ SSS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.173), (very\ good, 0.828)\}$$

Formal safety and security training practices to safety and security in T6

According to Table 5.36, the formal safety and security training practices in T6 is assessed as follows.

$$H^{FSS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.31), (very\ good, 0.69)\}$$

Based on R^1 and R^2, it can be transformed into 23.25% SSS4 ($O^4 = (0.31 \times 0.25) + (0.69 \times 0.75)$) and 76.75% SSS5 ($O^5 = (0.31 \times 0.25) + (0.69 \times 1)$) respectively. The FSS safety and security set in T6 is assessed as follows.

$$H^{FSS\ SSS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.233), (very\ good, 0.768)\}$$

Adequate monitoring and threat awareness to safety and security in T6

According to Table 5.36, the adequate monitoring and threat awareness in T6 is assessed as follows.

$$H^{AMT} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.15), (very\ good, 0.85)\}$$

Based on R^1 and R^2, it can be transformed into 11.25% SSS4 ($O^4 = (0.15 \times 0.25) + (0.85 \times 0.75)$) and 88.75% SSS5 ($O^5 = (0.15 \times 0.25) + (0.85 \times 1)$) respectively. The AMT safety and security set in T6 is assessed as follows.

$$H^{AMT\ SSS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.113), (very\ good, 0.888)\}$$

Safety and security officers and facilities to safety and security in T6

According to Table 5.36, the safety and security officers and facilities in T6 is assessed as follows.

$$H^{SOF} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.15), (very\ good, 0.85)\}$$

Based on R^1 and R^2, it can be transformed into 11.25% SSS4 ($O^4 = (0.15 \times 0.25) + (0.85 \times 0.75)$) and 88.75% SSS5 ($O^5 = (0.15 \times 0.25) + (0.85 \times 1)$) respectively. The SOF safety and security set in T6 is assessed as follows.

$$H^{SOF\ SSS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.113), (very\ good, 0.888)\}$$

Carbon footprint to Environment in T6

According to Table 5.36, the carbon footprint set in T6 is assessed as follows.

$$H^{CF} = \{(\text{very poor}, 0), (poor, 0.23), (medium, 0.31), (good, 0.23), (very\ good, 0.23)\}$$

Based on R^1, R^2, $R^3$and R^4, it can be transformed into 5.75% EVS1 ($O^1 = 0.23 \times 0.25$), 25% EVS2 ($O^2 = (0.23 \times 0.75) + (0.31 \times 0.25)$), 15.5% EVS3 ($O^3 = 0.31 \times 0.5$), 25% EVS4 ($O^4 = (0.31 \times 0.25) + (0.23 \times 0.75)$) and 28.75% EVS5 ($O^5 = (0.23 \times 0.25) + (0.23 \times 1)$) respectively. The CF environment set in T6 is assessed as follows.

$$H^{CF\ EVS} = \{(\text{very poor}, 0.058), (poor, 0.25), (medium, 0.155), (good, 0.25), (very\ good, 0.288)\}$$

Total water consumption to Environment in T6

According to Table 5.36, the total water consumption set in T6 is assessed as follows.

$$H^{WC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.15), (good, 0.38), (very\ good, 0.46)\}$$

Based on R^1, R^2 and R^3, it can be transformed into 3.75% EVS2 ($O^2 = 0.15 \times 0.25$), 7.5% EVS3 ($O^3 = 0.15 \times 0.5$), 32.25% EVS4 ($O^4 = (0.15 \times 0.25) + (0.38 \times 0.75)$) and 55.5% EVS5 ($O^5 = (0.38 \times 0.25) + (0.46 \times 1)$) respectively. The WC environment set in T6 is assessed as follows.

$$H^{WC\ EVS} = \{(\text{very poor}, 0), (poor, 0.038), (medium, 0.075), (good, 0.323), (very\ good, 0.555)\}$$

Total energy consumption to Environment in T6

According to Table 5.36, the total energy consumption in T6 is assessed as follows.

$$H^{EC} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.46), (very\ good, 0.54)\}$$

Based on R^1 and R^2, it can be transformed into 34.5% EVS4 ($O^4 = (0.46 \times 0.25) + (0.54 \times 0.75)$) and 65.5% EVS5 ($O^5 = (0.46 \times 0.25) + (0.54 \times 1)$) respectively. The EC environment set in T6 is assessed as follows.

$$H^{EC\ EVS} = \{(\text{very poor}, 0), (poor, 0), (medium, 0), (good, 0.345), (very\ good, 0.655)\}$$

Waste recycling to Environment in T6

According to Table 5.36, the waste recycling set in T6 is assessed as follows.

$$H^{WR} = \{(\text{very poor}, 0), (poor, 0.08), (medium, 0.31), (good, 0.31), (very\ good, 0.31)\}$$

Based on R^1, R^2, R^3 and R^4, it can be transformed into <u>2% EVS1</u> ($O^1 = 0.08 \times 0.25$), <u>13.75% EVS2</u> ($O^2 = (0.08 \times 0.75) + (0.31 \times 0.25)$), <u>15.5% EVS3</u> ($O^3 = 0.31 \times 0.5$), <u>31% EVS4</u> ($O^4 = (0.31 \times 0.25) + (0.31 \times 0.75)$) and <u>38.75% EVS5</u> ($O^5 = (0.31 \times 0.25) + (0.31 \times 1)$) respectively. The WR environment set in T6 is assessed as follows.

$$H^{WR\ EVS} = \{(\text{very poor}, 0.058), (poor, 0.25), (medium, 0.155), (good, 0.25), (very\ good, 0.288)\}$$

<u>Environment management programs to Environment in T6</u>

According to Table 5.36, the environment management programs set in T6 is assessed as follows.

$$H^{EMP} = \{(\text{very poor}, 0), (poor, 0.08), (medium, 0.46), (good, 0.15), (very\ good, 0.31)\}$$

Based on R^1, R^2, R^3 and R^4, it can be transformed into <u>2% EVS1</u> ($O^1 = 0.08 \times 0.25$), <u>17.5% EVS2</u> ($O^2 = (0.08 \times 0.75) + (0.46 \times 0.25)$), <u>23% EVS3</u> ($O^3 = 0.46 \times 0.5$), <u>22.75% EVS4</u> ($O^4 = (0.46 \times 0.25) + (0.15 \times 0.75)$) and <u>34.75% EVS5</u> ($O^5 = (0.15 \times 0.25) + (0.31 \times 1)$) respectively. The EMP environment set in T6 is assessed as follows.

$$H^{EMP\ EVS} = \{(\text{very poor}, 0.02), (poor, 0.175), (medium, 0.23), (good, 0.228), (very\ good, 0.348)\}$$

<u>Employment to social engagement in T6</u>

According to Table 5.36, the employment set in T6 is assessed as follows.

$$H^{EP} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.67), (good, 0.17), (very\ good, 0.17)\}$$

Based on R^1, R^2 and R^3, it can be transformed into <u>16.75% SES2</u> ($O^2 = 0.67 \times 0.25$), <u>33.5% SES3</u> ($O^3 = 0.67 \times 0.5$), <u>29.5% SES4</u> ($O^4 = (0.67 \times 0.25) + (0.17 \times 0.75)$) and <u>21.25% SES5</u> ($O^5 = (0.17 \times 0.25) + (0.17 \times 1)$) respectively. The EP social engagement set in T6 is assessed as follows.

$$H^{EP\ SES} = \{(\text{very poor}, 0), (poor, 0.168), (medium, 0.335), (good, 0.295), (very\ good, 0.213)\}$$

<u>Regional GDP to social engagement in T6</u>

According to Table 5.36, the regional GDP set in T6 is assessed as follows.

$$H^{GDP} = \{(\text{very poor}, 0), (poor, 0), (medium, 0.17), (good, 0.5), (very\ good, 0.33)\}$$

Based on R^1, R^2 and R^3, it can be transformed into <u>4.25% SES2</u> ($O^2 = 0.17 \times 0.25$), <u>8.5% SES3</u> ($O^3 = 0.17 \times 0.5$), <u>41.75% SES4</u> ($O^4 = (0.17 \times 0.25) + (0.5 \times 0.75)$) and <u>45.5% SES5</u> ($O^5 = (0.5 \times 0.25) + (0.33 \times 1)$) respectively. The GDP social engagement set in T6 is assessed as follows.

$$H^{GDP\ SES} = \{(\text{very poor}, 0), (poor, 0.043), (medium, 0.085), (good, 0.418), (very\ good, 0.455)\}$$

<u>Disclose of information to Environment in T6</u>

According to Table 5.36, the disclose of information set in T6 is assessed as follows.

$$H^{DI} = \{(\text{very poor}, 0), (poor, 0.33), (medium, 0.5), (good, 0.17), (very\ good, 0)\}$$

Based on R^2, R^3 and R^4, it can be transformed into <u>8.25% SES1</u> ($O^1 = 0.33 \times 0.25$), <u>37.25% SES2</u> ($O^2 = (0.33 \times 0.75) + (0.5 \times 0.25)$), <u>25% SES3</u> ($O^3 = 0.5 \times 0.5$), <u>25.25% SES4</u> ($O^4 = (0.5 \times 0.25) + (0.17 \times 0.75)$) and <u>4.25% SES5</u> ($O^5 = 0.17 \times 0.25$) respectively. The DI social engagement set in T6 is assessed as follows.

$$H^{DI\ SES} = \{(\text{very poor}, 0.083), (poor, 0.373), (medium, 0.25), (good, 0.253), (very\ good, 0.043)\}$$

Appendix III Aggregation of bottom level PPIs

Profitability in T6

Table III-1 Aggregation of bottom level PPIs (profitability)

Profitability	Very Poor	Poor	Medium	Good	Very Good	Weight
Revenue growth	0	0	0	0	1	0.318
EBIT margin	0	0	0	0.042	0.958	0.328
Net profit margin	0	0.182	0.5	0.318	0	0.354
Aggregation results	0	0.06057	0.16642	0.31002	0.46296	

Liquidity and solvency in T6

Table III-2 Aggregation of bottom level PPIs (liquidity and solvency)

Liquidity and Solvency	Very Poor	Poor	Medium	Good	Very Good	Weight
Current ratio	0.25	0.5	0.25	0	0	0.342
Debt to total asset	0.25	0.5	0.25	0	0	0.349
Debt to equity	1	0	0	0	0	0.309
Aggregation results	0.49290	0.34475	0.16233	0	0	

Human capital in T6

Table III-3 Aggregation of bottom level PPIs (human capital)

Human Capital	Very Poor	Poor	Medium	Good	Very Good	Weight
Knowledge and skills	0	0	0	0.533	0.468	0.246
Capability	0.035	0.178	0.145	0.5	0.143	0.243
Training and education opportunity	0.035	0.213	0.215	0.325	0.213	0.354
Commitment and Loyalty	0	0.108	0.215	0.535	0.143	0.157
Aggregation results	0.01918	0.12755	0.13569	0.47879	0.23877	

Organisation capital in T6

Table III-4 Aggregation of bottom level PPIs (organisation capital)

Organisation Capital	Very Poor	Poor	Medium	Good	Very Good	Weight
Culture	0.035	0.14	0.07	0.575	0.18	0.175
Leadership	0	0.108	0.215	0.43	0.248	0.296
Alignment	0.035	0.178	0.145	0.395	0.248	0.198
Teamwork	0	0.108	0.215	0.325	0.362	0.330
Aggregation results	0.01019	0.11567	0.16926	0.43447	0.27038	

Information capital in T6

Table III-5 Aggregation of bottom level PPIs (information capital)

Information Capital	Very Poor	Poor	Medium	Good	Very Good	Weight
IT systems	0.14	0.035	0.007	0.463	0.284	0.364
Databases	0.035	0.178	0.145	0.395	0.248	0.301
Networks	0	0.073	0.145	0.605	0.178	0.335
Aggregation results	0.05482	0.07853	0.10561	0.52936	0.23165	

Service fulfilment in T6

Table III-6 Aggregation of bottom level PPIs (service fulfilment)

Service Fulfilment	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Weight
Overall service reliability	0.048	0.208	0.13	0.38	0.245	0.361
Responsiveness to special requests	0.095	0.183	0.215	0.34	0.178	0.147
Accuracy of document & information	0.033	0.113	0.15	0.39	0.315	0.134
Incidence of cargo damage	0.03	0.143	0.105	0.405	0.328	0.188
Incidence of service delay	0.088	0.153	0.2	0.378	0.183	0.170
Aggregation results	0.04986	0.16525	0.14242	0.40269	0.23976	

Service costs in T6

Table III-7 Aggregation of bottom level PPIs (service costs)

Service Costs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Weight
Overall service costs	0.13	0.208	0.175	0.35	0.138	0.549
Cargo handling charges	0.118	0.248	0.21	0.315	0.12	0.315
Cost of terminal ancillary services	0.14	0.303	0.185	0.265	0.108	0.137
Aggregation results	0.12227	0.22789	0.18207	0.34578	0.12197	

Intermodal transport systems in T6

Table III-8 Aggregation of bottom level PPIs (intermodal transport systems)

Intermodal Transport Systems	Very Poor	Poor	Medium	Good	Very Good	Weight
Sea side connectivity	0.04	0.123	0.125	0.393	0.32	0.466
Land side connectivity	0.045	0.143	0.135	0.413	0.265	0.159
Reliability for multimodal operations	0.05	0.108	0.155	0.378	0.31	0.197
Efficiency of multimodal operations	0.06	0.128	0.135	0.368	0.31	0.178
Aggregation results	0.04050	0.11471	0.12408	0.40779	0.31289	

Value-Added Services in T6

Table III-9 Aggregation of bottom level PPIs (value-added services)

Value-Added Services	Very Poor	Poor	Medium	Good	Very Good	Weight
Facilities for adding value to cargoes	0.085	0.148	0.145	0.418	0.195	0.369
Capacity to handle different types of cargo	0.025	0.153	0.155	0.423	0.245	0.172
Service adaptation to customers	0.123	0.175	0.095	0.378	0.24	0.262
Tailored services to customers	0.1	0.128	0.135	0.413	0.215	0.197
Aggregation results	0.08081	0.14357	0.12357	0.43543	0.21660	

Information/Communication Integration in T6

Table III-10 Aggregation of bottom level PPIs (information/communication integration)

Information/Communication Integration	Very Poor	Poor	Medium	Good	Very Good	Weight
Integrated EDI for communication	0.005	0.098	0.165	0.428	0.305	0.291
Integrated IT to share data	0.015	0.123	0.155	0.423	0.285	0.261
Collaborate with channel members	0.02	0.148	0.175	0.418	0.24	0.232
Latest IT in the industry	0.033	0.17	0.145	0.403	0.26	0.216
Aggregation results	0.01700	0.12528	0.14353	0.44077	0.27339	

Safety and Security in T6

Table III-11 Aggregation of bottom level PPIs (safety and security)

Safety and Security	Very Poor	Poor	Medium	Good	Very Good	Weight
Identifying restricted areas and access control	0	0	0	0.173	0.828	0.298
Formal safety and security training practices	0	0	0	0.233	0.768	0.206
Adequate monitoring and threat awareness	0	0	0	0.113	0.888	0.231
Safety and security officers and facilities	0	0	0	0.113	0.888	0.265
Aggregation results	0	0	0	0.11594	0.88405	

Environment in T6

Table III-12 Aggregation of bottom level PPIs (environment)

Environment	Very Poor	Poor	Medium	Good	Very Good	Weight
Carbon footprint	0.058	0.25	0.155	0.25	0.288	0.158
Total water consumption	0	0.038	0.075	0.323	0.555	0.145
Total energy consumption	0	0	0	0.345	0.655	0.248
Waste recycling	0.058	0.25	0.155	0.25	0.288	0.149
Environment management programs	0.02	0.175	0.23	0.228	0.348	0.300

Aggregation results	0.01532	0.10642	0.11715	0.28159	0.47949	

Social Engagement in T6

Table III-13 Aggregation of bottom level PPIs (social engagement)

Social Engagement	Very Poor	Poor	Medium	Good	Very Good	Weight
Employment	0	0.168	0.335	0.295	0.213	0.578
Regional GDP	0	0.043	0.085	0.418	0.455	0.272
Disclose of information	0.083	0.373	0.25	0.253	0.043	0.150
Aggregation results	0.00687	0.15627	0.26982	0.32828	0.23873	

Appendix IV Mapping results from principal-PPIs to 6 dimensions and aggregation of the principal-PPIs

Table IV-1 Mapping results and relative weights and aggregation (supporting activities)

Supporting Activities	Very Low	Low	Medium	High	Very High	weight
Human capital	0.05106	0.12958	0.06784	0.39301	0.35846	0.419
Organisational capital	0.03910	0.12906	0.08463	0.36816	0.37899	0.192
Information capital	0.07445	0.0853	0.05280	0.42342	0.36399	0.389
Aggregation results	0.05187	0.10161	0.05723	0.41682	0.37244	

Table IV-2 Mapping results and relative weights and aggregation (financial strength)

Financial Strength	Very Low	Low	Medium	High	Very High	weight
Profitability	0.015	0.087	0.083	0.274	0.540	0.654
Liquidity and solvency	0.579	0.299	0.081	0.041	0.000	0.346
Aggregation results	0.13907	0.14111	0.08373	0.22279	0.41328	

Table IV-3 Mapping results and relative weights and aggregation (users' satisfaction)

Users' Satisfaction	Very Low	Low	Medium	High	Very High	weight
Service fulfilment	0.09117	0.15954	0.07121	0.33762	0.34043	0.723
Service costs	0.17924	0.21643	0.09103	0.30485	0.20841	0.277
Aggregation results	0.10017	0.16557	0.07047	0.34144	0.32233	

Table IV-4 Mapping results and relative weights and aggregation (terminal supply chain integration)

Terminal Supply Chain Integration	Very Low	Low	Medium	High	Very High	weight
Intermodal transport systems	0.06917	0.11705	0.06204	0.33686	0.41483	0.528
Value-added services	0.1167025	0.13857	0.061785	0.35746	0.32545	0.197
Information/communication integration	0.04832	0.12984	0.07176	0.36646	0.38358	0.275
Aggregation results	0.06468	0.11421	0.05794	0.35510	0.40805	

Table IV-5 Mapping results and relative weights and aggregation (sustainable growth)

Sustainable Growth	Very Low	Low	Medium	High	Very High	weight
Safety and security	0	0	0	0.08695	0.91303	0.602
Environment	0.04192	0.10910	0.05857	0.24048	0.54988	0.2
Social engagement	0.04593	0.18465	0.13491	0.31366	0.3208	0.198
Aggregation results	0.00929	0.03140	0.02052	0.12392	0.81483	

Appendix V Evaluate each port/terminal based on the lowest PPIs

- Vessel call capacity growth

The quantitative assessment grades of the vessel call capacity growth is defined as *{leq 0%, 5%, 10%, 15%, geq 20%}*.

$$H = \{\text{leq } 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), geq\ 20\%(H_5)\}$$

The data of the vessel call capacity growth between 2012 and 2013 in 4 alternative container ports is demonstrated in Table V-1.

Table V-1 Vessel capacity growth (2012-2013)

Port	2012			2013			Growth ('12-'13)
	No.Vessel	Total G/T	Ave. Capacity	No.Vessel	Total G/T	Ave. Capacity	
Busan North	7,702	136,447,656	17,716	7,386	113,404,531	15,354	-13.33%
Gwangyang	8,498	242,621,022	28,550	8,258	261,511,695	31,667	10.92%
Incheon	2,811	36,077,274	12,834	2,882	38,791,525	13,460	4.87%
Busan New	5,940	264,940,196	44,603	6,618	320,296,262	48,398	8.51%

Vessel call capacity growth in Busan New Port

The vessel call capacity growth in Busan New Port is 8.51%, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 5\%(H_2), \quad h_{j,i} = 8.51\%, \quad h_{j+1,i} = 10\%(H_3)$$

Thus, $B_{j+1,i} = \frac{8.51-5}{10-5} = 0.702$ DoB with $10\%(H_3)$ and $B_{j-1,i} = 1 - 0.702 = 0.298$ DoB with $5\%(H_2)$. Therefore, the vessel capacity growth set in Busan New Port is assessed as follows:

$$H^{capacity} = \{(\text{leq } 0\%, 0), (5\%, 0.298), (10\%, 0.702), (15\%, 0), (geq\ 20\%, 0)\}$$

In a similar way, the vessel call size growth sets of other ports are obtained and presented in Table V-2.

Table V-2 Vessel capacity growth sets

Port	Vessel call size growth
Busan North	$H^{capacity} = \{(\text{leq } 0\%, 1), (5\%, 0), (10\%, 0), (15\%, 0), (geq\ 20\%, 0)\}$
Gwangyang	$H^{capacity} = \{(\text{leq } 0\%, 0), (5\%, 0), (10\%, 0.816), (15\%, 0.184), (geq\ 20\%, 0)\}$
Incheon	$H^{capacity} = \{(\text{leq } 0\%, 0.025), (5\%, 0.975), (10\%, 0), (15\%, 0), (geq\ 20\%, 0)\}$
Busan New	$H^{capacity} = \{(\text{leq } 0\%, 0), (5\%, 0.298), (10\%, 0.702), (15\%, 0), (geq\ 20\%, 0)\}$

- Ship load rate

A set of quantitative grades *{leq 25TEU, 40TEU, 55TEU, 70TEU, 85TEU, geq 100TEU}* for ship load rate is already defined.

$$H = \{\text{leq } 25\text{TEU}(H_1), 40TEU(H_2), 55TEU(H_3), 70\text{TEU}(H_4), 85TEU(H_5), \text{geq } 100\text{TEU}(H_6)\}$$

The data of the ship load rate in 4 alternative ports is demonstrated in Table V-3.

Table V-3 Ship load rate (2013)

Port	Throughput (TEU)	Sum of Aver. Capacity (GT)	load rate (TEU/GT)
Busan North	6,124,253	74,969	81.69
Gwangyang	2,284,438	96,236	23.74
Incheon	1,232,935	38,460	32.06
Busan New	10,913,634	240,803	45.32

Ship load rate in Busan New Port

The ship load rate in Busan New Port is 45.32TEU/GT, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 40TEU(H_2), \quad h_{j,i} = 45.32TEU, \quad h_{j+1,i} = 55TEU(H_3)$$

Thus, $B_{j+1,i} = \frac{45.32-40}{55-40} = 0.355$ DoB with $55TEU(H_3)$ and $B_{j-1,i} = 1 - 0.355 = 0.645$ DoB with $40TEU(H_2)$. Therefore, the the ship load rate set in Busan New Port is assessed as follows:

$H^{LR} = \{(\text{leq } 25\text{TEU}, 0), (40\text{TEU}, 0.645), (55\text{TEU}, 0.355), (70\text{TEU}, 0), (85\text{TEU}, 0), (\text{geq } 100\text{TEU}, 0)\}$

In a similar way, the ship load rate sets of other ports are obtained and shown in Table V-4.

Table V-4 Ship load rate sets

Port	Ship load rate
Busan North	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0), (55TEU, 0), (70TEU, 0.221), (85TEU, 0.779), (geq 100TEU, 0)}
Gwangyang	$H^{loadrate}$ = {(leq 25TEU, 1), (40TEU, 0), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
Incheon	$H^{loadrate}$ = {(leq 25TEU, 0.529), (40TEU, 0.471), (55TEU, 0), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}
Busan New	$H^{loadrate}$ = {(leq 25TEU, 0), (40TEU, 0.645), (55TEU, 0.355), (70TEU, 0), (85TEU, 0), (geq 100TEU, 0)}

- Berth utilisation

A set of quantitative grades *{leq 300TEU, 600TEU, 900TEU, 1200TEU, 1500TEU, geq 1800TEU}* for berth utilization is already defined.

$H = \{\text{leq } 300\text{TEU}(H_1), 600TEU(H_2), 900TEU(H_3), 1200\text{TEU}(H_4), 1500TEU(H_5), \text{geq } 1800\text{TEU}(H_6)\}$

The data of the berth utilisation in 4 alternative ports is demonstrated in Table V-5.

Table V-5 Berth utilization

Terminal	Busan North	Gwangyang	Incheon	Busan New
Throughput (TEU)	6,124,253	2,284,438	1,232,935	10,913,634
Berth length (m)	5,673	3,700	1,267	6,850
Utilization (TEU/m)	1080	617	973	1593

Berth utilisation in Busan New Port

The berth utilization in Busan New Port is 1593TEU/m, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 1500TEU(H_5), \quad h_{j,i} = 1593TEU, \quad h_{j+1,i} = leq\ 1800TEU(H_6)$$

Thus, $B_{j+1,i} = \frac{1593-1500}{1800-1500} = 0.31$ DoB with $leq\ 1800TEU(H_6)$ and $B_{j-1,i} = 1 - 0.31 = 0.69$ DoB with $1500TEU(H_5)$. Therefore, the berth utilization set in Busan New Port is assessed as follows:

$H^{berth\ U}$ = {(less than 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0.69), (more than 1800TEU, 0.31)}

In a similar way, the berth utilisation sets of other ports are obtained and shown in Table V-6.

Table V-6 Berth utilization sets

Port	Berth utilization
Busan North	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.4), (1200TEU, 0.6), (1500TEU, 0), (geq 1800TEU, 0)}
Gwangyang	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0.943), (900TEU, 0.057), (1200TEU, 0), (1500TEU, 0), (geq 1800TEU, 0)}
Incheon	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0.243), (1200TEU, 0.757), (1500TEU, 0), (geq 1800TEU, 0)}
Busan New	$H^{berth\ U}$ = {(leq 300TEU, 0), (600TEU, 0), (900TEU, 0), (1200TEU, 0), (1500TEU, 0.69), (geq 1800TEU, 0.31)}

- Berth occupancy rate

A set of quantitative grades *{leq 45%, 50%, 55%, 60-80%, geq 80%}* for berth occupancy rate is already defined.

$$H = \{\text{leq } 45\%(H_1), 50\%(H_2), 55\%(H_3), 60-80\%(H_4), geq\ 80\%(H_5)\}$$

The data of the berth occupancy rate in 4 alternative ports is demonstrated in Table I-9.

Table V-7 Berth occupancy rate

Port	Busan North	Gwangyang	Incheon	Busan New
Berth occupancy (%)	61.2	43	50	44

<u>*Berth occupancy rate in Busan New Port*</u>

The berth occupancy rate in Busan New Port is 44%, this value can be directly transformed as belief degrees as follows:

$$H^{berth\ O} = \{(\text{leq } 45\%, 1), (50\%, 0), (55\%, 0), (60-80\%, 0), (\text{geq } 80\%, 0)\}$$

In a similar way, the berth occupancy rate sets of other ports are obtained and shown in Table V-8.

Table V-8 Berth occupancy rate sets

Port	Berth occupancy
Busan North	$H^{berth\ O} = \{(\text{leq } 45\%, 0), (50\%, 0), (55\%, 0), (60-80\%, 1), (\text{geq } 80\%, 0)\}$
Gwangyang	$H^{berth\ O} = \{(\text{leq } 45\%, 1), (50\%, 0), (55\%, 0), (60-80\%, 0), (\text{geq } 80\%, 0)\}$
Incheon	$H^{berth\ O} = \{(\text{leq } 45\%, 0), (50\%, 1), (55\%, 0), (60-80\%, 0), (\text{geq } 80\%, 0)\}$
Busan New	$H^{berth\ O} = \{(\text{leq } 45\%, 1), (50\%, 0), (55\%, 0), (60-80\%, 0), (\text{geq } 80\%, 0)\}$

- Crane efficiency

A set of quantitative grades *{leq 20moves, 25moves, 30moves, 35moves, 40moves, geq 45moves}* for crane efficiency is already defined.

$$H = \{leq\ 20moves(H_1), 25moves(H_2), 30moves(H_3), 35moves(H_4), 40moves(H_5), geq\ 45moves(H_6)\}$$

The data of the crane efficiency in 4 alternative ports is demonstrated in Table V-9.

Table V-9 Crane efficiency

Port	Busan North	Gwangyang	Incheon	Busan New
Crane efficiency (moves/h)	31.6	33	33	35

<u>*Crane efficiency in Busan New Port*</u>

The crane efficiency in Busan New Port is 35 moves/h, this value can be directly transformed as belief degrees (DoB) as follow:

$$H^{crane} = \{(leq\ 20moves, 0), (25moves, 0), (30moves, 0), (35moves, 1), (40moves, 0), (geq\ 45mvoes, 0)\}$$

In a similar way, the crane efficiency sets of other ports are obtained and shown in Table V-10.

Table V-10 Crane efficiency sets

Port	Crane efficiency
Busan North	$H^{crane} = \{(\text{leq 20moves}, 0), (\text{25moves}, 0), (\text{30moves}, 0.32), (\text{35moves}, 0.68), (\text{40moves}, 0), (\text{geq 45moves}, 0)\}$
Gwangyang	$H^{crane} = \{(\text{leq 20moves}, 0), (\text{25moves}, 0), (\text{30moves}, 0.4), (\text{35moves}, 0.6), (\text{40moves}, 0), (\text{geq 45moves}, 0)\}$
Incheon	$H^{crane} = \{(\text{leq 20moves}, 0), (\text{25moves}, 0), (\text{30moves}, 0.4), (\text{35moves}, 0.6), (\text{40moves}, 0), (\text{geq 45moves}, 0)\}$
Busan New	$H^{crane} = \{(\text{leq 20moves}, 0), (\text{25moves}, 0), (\text{30moves}, 0), (\text{35moves}, 1), (\text{40moves}, 0), (\text{geq 45moves}, 0)\}$

- Yard utilisation

A set of quantitative grades *{less than 2TEU, 4TEU, 6TEU, 8TEU, more than 10TEU}* for yard utilization is already defined.

$$H = \{leq\ 2TEU(H_1), 4TEU(H_2), 6TEU(H_3), 8TEU(H_4), geq 10TEU(H_5)\}$$

The data of the yard utilisation in 4 alternative ports is demonstrated in Table V-11.

Table V-11 Yard utilization

Port	Busan North	Gwangyang	Incheon	Busan New
Throughput (TEU)	6,124,253	2,284,438	1,232,935	10,913,634
CY area (㎡)	1,847,000	1,033,000	597,000	1,622,000
Utilization	3.3	2.2	2.1	6.7

Yard utilisation in Busan New Port

The yard utilization in Busan New port is 6.7 TEU/㎡, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 6TEU(H_3), \qquad h_{j,i} = 6.7TEU, \qquad h_{j+1,i} = 8TEU(H_4)$$

Thus, $B_{j+1,i} = \frac{6.7-6}{8-6} = 0.35$ DoB with $8TEU(H_4)$ and $B_{j-1,i} = 1 - 0.35 = 0.65$ DoB with $6TEU(H_3)$. Therefore, the yard utilization set in Busan New Port is assessed as follows:

$$H^{yard} = \{(leq\ 2TEU, 0), (4TEU, 0), (6TEU, 0.65), (8TEU, 0.35), (geq\ 10TEU, 0)\}$$

In a similar way, the yard utilisation sets of other ports are obtained and shown in Table V-12.

Table V-12 Yard utilization sets

Port	Yard utilization
Busan North	$H^{yard} = \{(leq\ 2TEU, 0.35), (4TEU, 0.65), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$
Gwangyang	$H^{yard} = \{(leq\ 2TEU, 0.9), (4TEU, 0.1), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$
Incheon	$H^{yard} = \{(leq\ 2TEU, 0.95), (4TEU, 0.05), (6TEU, 0), (8TEU, 0), (geq\ 10TEU, 0)\}$
Busan New	$H^{yard} = \{(leq\ 2TEU, 0), (4TEU,), (6TEU, 0.65), (8TEU, 0.35), (geq\ 10TEU, 0)\}$

- Labour utilisation

A set of quantitative grades *{leq 1000TEU, 2000TEU, 3000TEU, 4000TEU, 5000TEU, geq 6000TEU}* for labour utilization is already defined.

$$H = \{leq\ 1000TEU(H_1), 2000TEU(H_2), 3000TEU(H_3), 4000TEU(H_4), 5000TEU(H_5), geq\ 6000TEU(H_6)\}$$

The data of the labour utilisation in 4 alternative ports is demonstrated in Table V-13.

Table V-13 Labour utilisation

Port	Busan North	Gwangyang	Incheon	Busan New
Throughput (TEU)	6,124,253	2,284,438	1,232,935	10,913,634
Employee	1,857	-	-	2,927
Utilization	3,298	-	-	3,729

Note: No available data in Gwangyang and Incheon ports

Labour utilisation in Busan New Port

The labour utilisation in Busan New Port 3,729TEU/man, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 3000\text{TEU}(\text{H}_3), \qquad h_{j,i} = 3{,}729\ TEU, \qquad h_{j+1,i} = 4000\text{TEU}(\text{H}_4)$$

Thus, $B_{j+1,i} = \frac{3729-3000}{4000-3000} = 0.729$ DoB with $4000\text{TEU}(\text{H}_4)$ and $B_{j-1,i} = 1 - 0.729 = 0.271$ DoB with $3000\text{TEU}(\text{H}_3)$. Therefore, the labour utilization set in Busan New Port is assessed as follows:

$H^{labour} = \{(leq\ 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.271), (4000TEU, 0.729), (5000TEU, 0), (geq\ 6000TEU, 0)\}$

In a similar way, the labour utilisation sets of other ports are obtained and shown in Table V-14.

Table V-14 Labour utilisation sets

Port	Labour utilization
Busan North	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.702), (4000TEU, 0.298), (5000TEU, 0), (geq 6000TEU, 0)}
Gwangyang	-
Incheon	-
Busan New	H^{labour} = {(leq 1000TEU, 0), (2000TEU, 0), (3000TEU, 0.271), (4000TEU, 0.729), (5000TEU, 0), (leq 6000TEU, 0)}

- Vessel turnaround time

A set of quantitative grades {geq 5 days, 4 days, 3days, 2days, leq 1day} for vessel turnaround time is already defined.

$$H = \{geq\ 5days(H_1), 4days(H_2), 3days(H_3), 2days(H_4), leq\ 1day(H_5)\}$$

The information of the vessel turnaround time in 4 ports is demonstrated in Table V-15.

Table V-15 Vessel turnaround time

Port	Busan North	Gwangyang	Incheon	Busan New
Turnaround time (hour)	18.2	≤24	≤24	16.7

Note: Data in Busan North and Busan New ports represents the average value of the dedicated container terminals: Busan North Port (5 container terminals) and Busan New port (5 container terminals).
Data in Gwangyang and Incheon Port is based on questionnaire survey using interval assessment grades.

Vessel turnaround time in Busan New Port

The vessel turnaround time in Busan New Port can be directly transformed as belief degrees as follow:

$$H^{vessel\ T} = \{(\text{more than 5days}, 0), (\text{4days}, 0), (\text{3days}, 0), (\text{2days}, 0), (\text{less than 1day}, 1)\}$$

In a similar way, the vessel turnaround time sets of other ports are obtained and presented in Table V-16.

Table V-16 Vessel turnaround time sets

Port	Vessel turnaround time
Busan North	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Gwangyang	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Incheon	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}
Busan New	$H^{vessel\ T}$ = {(geq 5days, 0), (4days, 0), (3days, 0), (2days, 0), (leq 1day, 1)}

- Truck turnaround time

A set of quantitative grades *{geq 40 minutes, 35minutes, 30minutes, 25minutes, 20minutes, leq15minutes}* for truck turnaround time is already defined.

$$H = \{geq\ 40\ mins(H_1), 35mins(H_2), 30mins(H_3), 25mins(H_4), 20mins(H_5), leq\ 15mins(H_6)\}$$

The information of the truck turnaround in 4 ports is demonstrated in Table V-17.

Table V-17 Truck turnaround time

Port	Busan North	Gwangyang	Incheon	Busan New
Turnaround time (minute)	19.2	21.8	32.5	13.9

Truck turnaround time in Busan New Port

The truck turnaround time in Busan New Port can be directly transformed as belief degrees as follow:

$$H^{truck\ T} = \{(geq\ 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0), (leq\ 15mins, 1)\}$$

In a similar way, the truck turnaround time of other terminals is obtained and presented in Table V-18.

Table V-18 Truck turnaround time sets

Port	Truck turnaround time
Busan North	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0.84), (leq 15mins, 0.16)}
Gwangyang	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0.36), (20mins, 0.64), (leq 15mins, 0)}
Incheon	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0.5), (30mins, 0.5), (25mins, 0), (20mins, 0), (leq 15mins, 0)}
Busan New	$H^{truck\,T}$ = {(geq 40mins, 0), (35mins, 0), (30mins, 0), (25mins, 0), (20mins, 0), (leq 15mins, 1)}

- Container dwell time

A set of quantitative grades *{geq 4 weeks, 3 weeks, 10 days, 7 days, 5 days, leq 3 days}* for container dwell time is already defined.

$$H = \{geq\ 4weeks(H_1), 3weeks(H_2), 10days(H_3), 7days(H_4), 5days(H_5), leq\ 3days(H_6)\}$$

The information of the container dwell time in 4 ports is demonstrated in Table V-19.

Table V-19 Container dwell time

Port	Busan North	Gwangyang	Incheon	Busan New
Dwell time (day)	4.1	5.9	4.8	3.9

Container dwell time in Busan New Port

The container dwell time in Busan New Port is 3.9 days, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 5days(H_5), \qquad h_{j,i} = 3.9days, \qquad h_{j+1,i} = leq\ 3days(H_6)$$

Thus, $B_{j+1,i} = \frac{3.9-5}{3-5} = 0.55$ DoB with $\text{leq 3days}(\text{H}_6)$ and $B_{j-1,i} = 1 - 0.55 = 0.45$ DoB with $\text{5days}(\text{H}_5)$. Therefore, container dwell time set in Busan New Port is assessed as follows:

$$H^{dwell} = \{(geq\ 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.45), (leq\ 3days, 0.55)\}$$

In a similar way, the container dwell time sets of other ports are obtained and presented as follows (Table V-20).

Table V-20 Container dwell time sets

Port	Container dwell time
Busan North	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.55), (leq 3days, 0.45)}
Gwangyang	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0.45), (5days, 0.55), (leq 3days, 0)}
Incheon	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.9), (leq 3days, 0.1)}
Busan New	H^{dwell} = {(geq 4weeks, 0), (3weeks, 0), (10days, 0), (7days, 0), (5days, 0.45), (leq 3days, 0.55)}

- Revenue growth

A set of quantitative grades *{leq 0 %, 2 %, 4 %, 6 %, 8 %, geq 10 %}* for revenue growth is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{leq\ 0\%(H_1), 2\%(H_2), 4\%(H_3), 6\%(H_4), 8\%(H_5), geq\ 10\%(H_6)\}$$

The information of the revenue growth in 10 container terminals is demonstrated in Table V-21.

Table V-21 Revenue growth (2012-2013)

Port	Busan North	Gwangyang	Incheon	Busan New
Revenue growth (%)	-11.46	6.37	17.5	19.02

Note: The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

Revenue growth in Busan New Port

The revenue growth in Busan New Port is 19.02%, this value can be directly transformed as belief degrees as follows:

$$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 1)\}$$

In a similar way, the revenue growth sets of other ports are obtained and presented as follows (Table V-22).

Table V-22 Revenue growth sets

Port	Revenue growth
Busan North	$H^{revenue} = \{(\text{leq } 0\%, 1), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 0)\}$
Gwangyang	$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0.815), (8\%, 0.185), (\text{geq } 10\%, 0)\}$
Incheon	$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 1)\}$
Busan New	$H^{revenue} = \{(\text{leq } 0\%, 0), (2\%, 0), (4\%, 0), (6\%, 0), (8\%, 0), (\text{geq } 10\%, 1)\}$

- Operating profit margin

A set of quantitative grades *{less than 0%, 10%, 15%, 20%, 25%, more than 30%}* for operating profit margin is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{leq\ 0\%(H_1), 10\%(H_2), 15\%(H_3), 20\%(H_4), 25\%(H_5), geq\ 30\%(H_6)\}$$

The information of the operating profit margin in 4 ports is demonstrated in Table V-23.

Table V-23 Operating profit margin (2013)

Port	Busan North	Gwangyang	Incheon	Busan New
Operating profit margin (%)	-23.41	-0.66	17.3	20.94

Note: The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

Operating profit margin in Busan New Port

The operating profit margin in Busan New Port is 20.94%, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 20\%(\text{H}_4), \qquad h_{j,i} = 20.94\%, \qquad h_{j+1,i} = 25\%(\text{H}_5)$$

Thus, $B_{j+1,i} = \frac{20.94-20}{25-20} = 0.188$ DoB with $25\%(\text{H}_5)$ and $B_{j-1,i} = 1 - 0.188 = 0.812$ DoB with $20\%(\text{H}_4)$. Therefore, operating profit margin set in Busan New Ports is assessed as follows:

$$H^{operating\ M} = \{(\text{leq } 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.812), (25\%, 0.188), (\text{geq } 30\%, 0)\}$$

In a similar way, the operating profit margin sets of other ports are obtained and presented as follows (Table V-24).

Table V-24 Operating profit margin sets

Port	Operating profit margin
Busan North	$H^{operating\ M} = \{(\text{leq } 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\text{geq } 30\%, 0)\}$
Gwangyang	$H^{operating\ M} = \{(\text{leq } 0\%, 1), (10\%, 0), (15\%, 0), (20\%, 0), (25\%, 0), (\text{geq } 30\%, 0)\}$
Incheon	$H^{operating\ M} = \{(\text{leq } 0\%, 0), (10\%, 0), (15\%, 0.54), (20\%, 0.46), (25\%, 0), (\text{geq } 30\%, 0)\}$
Busan New	$H^{operating\ M} = \{(\text{leq } 0\%, 0), (10\%, 0), (15\%, 0), (20\%, 0.812), (25\%, 0.188), (\text{geq } 30\%, 0)\}$

- Net profit margin

A set of quantitative grades {leq 0 %, 5 %, 10 %, 15 %, 20 %, geq 25 %} for net profit margin is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{leq\ 0\%(H_1), 5\%(H_2), 10\%(H_3), 15\%(H_4), 20\%(H_5), geq\ 25\%(H_6)\}$$

The information of the net profit margin in 4 ports is demonstrated in Table V-25.

Table V-25 Net profit margin (2013)

Port	Busan North	Gwangyang	Incheon	Busan New
New profit margin (%)	-23.12	3.34	11.4	11.01

Note: The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

<u>Net profit margin in Busan New Port</u>

The net profit margin in Busan New Port is 11.01%, this value can be transformed as degrees of belief (DoB) in terms of Eq. (5.40).

$$h_{j-1,i} = 10\%(H_3), \qquad h_{j,i} = 11.01\%, \qquad h_{j+1,i} = 15\%(H_4)$$

Thus, $B_{j+1,i} = \frac{11.01-10}{15-10} = 0.202$ DoB with $15\%(H_4)$ and $B_{j-1,i} = 1 - 0.202 = 0.798$ DoB with $10\%(H_3)$. Therefore, net profit margin set in Busan New Port is assessed as follows:

$$H^{net\ M} = \{(leq\ 0\%, 0), (5\%, 0), (10\%, 0.798), (15\%, 0.202), (20\%, 0), (geq\ 25\%, 0)\}$$

In a similar way, the net profit margin sets of other ports are obtained and presented as follows (Table V-26).

Table V-26 Net profit margin sets

Port	Net profit margin
Busan North	$H^{net\ M}$ = {(leq 0%, 1), (5%, 0), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
Gwangyang	$H^{net\ M}$ = {(leq 0%, 0.332), (5%, 0.668), (10%, 0), (15%, 0), (20%, 0), (geq 25%, 0)}
Incheon	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.72), (15%, 0.28), (20%, 0), (geq 25%, 0)}
Busan New	$H^{net\ M}$ = {(leq 0%, 0), (5%, 0), (10%, 0.798), (15%, 0.202), (20%, 0), (geq 25%, 0)}

- Current ratio

A set of quantitative grades {leq 1, between 1 and 2, geq 2} for current ratio is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{leq\ 1(H_1), between\ 1\ and\ 2(H_2), geq\ 2(H_3)\}$$

The information of the current ratio in 4 ports is demonstrated in Table V-27.

Table V-27 Current ratio

Port	Busan North	Gwangyang	Incheon	Busan New
Current ratio	2.457	0.976	2.789	2.349

Note: The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

<u>Current ratio in Busan New Port</u>

The current ratio in Busan New Port is 2.349 (234.9%), this value can be directly transformed as belief degrees as follows:

$$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$$

In a similar way, the current ratio sets of other ports are obtained and presented as follows (Table V-28).

Table V-28 Current ratio sets

Port	Current ratio
Busan North	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
Gwangyang	$H^{CR} = \{(leq\ 1{,}1)(between\ 1\ and\ 2, 0), (geq\ 2, 0)\}$
Incheon	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$
Busan New	$H^{CR} = \{(leq\ 1{,}0)(between\ 1\ and\ 2, 0), (geq\ 2, 1)\}$

- Debt to total assets

A set of quantitative grades {geq 0.5, leq 0.5} for debt to total assets is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{geq\ 0.5(H_1), leq\ 0.5(H_2)\}$$

The information of the debt to total assets in 4 ports is demonstrated in Table V-29.

Table V-29 Debt to total assets

Port	Busan North	Gwangyang	Incheon	Busan New
Debt to total assets	2.060	0.976	0.406	0.701

Note: The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

Debt to total assets in Busan New Port

The debt to total assets in Busan New Port is 0.701 (70.1%), this value can be directly transformed as belief degrees as follows:

$$H^{DA} = \{(geq\ 0.5{,}1), (leq\ 0.5, 0)\}$$

In a similar way, the debt to total assets of other ports are obtained and presented as follows (Table V-30).

Table V-30 Debt to total assets sets

Port	Debt to total assets sets
Busan North	$H^{DA} = \{(geq\ 0.5{,}1), (leq\ 0.5, 0)\}$
Gwangyang	$H^{DA} = \{(geq\ 0.5{,}1), (leq\ 0.5, 0)\}$
Incheon	$H^{DA} = \{(geq\ 0.5{,}0), (leq\ 0.5, 1)\}$
Busan New	$H^{DA} = \{(geq\ 0.5{,}1), (leq\ 0.5, 0)\}$

- Debt to owner's equity

A set of quantitative grades {geq 2, 1.8, 1.6, 1.4, 1.2, leq 1} for debt to owner's equity is already defined and demonstrated based on Eqs. (5.33)- (5.34) as follows:

$$H = \{geq\ 2(H_1), 1.8(H_2), 1.6(H_3), 1.4(H_4), 1.2(H_5), leq\ 1(H_6)\}$$

The information of the debt to owner's equity in 4 ports is demonstrated in Table V-31.

Table V-31 Debt to owner's equity (2013)

Port	Busan North	Gwangyang*	Incheon	Busan New
Debt to owner's equity	0.154	-1.074	0.83	4.769

Note: *Impairment of capital in Gwangyang port, which means they are in a perilous financial condition.
The data represents the average value obtained from dedicated container terminals in each port: Busan North Port (3 container terminals: an individual financial statement), Gwangyang Port (2 container terminals: an individual

financial statement), Incheon Port (2 container terminals: an individual financial statement; 1 container terminal: a consolidated financial statement) and Busan New port (4 container terminals: an individual financial statement).

Debt to owner's equity in Busan New Port

The debt to owner's equity in Busan New Port is 4.769 (476.9%), this value can be directly transformed as degrees of belief (DoB) as follows:

$$H^{DE} = \{(geq\ 2{,}1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$$

In a similar way, the debt to owner's equity sets of other ports are obtained and presented as follows (Table V-32).

Table V-32 Debt to owner's equity sets

Port	Debt to owner's equity
Busan North	$H^{DE} = \{(geq\ 2{,}0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
Gwangyang	$H^{DE} = \{(geq\ 2{,}1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$
Incheon	$H^{DE} = \{(geq\ 2{,}0), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 1)\}$
Busan New	$H^{DE} = \{(geq\ 2{,}1), (1.8, 0), (1.6, 0), (1.4, 0), (1.2, 0), (leq\ 1, 0)\}$

- Qualitative PPIs (Busan North Port)

31 assessors from terminal operators in Busan North Port evaluated on the SA, TSCI, SSS and EVS. 126-7 samples from shipping lines and freight forwarders who have experience in using the terminal services provided by terminal operators in Busan North Port were used for the assessments of the US and TSCI and 18 samples from port authority and government were used for the judgements on SG.

Supporting Activities

Table V-33 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	1	4	24	2	31
Capability	0	3	13	14	1	31
Training and education opportunity	3	5	12	8	3	31
Commitment and Loyalty	1	3	11	11	5	31
Organisation Capital (OCS)						
Culture	1	5	7	15	3	31
Leadership	0	5	5	14	7	31
Alignment	1	4	6	15	5	31
Teamwork	1	4	6	15	5	31
Information Capital (ICS)						
IT systems	0	2	6	20	3	31
Databases	0	3	11	16	1	31
Networks	1	5	5	18	2	31

Table V-34 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.03	0.13	0.77	0.06	1.00
Capability	0.00	0.10	0.42	0.45	0.03	1.00
Training and education opportunity	0.10	0.16	0.39	0.26	0.10	1.00
Commitment and Loyalty	0.03	0.10	0.35	0.35	0.16	1.00
Organisation Capital (OCS)						
Culture	0.03	0.16	0.23	0.48	0.10	1.00
Leadership	0.00	0.16	0.16	0.45	0.23	1.00
Alignment	0.03	0.13	0.19	0.48	0.16	1.00
Teamwork	0.03	0.13	0.19	0.48	0.16	1.00

Information Capital (ICS)						
IT systems	0.00	0.06	0.19	0.65	0.10	1.00
Databases	0.00	0.10	0.35	0.52	0.03	1.00
Networks	0.03	0.16	0.16	0.58	0.06	1.00

Users' Satisfaction

Table V-35 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	1	5	57	48	16	127
Responsiveness to special requests	4	10	60	40	12	126
Accuracy of document & information	0	13	46	57	11	127
Incidence of cargo damage	1	8	46	49	23	127
Incidence of service delay	1	16	73	31	6	127
Service Costs (SCU)						
Overall service costs	0	16	62	40	9	127
Cargo handling charges	0	17	69	36	5	127
Cost of terminal ancillary services	0	26	54	43	4	127

Table V-36 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.01	0.04	0.45	0.38	0.13	1.00
Responsiveness to special requests	0.03	0.08	0.48	0.32	0.10	1.00
Accuracy of document & information	0.00	0.10	0.36	0.45	0.09	1.00
Incidence of cargo damage	0.01	0.06	0.36	0.39	0.18	1.00
Incidence of service delay	0.01	0.13	0.57	0.24	0.05	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.13	0.49	0.31	0.07	1.00
Cargo handling charges	0.00	0.13	0.54	0.28	0.04	1.00
Cost of terminal ancillary services	0.00	0.20	0.43	0.34	0.03	1.00

Terminal Supply Chain Integration

Table V-37 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	1	19	56	59	16	151
Land side connectivity	2	17	50	58	24	151
Reliability for multimodal operations	1	6	68	55	21	151
Efficiency of multimodal operations	2	9	69	59	12	151
Value-Added Services (VAST)						
Facilities for adding value to cargoes	11	21	60	50	9	151
Capacity to handle different types of cargo	3	18	68	43	19	151
Service adaptation to customers	3	26	49	52	21	151
Tailored services to customers	2	24	64	48	13	151
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	6	58	67	19	151
Integrated IT to share data	1	11	60	59	20	151
Collaborate with channel members	1	9	71	57	13	151
Latest IT in the industry	1	21	67	52	10	151

Table V-38 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.01	0.13	0.37	0.39	0.11	1.00
Land side connectivity	0.01	0.11	0.33	0.38	0.16	1.00
Reliability for multimodal operations	0.01	0.04	0.45	0.36	0.14	1.00

Efficiency of multimodal operations	0.01	0.06	0.46	0.39	0.08	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.07	0.14	0.40	0.33	0.06	1.00
Capacity to handle different types of cargo	0.02	0.12	0.45	0.28	0.13	1.00
Service adaptation to customers	0.02	0.17	0.32	0.34	0.14	1.00
Tailored services to customers	0.01	0.16	0.42	0.32	0.09	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.01	0.04	0.38	0.44	0.13	1.00
Integrated IT to share data	0.01	0.07	0.40	0.39	0.13	1.00
Collaborate with channel members	0.01	0.06	0.47	0.38	0.09	1.00
Latest IT in the industry	0.01	0.14	0.44	0.34	0.07	1.00

Sustainable Growth

Table V-39 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	2	4	18	24	48
Formal safety and security training practices	0	3	5	22	18	48
Adequate monitoring and threat awareness	0	2	6	23	17	48
Safety and security officers and facilities	0	2	4	15	27	48
Environment (EVS)						
Carbon footprint	5	14	19	6	4	48
Total water consumption	3	3	14	15	13	48
Total energy consumption	1	2	8	26	11	48
Waste recycling	2	3	13	22	8	48
Environment management programs	1	9	23	10	5	48
Social Engagement (SES)						
Employment	0	1	9	7	1	18
Regional GDP	0	1	8	6	3	18
Disclose of information	0	4	8	6	0	18

Table V-40 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.04	0.08	0.38	0.50	1.00
Formal safety and security training practices	0.00	0.06	0.10	0.46	0.38	1.00
Adequate monitoring and threat awareness	0.00	0.04	0.13	0.48	0.35	1.00
Safety and security officers and facilities	0.00	0.04	0.08	0.31	0.56	1.00
Environment (EVS)						
Carbon footprint	0.10	0.29	0.40	0.13	0.08	1.00
Total water consumption	0.06	0.06	0.29	0.31	0.27	1.00
Total energy consumption	0.02	0.04	0.17	0.54	0.23	1.00
Waste recycling	0.04	0.06	0.27	0.46	0.17	1.00
Environment management programs	0.02	0.19	0.48	0.21	0.10	1.00
Social Engagement (SES)						
Employment	0.00	0.06	0.50	0.39	0.06	1.00
Regional GDP	0.00	0.06	0.44	0.33	0.17	1.00
Disclose of information	0.00	0.22	0.44	0.33	0.00	1.00

- Gwanyang Port

40 assessors from terminal operators in Gwangyang Port evaluated on the SA, TSCI, SSS and EVS. 85 samples from shipping lines and freight forwarders who have experience in using the terminal services provided by terminal operators in Gwangyang Port were used for the assessments of the US and TSCI and 30 samples from port authority and government were used for the judgements on SG.

Supporting Activities

Table V-41 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0	1	14	22	3	40
Capability	0	8	12	18	2	40
Training and education opportunity	2	9	14	11	4	40
Commitment and Loyalty	0	4	20	15	1	40
Organisation Capital (OCS)						
Culture	0	5	18	15	2	40
Leadership	1	2	14	21	2	40
Alignment	1	1	16	17	5	40
Teamwork	0	7	12	18	3	40
Information Capital (ICS)						
IT systems	1	7	11	20	1	40
Databases	1	6	16	15	2	40
Networks	0	2	18	17	3	40

Table V-42 Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.00	0.03	0.35	0.55	0.08	1.00
Capability	0.00	0.20	0.30	0.45	0.05	1.00
Training and education opportunity	0.05	0.23	0.35	0.28	0.10	1.00
Commitment and Loyalty	0.00	0.10	0.50	0.38	0.03	1.00
Organisation Capital (OCS)						
Culture	0.00	0.13	0.45	0.38	0.05	1.00
Leadership	0.03	0.05	0.35	0.53	0.05	1.00
Alignment	0.03	0.03	0.40	0.43	0.13	1.00
Teamwork	0.00	0.18	0.30	0.45	0.08	1.00
Information Capital (ICS)						
IT systems	0.03	0.18	0.28	0.50	0.03	1.00
Databases	0.03	0.15	0.40	0.38	0.05	1.00
Networks	0.00	0.05	0.45	0.43	0.08	1.00

Users' Satisfaction

Table V-43 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	4	27	40	14	85
Responsiveness to special requests	0	9	17	41	18	85
Accuracy of document & information	0	5	33	31	16	85
Incidence of cargo damage	0	10	20	35	20	85
Incidence of service delay	3	1	31	33	17	85
Service Costs (SCU)						
Overall service costs	0	15	35	27	8	85
Cargo handling charges	0	8	40	30	7	85
Cost of terminal ancillary services	0	13	34	31	7	85

Table V-44 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.05	0.32	0.47	0.16	1.00
Responsiveness to special requests	0.00	0.11	0.20	0.48	0.21	1.00
Accuracy of document & information	0.00	0.06	0.39	0.36	0.19	1.00
Incidence of cargo damage	0.00	0.12	0.24	0.41	0.24	1.00

Incidence of service delay	0.04	0.01	0.36	0.39	0.20	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.18	0.41	0.32	0.09	1.00
Cargo handling charges	0.00	0.09	0.47	0.35	0.08	1.00
Cost of terminal ancillary services	0.00	0.15	0.40	0.36	0.08	1.00

Terminal Supply Chain Integration

Table V-45 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	15	42	53	15	125
Land side connectivity	3	16	45	49	12	125
Reliability for multimodal operations	0	12	38	63	12	125
Efficiency of multimodal operations	0	13	52	47	13	125
Value-Added Services (VAST)						
Facilities for adding value to cargoes	5	19	45	53	3	125
Capacity to handle different types of cargo	1	13	43	57	11	125
Service adaptation to customers	1	11	41	55	17	125
Tailored services to customers	3	7	43	58	14	125
Information/Communication Integration (ICIT)						
Integrated EDI for communication	4	4	44	54	19	125
Integrated IT to share data	4	10	46	46	19	125
Collaborate with channel members	5	8	54	47	11	125
Latest IT in the industry	1	13	51	45	15	125

Table V-46 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.12	0.34	0.42	0.12	1.00
Land side connectivity	0.02	0.13	0.36	0.39	0.10	1.00
Reliability for multimodal operations	0.00	0.10	0.30	0.50	0.10	1.00
Efficiency of multimodal operations	0.00	0.10	0.42	0.38	0.10	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.04	0.15	0.36	0.42	0.02	1.00
Capacity to handle different types of cargo	0.01	0.10	0.34	0.46	0.09	1.00
Service adaptation to customers	0.01	0.09	0.33	0.44	0.14	1.00
Tailored services to customers	0.02	0.06	0.34	0.46	0.11	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.03	0.03	0.35	0.43	0.15	1.00
Integrated IT to share data	0.03	0.08	0.37	0.37	0.15	1.00
Collaborate with channel members	0.04	0.06	0.43	0.38	0.09	1.00
Latest IT in the industry	0.01	0.10	0.41	0.36	0.12	1.00

Sustainable Growth

Table V-47 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	2	6	28	34	70
Formal safety and security training practices	1	2	6	26	35	70
Adequate monitoring and threat awareness	0	3	9	26	32	70
Safety and security officers and facilities	0	1	5	28	36	70
Environment (EVS)						
Carbon footprint	2	35	14	19	0	70
Total water consumption	0	34	16	13	7	70
Total energy consumption	0	28	22	14	6	70

Waste recycling	0	27	11	25	6	69
Environment management programs	0	32	11	20	7	70
Social Engagement (SES)						
Employment	0	10	16	4	0	30
Regional GDP	0	5	17	8	0	30
Disclose of information	0	4	15	9	2	30

Table V-48 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.03	0.09	0.40	0.49	1.00
Formal safety and security training practices	0.01	0.03	0.09	0.37	0.50	1.00
Adequate monitoring and threat awareness	0.00	0.04	0.13	0.37	0.46	1.00
Safety and security officers and facilities	0.00	0.01	0.07	0.40	0.51	1.00
Environment (EVS)						
Carbon footprint	0.03	0.50	0.20	0.27	0.00	1.00
Total water consumption	0.00	0.49	0.23	0.19	0.10	1.00
Total energy consumption	0.00	0.40	0.31	0.20	0.09	1.00
Waste recycling	0.00	0.39	0.16	0.36	0.09	1.00
Environment management programs	0.00	0.46	0.16	0.29	0.10	1.00
Social Engagement (SES)						
Employment	0.00	0.33	0.53	0.13	0.00	1.00
Regional GDP	0.00	0.17	0.57	0.27	0.00	1.00
Disclose of information	0.00	0.13	0.50	0.30	0.07	1.00

- Incheon Port

39 assessors from terminal operators in Incheon Port evaluated on the SA, TSCI, SSS and EVS. 84 samples from shipping lines and freight forwarders who have experience in using the terminal services provided by terminal operators in Incheon Port were used for the assessments of the US and TSCI and 18 samples from port authority and government were used for the judgements on SG.

Supporting Activities

Table V-49 Judgements on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	1	0	4	22	12	39
Capability	2	0	10	17	10	39
Training and education opportunity	1	2	12	15	9	39
Commitment and Loyalty	1	1	9	18	10	39
Organisation Capital (OCS)						
Culture	1	1	11	20	6	39
Leadership	2	0	11	18	8	39
Alignment	1	2	11	18	7	39
Teamwork	0	3	11	17	8	39
Information Capital (ICS)						
IT systems	2	0	11	18	8	39
Databases	2	0	13	14	10	39
Networks	2	1	13	17	6	39

Table V-50. Degrees of Belief on assessment grades for supporting activities

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Human Capital (HCS)						
Knowledge and skills	0.03	0.00	0.10	0.56	0.31	1.00

Capability	0.05	0.00	0.26	0.44	0.26	1.00
Training and education opportunity	0.03	0.05	0.31	0.38	0.23	1.00
Commitment and Loyalty	0.03	0.03	0.23	0.46	0.26	1.00
Organisation Capital (OCS)						
Culture	0.03	0.03	0.28	0.51	0.15	1.00
Leadership	0.05	0.00	0.28	0.46	0.21	1.00
Alignment	0.03	0.05	0.28	0.46	0.18	1.00
Teamwork	0.00	0.08	0.28	0.44	0.21	1.00
Information Capital (ICS)						
IT systems	0.05	0.00	0.28	0.46	0.21	1.00
Databases	0.05	0.00	0.33	0.36	0.26	1.00
Networks	0.05	0.03	0.33	0.44	0.15	1.00

<u>Users' Satisfaction</u>

Table V-51 Judgements on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0	10	31	35	8	84
Responsiveness to special requests	1	8	38	32	5	84
Accuracy of document & information	0	14	28	31	11	84
Incidence of cargo damage	0	14	32	35	3	84
Incidence of service delay	1	14	33	25	11	84
Service Costs (SCU)						
Overall service costs	0	11	46	17	10	84
Cargo handling charges	1	10	39	28	6	84
Cost of terminal ancillary services	0	20	31	25	8	84

Table V-52 Degrees of Belief on assessment grades for users' satisfaction

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied	Sum
Service Fulfilment (SFU)						
Overall service reliability	0.00	0.12	0.37	0.42	0.10	1.00
Responsiveness to special requests	0.01	0.10	0.45	0.38	0.06	1.00
Accuracy of document & information	0.00	0.17	0.33	0.37	0.13	1.00
Incidence of cargo damage	0.00	0.17	0.38	0.42	0.04	1.00
Incidence of service delay	0.01	0.17	0.39	0.30	0.13	1.00
Service Costs (SCU)						
Overall service costs	0.00	0.13	0.55	0.20	0.12	1.00
Cargo handling charges	0.01	0.12	0.46	0.33	0.07	1.00
Cost of terminal ancillary services	0.00	0.24	0.37	0.30	0.10	1.00

<u>Terminal Supply Chain Integration</u>

Table V-53 Judgements on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0	15	36	60	12	123
Land side connectivity	3	20	37	54	9	123
Reliability for multimodal operations	4	8	41	62	8	123
Efficiency of multimodal operations	4	14	44	52	9	123
Value-Added Services (VAST)						
Facilities for adding value to cargoes	7	23	41	39	7	117
Capacity to handle different types of cargo	4	17	57	26	13	117
Service adaptation to customers	2	16	47	38	14	117
Tailored services to customers	4	13	46	45	9	117
Information/Communication Integration (ICIT)						
Integrated EDI for communication	1	12	41	56	13	123
Integrated IT to share data	2	12	44	56	9	123

Collaborate with channel members	2	8	36	61	16	123
Latest IT in the industry	3	8	52	51	9	123

Table V-54 Degrees of Belief on assessment grades for terminal supply chain integration

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Intermodal Transport Systems (ITST)						
Sea side connectivity	0.00	0.12	0.29	0.49	0.10	1.00
Land side connectivity	0.02	0.16	0.30	0.44	0.07	1.00
Reliability for multimodal operations	0.03	0.07	0.33	0.50	0.07	1.00
Efficiency of multimodal operations	0.03	0.11	0.36	0.42	0.07	1.00
Value-Added Services (VAST)						
Facilities for adding value to cargoes	0.06	0.20	0.35	0.33	0.06	1.00
Capacity to handle different types of cargo	0.03	0.15	0.49	0.22	0.11	1.00
Service adaptation to customers	0.02	0.14	0.40	0.32	0.12	1.00
Tailored services to customers	0.03	0.11	0.39	0.38	0.08	1.00
Information/Communication Integration (ICIT)						
Integrated EDI for communication	0.01	0.10	0.33	0.46	0.11	1.00
Integrated IT to share data	0.02	0.10	0.36	0.46	0.07	1.00
Collaborate with channel members	0.02	0.07	0.29	0.50	0.13	1.00
Latest IT in the industry	0.02	0.07	0.42	0.41	0.07	1.00

Sustainable Growth

Table V-55 Judgements on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0	0	2	29	29	60
Formal safety and security training practices	0	3	19	23	15	60
Adequate monitoring and threat awareness	0	0	12	29	19	60
Safety and security officers and facilities	0	0	6	32	22	60
Environment (EVS)						
Carbon footprint	8	25	12	9	6	60
Total water consumption	4	18	15	14	9	60
Total energy consumption	4	12	17	15	12	60
Waste recycling	1	6	26	16	11	60
Environment management programs	1	21	23	10	5	60
Social Engagement (SES)						
Employment	0	5	11	2	0	18
Regional GDP	0	4	11	3	0	18
Disclose of information	0	2	7	7	2	18

Table V-56 Degrees of Belief on assessment grades for sustainable growth

PPIs	Very Poor	Poor	Medium	Good	Very Good	Sum
Safety and Security (SSS)						
Identifying restricted areas and access control	0.00	0.00	0.03	0.48	0.48	1.00
Formal safety and security training practices	0.00	0.05	0.32	0.38	0.25	1.00
Adequate monitoring and threat awareness	0.00	0.00	0.20	0.48	0.32	1.00
Safety and security officers and facilities	0.00	0.00	0.10	0.53	0.37	1.00
Environment (EVS)						
Carbon footprint	0.13	0.42	0.20	0.15	0.10	1.00
Total water consumption	0.07	0.30	0.25	0.23	0.15	1.00
Total energy consumption	0.07	0.20	0.28	0.25	0.20	1.00
Waste recycling	0.02	0.10	0.43	0.27	0.18	1.00
Environment management programs	0.02	0.35	0.38	0.17	0.08	1.00
Social Engagement (SES)						
Employment	0.00	0.28	0.61	0.11	0.00	1.00
Regional GDP	0.00	0.22	0.61	0.17	0.00	1.00
Disclose of information	0.00	0.11	0.39	0.39	0.11	1.00

Appendix VI Mapping process (qualitative PPIs)

- Busan North Port

Mapping to human capital

Table VI-1 Results of mapping to human capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Knowledge and skills	0.00	0.03	0.13	0.77	0.06
Capability	0.00	0.10	0.42	0.45	0.03
Training and education opportunity	0.10	0.16	0.39	0.26	0.10
Commitment and Loyalty	0.03	0.10	0.35	0.35	0.16
Mapping to Human Capital					
Knowledge and skills	0.008	0.055	0.065	0.610	0.253
Capability	0.025	0.180	0.210	0.443	0.143
Training and education opportunity	0.14	0.218	0.195	0.293	0.165
Commitment and Loyalty	0.055	0.163	0.175	0.350	0.248

Mapping to organisational capital

Table VI-2 Results of mapping to organisational capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Culture	0.03	0.16	0.23	0.48	0.10
Leadership	0.00	0.16	0.16	0.45	0.23
Alignment	0.03	0.13	0.19	0.48	0.16
Teamwork	0.03	0.13	0.19	0.48	0.16
Mapping to Organisation Capital					
Culture	0.070	0.178	0.115	0.418	0.220
Leadership	0.040	0.160	0.080	0.378	0.343
Alignment	0.063	0.145	0.095	0.408	0.280
Teamwork	0.063	0.145	0.095	0.408	0.280

Mapping to information capital

Table VI-3 Results of mapping to information capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
IT systems	0.00	0.06	0.19	0.65	0.10
Databases	0.00	0.10	0.35	0.52	0.03
Networks	0.03	0.16	0.16	0.58	0.06
Mapping to Information Capital					
IT systems	0.015	0.093	0.093	0.535	0.263
Databases	0.025	0.163	0.175	0.478	0.160
Networks	0.070	0.160	0.080	0.475	0.205

Mapping to service fulfilment

Table VI-4 Results of mapping to service fulfilment

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service reliability	0.01	0.04	0.45	0.38	0.13
Responsiveness to special requests	0.03	0.08	0.48	0.32	0.10
Accuracy of document & information	0.00	0.10	0.36	0.45	0.09
Incidence of cargo damage	0.01	0.06	0.36	0.39	0.18
Incidence of service delay	0.01	0.13	0.57	0.24	0.05
Mapping to Service Fulfilment					
Overall service reliability	0.020	0.143	0.225	0.398	0.225
Responsiveness to special requests	0.050	0.180	0.240	0.360	0.180
Accuracy of document & information	0.025	0.165	0.180	0.428	0.203

Incidence of cargo damage	0.025	0.135	0.180	0.383	0.278
Incidence of service delay	0.043	0.240	0.285	0.323	0.110

Mapping to service costs

Table VI-5 Results of mapping to service costs

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service costs	0.00	0.13	0.49	0.31	0.07
Cargo handling charges	0.00	0.13	0.54	0.28	0.04
Cost of terminal ancillary services	0.00	0.20	0.43	0.34	0.03
Mapping to Service Costs					
Overall service costs	0.033	0.220	0.245	0.355	0.148
Cargo handling charges	0.033	0.233	0.270	0.345	0.110
Cost of terminal ancillary services	0.050	0.258	0.215	0.363	0.115

Mapping to intermodal transport systems

Table VI-6 Results of mapping to intermodal transport systems

PPIs	Very Poor	Poor	Medium	Good	Very Good
Sea side connectivity	0.01	0.13	0.37	0.39	0.11
Land side connectivity	0.01	0.11	0.33	0.38	0.16
Reliability for multimodal operations	0.01	0.04	0.45	0.36	0.14
Efficiency of multimodal operations	0.01	0.06	0.46	0.39	0.08
Mapping to Intermodal Transport Systems					
Sea side connectivity	0.043	0.190	0.185	0.385	0.208
Land side connectivity	0.038	0.165	0.165	0.368	0.255
Reliability for multimodal operations	0.020	0.143	0.225	0.383	0.230
Efficiency of multimodal operations	0.01	0.160	0.230	0.408	0.178

Mapping to value-added services

Table VI-7 Results of mapping to value-added services

PPIs	Very Poor	Poor	Medium	Good	Very Good
Facilities for adding value to cargoes	0.07	0.14	0.40	0.33	0.06
Capacity to handle different types of cargo	0.02	0.12	0.45	0.28	0.13
Service adaptation to customers	0.02	0.17	0.32	0.34	0.14
Tailored services to customers	0.01	0.16	0.42	0.32	0.09
Mapping to Value-Added Services					
Facilities for adding value to cargoes	0.105	0.205	0.200	0.348	0.143
Capacity to handle different types of cargo	0.050	0.203	0.225	0.323	0.200
Service adaptation to customers	0.063	0.208	0.160	0.335	0.225
Tailored services to customers	0.050	0.225	0.210	0.345	0.170

Mapping to information/communication integration

Table VI-8 Results of mapping to information/communication integration

PPIs	Very Poor	Poor	Medium	Good	Very Good
Integrated EDI for communication	0.01	0.04	0.38	0.44	0.13
Integrated IT to share data	0.01	0.07	0.40	0.39	0.13
Collaborate with channel members	0.01	0.06	0.47	0.38	0.09
Latest IT in the industry	0.01	0.14	0.44	0.34	0.07
Mapping to Information/Communication Integration					
Integrated EDI for communication	0.020	0.125	0.190	0.425	0.240
Integrated IT to share data	0.028	0.153	0.200	0.393	0.228
Collaborate with channel members	0.025	0.163	0.235	0.403	0.185
Latest IT in the industry	0.045	0.215	0.220	0.365	0.155

Mapping to safety and security

Table VI-9 Results of mapping to safety and security

PPIs	Very Poor	Poor	Medium	Good	Very Good
Identifying restricted areas and access control	0.00	0.04	0.08	0.38	0.50
Formal safety and security training practices	0.00	0.06	0.10	0.46	0.38
Adequate monitoring and threat awareness	0.00	0.04	0.13	0.48	0.35
Safety and security officers and facilities	0.00	0.04	0.08	0.31	0.56
Mapping to Safety and Security					
Identifying restricted areas and access control	0.010	0.050	0.040	0.305	0.595
Formal safety and security training practices	0.015	0.070	0.050	0.370	0.495
Adequate monitoring and threat awareness	0.010	0.063	0.065	0.393	0.470
Safety and security officers and facilities	0.010	0.050	0.040	0.253	0.638

Mapping to environment

Table VI-10 Results of mapping to environment

PPIs	Very Poor	Poor	Medium	Good	Very Good
Carbon footprint	0.10	0.29	0.40	0.13	0.08
Total water consumption	0.06	0.06	0.29	0.31	0.27
Total energy consumption	0.02	0.04	0.17	0.54	0.23
Waste recycling	0.04	0.06	0.27	0.46	0.17
Environment management programs	0.02	0.19	0.48	0.21	0.10
Mapping to Environment					
Carbon footprint	0.173	0.318	0.200	0.198	0.113
Total water consumption	0.075	0.118	0.145	0.305	0.348
Total energy consumption	0.030	0.073	0.085	0.448	0.365
Waste recycling	0.055	0.113	0.135	0.413	0.285
Environment management programs	0.068	0.263	0.240	0.278	0.153

Mapping to social engagement

Table VI-11 Results of mapping to social engagement

PPIs	Very Poor	Poor	Medium	Good	Very Good
Employment	0.00	0.06	0.50	0.39	0.06
Regional GDP	0.00	0.06	0.44	0.33	0.17
Disclose of information	0.00	0.22	0.44	0.33	0.00
Mapping to Social Engagement					
Employment	0.015	0.170	0.250	0.418	0.158
Regional GDP	0.015	0.155	0.220	0.358	0.253
Disclose of information	0.000	0.275	0.220	0.358	0.083

- Gwangyang Port

Mapping to human capital

Table VI-12 Results of mapping to human capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Knowledge and skills	0.00	0.03	0.35	0.55	0.08
Capability	0.00	0.20	0.30	0.45	0.05
Training and education opportunity	0.05	0.23	0.35	0.28	0.10
Commitment and Loyalty	0.00	0.10	0.50	0.38	0.03
Mapping to Human Capital					
Knowledge and skills	0.008	0.110	0.175	0.500	0.218
Capability	0.050	0.225	0.150	0.413	0.163
Training and education opportunity	0.108	0.260	0.175	0.298	0.170
Commitment and Loyalty	0.025	0.200	0.250	0.410	0.125

Mapping to organisational capital

Table VI-13 Results of mapping to organisational capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Culture	0.00	0.13	0.45	0.38	0.05
Leadership	0.03	0.05	0.35	0.53	0.05
Alignment	0.03	0.03	0.40	0.43	0.13
Teamwork	0.00	0.18	0.30	0.45	0.08
Mapping to Organisation Capital					
Culture	0.033	0.210	0.225	0.398	0.145
Leadership	0.043	0.125	0.175	0.485	0.183
Alignment	0.038	0.123	0.200	0.423	0.238
Teamwork	0.045	0.210	0.150	0.413	0.193

Mapping to information capital

Table VI-14 Results of mapping to information capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
IT systems	0.03	0.18	0.28	0.50	0.03
Databases	0.03	0.15	0.40	0.38	0.05
Networks	0.00	0.05	0.45	0.43	0.08
Mapping to Information Capital					
IT systems	0.075	0.205	0.140	0.445	0.155
Databases	0.068	0.213	0.200	0.385	0.145
Networks	0.013	0.150	0.225	0.435	0.188

Mapping to service fulfilment

Table VI-15 Results of mapping to service fulfilment

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service reliability	0.00	0.05	0.32	0.47	0.16
Responsiveness to special requests	0.00	0.11	0.20	0.48	0.21
Accuracy of document & information	0.00	0.06	0.39	0.36	0.19
Incidence of cargo damage	0.00	0.12	0.24	0.41	0.24
Incidence of service delay	0.04	0.01	0.36	0.39	0.20
Mapping to Service Fulfilment					
Overall service reliability	0.013	0.118	0.160	0.433	0.278
Responsiveness to special requests	0.028	0.133	0.100	0.410	0.330
Accuracy of document & information	0.015	0.143	0.195	0.368	0.280
Incidence of cargo damage	0.030	0.150	0.120	0.368	0.343
Incidence of service delay	0.043	0.098	0.180	0.383	0.298

Mapping to service costs

Table VI-16 Results of mapping to service costs

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service costs	0.00	0.18	0.41	0.32	0.09
Cargo handling charges	0.00	0.09	0.47	0.35	0.08
Cost of terminal ancillary services	0.00	0.15	0.40	0.36	0.08
Mapping to Service Costs					
Overall service costs	0.045	0.238	0.205	0.343	0.170
Cargo handling charges	0.023	0.185	0.235	0.380	0.168
Cost of terminal ancillary services	0.038	0.213	0.200	0.370	0.170

Mapping to intermodal transport systems

Table VI-17 Results of mapping to intermodal transport systems

PPIs	Very Poor	Poor	Medium	Good	Very Good

Sea side connectivity	0.00	0.12	0.34	0.42	0.12
Land side connectivity	0.02	0.13	0.36	0.39	0.10
Reliability for multimodal operations	0.00	0.10	0.30	0.50	0.10
Efficiency of multimodal operations	0.00	0.10	0.42	0.38	0.10
Mapping to Intermodal Transport Systems					
Sea side connectivity	0.30	0.175	0.170	0.400	0.225
Land side connectivity	0.053	0.188	0.180	0.383	0.198
Reliability for multimodal operations	0.025	0.150	0.150	0.450	0.225
Efficiency of multimodal operations	0.025	0.180	0.210	0.390	0.195

Mapping to value-added services

Table VI-18 Results of mapping to value-added services

PPIs	Very Poor	Poor	Medium	Good	Very Good
Facilities for adding value to cargoes	0.04	0.15	0.36	0.42	0.02
Capacity to handle different types of cargo	0.01	0.10	0.34	0.46	0.09
Service adaptation to customers	0.01	0.09	0.33	0.44	0.14
Tailored services to customers	0.02	0.06	0.34	0.46	0.11
Mapping to Value-Added Services					
Facilities for adding value to cargoes	0.078	0.203	0.180	0.405	0.125
Capacity to handle different types of cargo	0.035	0.160	0.170	0.430	0.205
Service adaptation to customers	0.033	0.150	0.165	0.413	0.250
Tailored services to customers	0.035	0.130	0.170	0.430	0.225

Mapping to information/communication integration

Table VI-19 Results of mapping to information/communication integration

PPIs	Very Poor	Poor	Medium	Good	Very Good
Integrated EDI for communication	0.03	0.03	0.35	0.43	0.15
Integrated IT to share data	0.03	0.08	0.37	0.37	0.15
Collaborate with channel members	0.04	0.06	0.43	0.38	0.09
Latest IT in the industry	0.01	0.10	0.41	0.36	0.12
Mapping to Information/Communication Integration					
Integrated EDI for communication	0.038	0.110	0.175	0.410	0.258
Integrated IT to share data	0.050	0.153	0.185	0.370	0.243
Collaborate with channel members	0.055	0.153	0.215	0.393	0.185
Latest IT in the industry	0.035	0.178	0.205	0.373	0.210

Mapping to safety and security

Table VI-20 Results of mapping to safety and security

PPIs	Very Poor	Poor	Medium	Good	Very Good
Identifying restricted areas and access control	0.00	0.03	0.09	0.40	0.49
Formal safety and security training practices	0.01	0.03	0.09	0.37	0.50
Adequate monitoring and threat awareness	0.00	0.04	0.13	0.37	0.46
Safety and security officers and facilities	0.00	0.01	0.07	0.40	0.51
Mapping to Safety and Security					
Identifying restricted areas and access control	0.008	0.045	0.045	0.323	0.590
Formal safety and security training practices	0.018	0.045	0.045	0.300	0.593
Adequate monitoring and threat awareness	0.010	0.063	0.063	0.310	0.553
Safety and security officers and facilities	0.003	0.025	0.035	0.318	0.610

Mapping to environment

Table VI-21 Results of mapping to environment

PPIs	Very Poor	Poor	Medium	Good	Very Good
Carbon footprint	0.03	0.50	0.20	0.27	0.00
Total water consumption	0.00	0.49	0.23	0.19	0.10

Total energy consumption	0.00	0.40	0.31	0.20	0.09
Waste recycling	0.00	0.39	0.16	0.36	0.09
Environment management programs	0.00	0.46	0.16	0.29	0.10
Mapping to Environment					
Carbon footprint	0.155	0.425	0.100	0.253	0.068
Total water consumption	0.123	0.425	0.115	0.200	0.148
Total energy consumption	0.100	0.378	0.155	0.228	0.140
Waste recycling	0.098	0.333	0.080	0.310	0.180
Environment management programs	0.115	0.385	0.080	0.258	0.173

Mapping to social engagement

Table VI-22 Results of mapping to social engagement

PPIs	Very Poor	Poor	Medium	Good	Very Good
Employment	0.00	0.33	0.53	0.13	0.00
Regional GDP	0.00	0.17	0.57	0.27	0.00
Disclose of information	0.00	0.13	0.50	0.30	0.07
Mapping to Social Engagement					
Employment	0.083	0.380	0.265	0.230	0.033
Regional GDP	0.043	0.270	0.285	0.345	0.068
Disclose of information	0.033	0.223	0.250	0.350	0.145

- Incheon Port

Mapping to human capital

Table VI-23 Results of mapping to human capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Knowledge and skills	0.03	0.00	0.10	0.56	0.31
Capability	0.05	0.00	0.26	0.44	0.26
Training and education opportunity	0.03	0.05	0.31	0.38	0.23
Commitment and Loyalty	0.03	0.03	0.23	0.46	0.26
Mapping to Human Capital					
Knowledge and skills	0.030	0.025	0.050	0.445	0.450
Capability	0.050	0.065	0.130	0.395	0.370
Training and education opportunity	0.043	0.115	0.155	0.363	0.325
Commitment and Loyalty	0.038	0.080	0.115	0.403	0.375

Mapping to organisational capital

Table VI-24 Results of mapping to organisational capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
Culture	0.03	0.03	0.28	0.51	0.15
Leadership	0.05	0.00	0.28	0.46	0.21
Alignment	0.03	0.05	0.28	0.46	0.18
Teamwork	0.00	0.08	0.28	0.44	0.21
Mapping to Organisation Capital					
Culture	0.038	0.093	0.140	0.453	0.278
Leadership	0.050	0.070	0.140	0.415	0.325
Alignment	0.043	0.108	0.140	0.415	0.295
Teamwork	0.020	0.130	0.140	0.400	0.320

Mapping to information capital

Table VI-25 Results of mapping to information capital

PPIs	Very Poor	Poor	Medium	Good	Very Good
IT systems	0.05	0.00	0.28	0.46	0.21
Databases	0.05	0.00	0.33	0.36	0.26
Networks	0.05	0.03	0.33	0.44	0.15

Mapping to Information Capital					
IT systems	0.050	0.070	0.140	0.415	0.325
Databases	0.050	0.083	0.165	0.353	0.350
Networks	0.058	0.105	0.165	0.413	0.260

Mapping to service fulfilment

Table VI-26 Results of mapping to service fulfilment

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service reliability	0.00	0.12	0.37	0.42	0.10
Responsiveness to special requests	0.01	0.10	0.45	0.38	0.06
Accuracy of document & information	0.00	0.17	0.33	0.37	0.13
Incidence of cargo damage	0.00	0.17	0.38	0.42	0.04
Incidence of service delay	0.01	0.17	0.39	0.30	0.13
Mapping to Service Fulfilment					
Overall service reliability	0.030	0.183	0.185	0.408	0.205
Responsiveness to special requests	0.035	0.188	0.225	0.398	0.155
Accuracy of document & information	0.043	0.210	0.165	0.360	0.223
Incidence of cargo damage	0.043	0.223	0.190	0.410	0.145
Incidence of service delay	0.053	0.225	0.195	0.323	0.205

Mapping to service costs

Table VI-27 Results of mapping to service costs

PPIs	S. dissatisfied	Dissatisfied	Neutral	Satisfied	S. satisfied
Overall service costs	0.00	0.13	0.55	0.20	0.12
Cargo handling charges	0.01	0.12	0.46	0.33	0.07
Cost of terminal ancillary services	0.00	0.24	0.37	0.30	0.10
Mapping to Service Costs					
Overall service costs	0.033	0.235	0.275	0.288	0.170
Cargo handling charges	0.040	0.205	0.230	0.363	0.153
Cost of terminal ancillary services	0.060	0.273	0.185	0.318	0.175

Mapping to intermodal transport systems

Table VI-28 Results of mapping to intermodal transport systems

PPIs	Very Poor	Poor	Medium	Good	Very Good
Sea side connectivity	0.00	0.12	0.29	0.49	0.10
Land side connectivity	0.02	0.16	0.30	0.44	0.07
Reliability for multimodal operations	0.03	0.07	0.33	0.50	0.07
Efficiency of multimodal operations	0.03	0.11	0.36	0.42	0.07
Mapping to Intermodal Transport Systems					
Sea side connectivity	0.030	0.163	0.145	0.440	0.223
Land side connectivity	0.060	0.195	0.150	0.405	0.180
Reliability for multimodal operations	0.048	0.135	0.165	0.458	0.195
Efficiency of multimodal operations	0.058	0.173	0.180	0.405	0.175

Mapping to value-added services

Table VI-29 Results of mapping to value-added services

PPIs	Very Poor	Poor	Medium	Good	Very Good
Facilities for adding value to cargoes	0.06	0.20	0.35	0.33	0.06
Capacity to handle different types of cargo	0.03	0.15	0.49	0.22	0.11
Service adaptation to customers	0.02	0.14	0.40	0.32	0.12
Tailored services to customers	0.03	0.11	0.39	0.38	0.08
Mapping to Value-Added Services					
Facilities for adding value to cargoes	0.110	0.238	0.175	0.335	0.143
Capacity to handle different types of cargo	0.068	0.235	0.245	0.288	0.175
Service adaptation to customers	0.055	0.205	0.200	0.340	0.200

Tailored services to customers	0.058	0.180	0.195	0.383	0.175

Mapping to information/communication integration

Table VI-30 Results of mapping to information/communication integration

PPIs	Very Poor	Poor	Medium	Good	Very Good
Integrated EDI for communication	0.01	0.10	0.33	0.46	0.11
Integrated IT to share data	0.02	0.10	0.36	0.46	0.07
Collaborate with channel members	0.02	0.07	0.29	0.50	0.13
Latest IT in the industry	0.02	0.07	0.42	0.41	0.07
Mapping to Information/Communication Integration					
Integrated EDI for communication	0.035	0.158	0.165	0.428	0.225
Integrated IT to share data	0.045	0.165	0.180	0.435	0.185
Collaborate with channel members	0.038	0.125	0.145	0.448	0.255
Latest IT in the industry	0.038	0.158	0.210	0.413	0.173

Mapping to safety and security

Table VI-31 Results of mapping to safety and security

PPIs	Very Poor	Poor	Medium	Good	Very Good
Identifying restricted areas and access control	0.00	0.00	0.03	0.48	0.48
Formal safety and security training practices	0.00	0.05	0.32	0.38	0.25
Adequate monitoring and threat awareness	0.00	0.00	0.20	0.48	0.32
Safety and security officers and facilities	0.00	0.00	0.10	0.53	0.37
Mapping to Safety and Security					
Identifying restricted areas and access control	0.000	0.008	0.015	0.368	0.600
Formal safety and security training practices	0.013	0.118	0.160	0.365	0.345
Adequate monitoring and threat awareness	0.000	0.050	0.100	0.410	0.440
Safety and security officers and facilities	0.000	0.025	0.050	0.423	0.503

Mapping to environment

Table VI-32 Results of mapping to environment

PPIs	Very Poor	Poor	Medium	Good	Very Good
Carbon footprint	0.13	0.42	0.20	0.15	0.10
Total water consumption	0.07	0.30	0.25	0.23	0.15
Total energy consumption	0.07	0.20	0.28	0.25	0.20
Waste recycling	0.02	0.10	0.43	0.27	0.18
Environment management programs	0.02	0.35	0.38	0.17	0.08
Mapping to Environment					
Carbon footprint	0.235	0.365	0.100	0.163	0.138
Total water consumption	0.145	0.288	0.125	0.235	0.208
Total energy consumption	0.120	0.220	0.140	0.258	0.263
Waste recycling	0.45	0.183	0.215	0.310	0.248
Environment management programs	0.108	0.358	0.190	0.223	0.123

Mapping to social engagement

Table VI-33 Results of mapping to social engagement

PPIs	Very Poor	Poor	Medium	Good	Very Good
Employment	0.00	0.28	0.61	0.11	0.00
Regional GDP	0.00	0.22	0.61	0.17	0.00
Disclose of information	0.00	0.11	0.39	0.39	0.11
Mapping to Social Engagement					
Employment	0.070	0.363	0.305	0.235	0.028
Regional GDP	0.055	0.318	0.305	0.280	0.043
Disclose of information	0.028	0.180	0.195	0.390	0.208

Appendix VII Questionnaire Surveys

SURVEY (TERMINAL OPERATORS)

Thank you very much for your participation.

A research project at Liverpool Logistics, Offshore and Marine (LOOM) Research Institute is currently being carried out on "Measurement, Modelling and Analysis of Container Port Performance". The aim of this research is to develop a new Port Performance Indicators (PPIs) assessment methodology for container ports and a decision support tool to enhance quantitative port performance analysis. These analysis models are capable of helping decision makers and stakeholders in container terminal operations for measuring and evaluating their performance under dynamic environments.

The survey will only take approximately 20 to 30 minutes of your time. Your participation in this survey is completely voluntary. Anonymity is guaranteed and all the data will be treated in ethical and confidential manner. Your responses and contact details will be strictly confidential. The data from the study will only be used in research publications. You will not be identified in any way in these publications. However, you can stop taking part in this research at any time without explanation or prejudice. You may also withdraw any unprocessed data from the study.

There are no risks associated with the study, but if you have any question regarding the questionnaire or problems answering any question, please advise or contact the researcher. If you know of others that might be interested in this study, could you please pass this information sheet onto them so they may contact the researcher to volunteer for the study? If you have any questions about the study, please do not hesitate to contact the researcher.

Thank you,

Yours faithfully

Researcher
Min-Ho Ha
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E-mail: m.ha@2012.ljmu.ac.uk

I. DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company's name:

2. Which port are you currently working at?
   Port:

3. What is your position in the company?

4. How many years have you been in the port industry?
   a. Less than 5 years
   b. Between 5 to 10 years
   c. Between 11 to 15 years
   d. More than 15 years

II. TERMINAL SUPPORT ACTIVITIES

'TERMINAL SUPPORT ACTIVITIES' in this study can be defined as the terminal internal activities (i.e. HR, organisation, technology and process, etc.) for supporting cargo/vessel services (known as CORE ACTIVITY in this study). It is not directly concerned with cargo or vessel services but is really crucial perspectives to improve organizations' effectiveness or efficiency.

1. With regard to the TERMINAL SUPPORT ACTIVITIES, please judge the most appropriate linguistic term to indicate each of the questions below to your container terminal.

	Very Poor (Very Low)	Poor (Low)	Medium	Good (High)	Very Good (Very High)
HUMAN CAPITAL					
Our workforces' *knowledge and skills* to perform their job is:					
Our workforces' *capability* to develop new strategy and services is:					
Offering constantly *training and education opportunities* to enhance the workforces' capability is:					
Our workforce's *commitment and loyalty* is:					
ORGANISATION CAPITAL					
Our organisational *culture* in which employees understand the mission, vision, goal and core values that needed to execute the firm's strategy is:					
Our *leadership* that mobilises the organisation toward its strategy at all levels is:					
Our *alignment* between firm's objectives and individual, team and departmental goals and incentives is:					
Our *teamwork*, in particular, sharing knowledge and collaboration throughout the organization is:					
INFORMATION CAPITAL					
Our *IT infrastructure system* in terms of functionality, compatibility and accessibility in operation is:					
Our *databases*, in particular, application for promoting analysis, interpretation and sharing of information and knowledge is:					
Our *networks* for internal and (or) external communication is:					

III. TERMINAL SUPPLY CHAIN INTEGRATION

'TERMINAL SUPPLY CHAIN INTEGRATION refers to a strategy undertaken by a container terminal to integrate various functions and organizations with partners in the supply chain as opposed to being an isolated node that provides basic ship-shore operation.

1. With regard to the TERMINAL SUPPLY CHAIN INTEGRATION, please judge the most appropriate linguistic term to indicate each of the questions below to your container terminal.

	Very Poor	Poor	Medium	Good	Very Good
INTERMODAL TRANSPORT SYSTEMS					
Having adequate *seaside connectivity* for the multimodal interface					
Having adequate *landside connectivity* for the multimodal interface					
Having *reliable services operations* for the multi-modal interface					
Having *efficient services operations* for the multimodal interface					
VALUE-ADDED SERVICES					
Having *adequate facilities for adding valu*e to cargoes such as pre-assembly, manufacturing, and packaging					
Having the *capability to handle different types of cargo*					
Having *capability to adopt service to meet customers' specifications*					
Having tailored services to customers					
INFORMATION AND COMMUNICATION SYSTEMS					
Using *Integrated Electronic Data Interchange (EDI)* to communicate with partners in the supply chain					
Using *integrated information technology (IT) systems* to share data/information with partners in the supply chain					
Collaborating with channel members for channel optimization					
Using *the latest technology* to support supply chain goals					

IV. TERMINAL SUSTAINABLE GROWTH

‘TERMINAL SUSTAINABLE GROWTH’ refers to long term development with ecological health and community integrity. This indicator can be used to enhance environment, safety and security, and socio-economic sustainability.

1. With regard to the TERMINAL SUSTAINABLE GROWTH, please judge the most appropriate linguistic term to indicate each of the questions below to your container terminal.

SAFETY AND SECURITY	Very Poor	Poor	Medium	Good	Very Good
We clearly *identify restricted areas and control access to these areas*					
We have *a formal safety and security training programme and conduct a regular safety and security training test* (monthly)					
We adequately *monitor vulnerable targets and aware threat* if the targets are damaged					
We have *reliable safety and security officers and facilities*					
ENVIRONMENTAL					
We *calculate carbon footprint and identify the different emission sources*					
We *monitor the water consumption and identify the different water usages*					
We *monitor the energy consumption and effort to save the energy*					
We *recycle waste and identify what is being recycled*					
We have *environmental management programmes* such as policy, objectives and targets, monitoring programme and environmental report, etc.					

< Thank you very much for your participation >

SURVEY (PORT USERS)

I. DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company’s name:

2. Which category does your organization fall in?
   a. Shipping Line
   b. Cargo owners or their agents
   c. Logistic Service provider
   Other, please specify:

3. Which container terminal and port does your company usually use?
   Terminal:
   Port:

4. What is position in the company?

5. How many years have you been in the business?
   a. Less than 5 years
   b. Between 5 to 10 years
   c. Between 11 to 15 years
   d. More than 15 years

II. PORT USERS' SATISFACTION

'PORT USERS' SATISFACTION' in this study is to measure whether a terminal operator meets users' needs and expectations on the quality of service provided by the terminal.

1. With regard to the PORT USERS' SATISFACTION, please judge the most appropriate linguistic term to indicate each of the questions below to the container terminal/port that you use (based on Question 3 in I. DEMOGRAPHIC/ COMPANY BACKGROUND).

SERVICE FULFILMENT	Very Poor	Poor	Medium	Good	Very Good
Terminal operator's *overall reliability* of service is:					
Terminal operator's *responsiveness to special requests* is:					
Terminal operator's *provision of adequate and on-time documents and information* is:					
Terminal operator's *incidence of cargo damage* is:					
Terminal operator's *incidence of delay* is:					
SERVICE COSTS	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
We satisfied with *total service cost of a terminal*.					
We satisfied with *cargo handling charge* of a terminal.					
We satisfied with cost of *terminal ancillary services*.					

III. TERMINAL SUPPLY CHAIN INTEGRATION

'TERMINAL SUPPLY CHAIN INTEGRATION refers to a strategy undertaken by a seaport terminal to integrate various functions and organizations in the supply chain to become an integral part of the supply chain as opposed to being an isolated node that provides a basic ship-shore operation.

1. With regard to the TERMINAL SUPPLY CHAIN INTEGRATION, please judge the most appropriate linguistic term to indicate each of the questions below to the container terminal/port that you use (based on Question 3 in I. DEMOGRAPHIC/ COMPANY BACKGROUND).

	Very Poor	Poor	Medium	Good	Very Good
INTERMODAL TRANSPORT SYSTEMS					
Having adequate *seaside connectivity* for the multimodal interface					
Having adequate *landside connectivity* for the multimodal interface					
Having *reliable services operations* for the multi-modal interface					
Having *efficient services operations* for the multimodal interface					
VALUE-ADDED SERVICES					
Having *adequate facilities for adding valu*e to cargoes such as pre-assembly, manufacturing, and packaging					
Having the *capability to handle different types of cargo*					
Having *capability to adopt service to meet customers' specifications*					
Having tailored services to customers					
INFORMATION AND COMMUNICATION SYSTEMS					
Using *Integrated Electronic Data Interchange (EDI)* to communicate with partners in the supply chain					
Using *integrated information technology (IT) systems* to share data/ information with partners in the supply chain					
Collaborating with channel members for channel optimization					
Using *the latest technology* to support supply chain goals					

< Thank you very much for your participation >

SURVEY (PORT ADMINISTRATORS)

I. DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your organisation's name:

2. Which category does your organization fall in?
   a. Port authority
   b. Central or local government
   c. Non-governmental organization

   If you are a NGO, please specify:

3. Which container terminal and port does your company monitor and administrate?
   Terminal: Port:

4. What is your position in the organisation?

5. How many years have you been in the business?
   a. Less than 5 years
   b. Between 5 to 10 years
   c. Between 11 to 15 years
   d. More than 15 years

II. TERMINAL SUSTAINABLE GROWTH

'TERMINAL SUSTAINABLE GROWTH' refers to long term development with ecological health and community integrity. This indicator can be used to enhance environment, safety and security, and socio-economic sustainability.

With regard to the TERMINAL SUSTAINABLE GROWTH, please judge the most appropriate linguistic term to indicate each of the questions below to the container terminal/port that you monitor or administrate (based on Question 2 in I.DEMOGRAPHIC/ COMPANY BACKGROUND)

SAFETY AND SECURITY	Very Poor	Poor	Medium	Good	Very Good
Terminal operator clearly *identify restricted areas and control access to these areas*					
Terminal operator has *a formal safety and security training programme and conduct a regular safety and security training test* (monthly)					
Terminal operator adequately *monitor vulnerable targets and aware threat* if the targets are damaged					
Terminal operator has *reliable safety and security officers and facilities*					
ENVIRONMENTAL					
Terminal operator *calculates carbon footprint and identify the different emission sources*					
Terminal operator *monitors the water consumption and identify the different water usages*					
Terminal operator *monitors the energy consumption and effort to save the energy*					
Terminal operator *recycles waste and identify what is being recycled*					
Terminal operator has *environmental management programmes* such as policy, objectives and targets, monitoring programme and environmental report, etc.					
SOCIAL AND ECONOMIC					
Terminal operator's contribution to create the employment opportunity compared to others in the port is:					
Terminal operator's *contribution to the regional GDP* of a country compared to others in the port is:					
Terminal operator's *social responsibility concerning public documents* (environment, safety and security, annual report, etc.) we report are:					

< Thank you very much for your participation >

SURVEY for Weighting Assignment to Port Performance Indicators (PPIs)

Analytic Hierarchy Process

In order to conduct an overall container port performance measurement, weights assignment to each port performance indicators (PPIs) plays an important role in the context of measurement process.
A critical characteristic of the AHP is the consistency of the pairwise judgements. Where the value of CR is greater than 0.1 which indicates an inconsistency in the pairwise judgements and the expert needs to revision the pairwise judgements. Therefore, the judgements should inform an acceptable level with the CR of 0.10 or less. For your better understanding, please refer to the example below.

Example

In the pairwise comparison of three PPIs, if you judge A > B and B > C, then you must judge A > C

Based on pairwise comparisons between A and B, B and C, the right answer for comparison between A and C must be more than 5.

Pairwise comparisons																		
PPIs	High			Average		Low			Equal	Low			Average			High		PPIs
A	(9)	(8)	(7)	(6)	(5)	**(4)**	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	B
B	(9)	(8)	(7)	(6)	(5)	(4)	(3)	**(2)**	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	C
A	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	C

PART A: WEIGHTS ASSIGNMENT

1. For the "OVERALL CONTAINER PORT PERFORMANCE MEASUREMENT", there are 6 PPIs in the level 2: *core (operational) activities (CA), support activities (SA), financial strength (FS), users' satisfaction (US), terminal supply chain integration (TSCI), and sustainable growth (SG)*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons																		
PPIs	High			Average		Low			Equal	Low			Average			High		PPIs
Core activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Support activities
Core activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Financial strength
Core activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Users' satisfaction
Core activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Terminal supply chain integration
Core activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Sustainable growth
Support activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Financial strength
Support activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Users' satisfaction
Support activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Terminal supply chain integration
Support activities	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Sustainable growth
Financial strength	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Users' satisfaction
Financial strength	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Terminal supply chain integration
Financial strength	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Sustainable growth
Users' satisfaction	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Terminal supply chain integration
Users' satisfaction	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Sustainable growth
Terminal supply chain integration	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Sustainable growth

2. For the "CORE ACTIVITIES" performance measurement, there are 3 PPIs in the level 3: *output, productivity and lead-time*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons																		
PPIs	High			Average		Low			Equal	Low			Average			High		PPIs
Output	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Productivity
Output	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Lead-time
Productivity	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Lead-time

2-1. For the "OUTPUT" performance measurement, there are 2 PPIs in the level 4: *"percentage of growth in TEU throughput (TEUs/year)" and "percentage of growth in vessel call size (tons/no. of vessels)"*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Throughput growth	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Vessel call size growth

2-2. For the "PRODUCTIVITY" performance measurement, there are 6 PPIs in the level 4: *"ship load rate (TEU/average vessel capacity"), "berth utilization (TEU/berth length)", "berth occupancy (% of occupancy)", "crane efficiency (movement/h)", "yard utilization (TEU/area of container yard)" and "labour (TEU/employee)"*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Ship load rate	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Berth utilization
Ship load rate	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Berth occupancy
Ship load rate	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Crane efficiency
Ship load rate	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Yard utilization
Ship load rate	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Labour productivity
Berth utilization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Berth occupancy
Berth utilization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Crane efficiency
Berth utilization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Yard utilization
Berth utilization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Labour productivity
Berth occupancy	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Crane efficiency
Berth occupancy	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Yard utilization
Berth occupancy	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Labour productivity
Crane efficiency	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Yard utilization
Crane efficiency	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Labour productivity
Yard utilization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Labour productivity

2-3. For the "LEAD-TIME" performance measurement, there are 3 PPIs in the level 4: *"vessel turnaround time (vessel waiting & berthing/unberthing time, vessel working (service) time at berth", "truck turnaround time" and "container dwell time".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Vessel turnaround time	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Truck turnaround time
Vessel turnaround time	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Container dwell time
Truck turnaround time	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Container dwell time

3. For the "SUPPORT ACTIVITIES" performance measurement, there are 3 PPIs in the level 3: *human capital, organisation capital and information capital*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

3-1. For the "HUMAN CAPITAL" performance measurement, there are 4 PPIs in the level 4: *"workforce's knowledge and skills: understanding of given tasks and environment", "workforce's capability to develop new strategy, etc.", "workforce's training and education opportunity" and "workforce's commitment and loyalty".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Workforce's knowledge and skills	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's capability
Workforce's knowledge and skills	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's training and education opportunity
Workforce's knowledge and skills	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's commitment and loyalty
Workforce's capability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's training and education opportunity
Workforce's capability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's commitment and loyalty
Workforce's training and education opportunity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Workforce's commitment and loyalty

3-2. For the “ORGANISATION CAPITAL” performance measurement, there are 4 PPIs in the level 4: *“Culture: employees conceive of and internalise the mission, vision and core values needed to execute the firm’s strategy”, “Leadership: mobilise the organisation toward its strategy”, “Alignment: between organisation’s strategic objectives and individual, team and departmental goals” and “Teamwork: knowledge sharing and collaboration”*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Leadership
Culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Alignment
Culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Teamwork
Leadership	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Alignment
Leadership	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Teamwork
Alignment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Teamwork

3-3. For the “INFORMATION CAPITAL” performance measurement, there are 3 PPIs in the level 4: *“IT Systems (infrastructure): functionality, compatibility and accessibility in operation”, “Databases: application for promoting analysis, interpretation and sharing of information and knowledge” and “Networks: internal/external communication”*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
IT systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Databases
IT systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Networks
Databases	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Networks

4. For the “FINANCIAL STRENGTH” measurement, there are 2 PPIs in the level 3: *profitability and liquidity and solvency*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

4-1. For the “PROFITABILITY” performance measurement, there are 3 PPIs in the level 4: *“growth on revenue (revenue/last year revenue)”, “operating profit margin (operating profit /revenue)” and “net profit margin (net income/revenue)”*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Revenue growth	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Operating profit margin
Revenue growth	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Net profit margin
Operating profit margin	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Net profit margin

4-2. For the “LIQUIDITY AND SOLVENCY” performance measurement, there are 3 PPIs in the level 4: *“current ratio (current assets/current liabilities)”, “debt to total asset ratio (total debt/total asset)”and “debt to equity (total debt/owner’s equity)”*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Current ratio	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Debt to asset
Current ratio	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Debt to equity
Debt to asset	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Debt to equity

5. For the “USERS’ SATISFACTION” performance measurement, there are 2 PPIs in the level 3: *service fulfilment and service cost*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

5-1. For the “SERVICE FULFILMENT” performance measurement, there are 5 PPIs in the level 4: *“overall reliability of the terminal”, “responsiveness to special requests”, “provision of adequate documents and on-time* *information", "incidence of cargo damage" and "incidence of delay".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Overall reliability of the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Responsiveness to special requests
Overall reliability of the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Provision of adequate documents and on-time information
Overall reliability of the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of cargo damage
Overall reliability of the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of delay
Responsiveness to special requests	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Provision of adequate documents and on-time information
Responsiveness to special requests	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of cargo damage
Responsiveness to special requests	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of delay
Provision of adequate documents and on-time information	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of cargo damage
Provision of adequate documents and on-time information	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of delay
Incidence of cargo damage	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Incidence of delay

5-2. For the "SERVICE COSTS" performance measurement, there are 3 PPIs in the level 4: *"Overall cost of using the port", "cargo handling charge" and "terminal ancillary service charge".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Overall cost of using the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Cargo handling charge
Overall cost of using the terminal	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal ancillary service charge
Cargo handling charge	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal ancillary service charge

6. For the "TERMINAL SUPPLY CHAIN INTEGRATION" performance measurement, there are 3 PPIs in the level 3: *intermodal transport systems, value-added services and information and communication integration*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

6-1. For the "INTERMODAL TRANSPORT SYSTEMS" performance measurement, there are 4 PPIs in the level 4: *"sea side connectivity", "land side connectivity", "reliability for multimodal operations" and "efficient multimodal operations".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Seaside connectivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Land side connectivity
Seaside connectivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Reliability for multimodal operations
Seaside connectivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Efficient multimodal operations
Land side connectivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Reliability for multimodal operations
Land side connectivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Efficient multimodal operations

Reliability for multimodal operations	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Efficient multimodal operations

6-2. For the "VALUE-ADDED SERVICES" performance measurement, there are 4 PPIs in the level 4: *"facilities to add value to cargoes", "service adaptation to customers", "capacity to handle different types of cargo" and "tailored services to customers".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Facilities to add value to cargoes	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service adaptation to customers
Facilities to add value to cargoes	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Capacity to handle different types of cargo
Facilities to add value to cargoes	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Tailored services to customers
Service adaptation to customers	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Capacity to handle different types of cargo
Service adaptation to customers	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Tailored services to customers
Capacity to handle different types of cargo	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Tailored services to customers

6-3. For the "INFORMATION AND COMMUNICATION INTEGRATION" performance measurement, there are 4 PPIs in the level 4: *"integrated EDI for communication", "integrated IT to share data", "single window computerized port service systems" and "latest IT in the industry".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Integrated EDI for communication	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Integrated IT to share data
Integrated EDI for communication	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Collaborate with channel members for channel optimization
Integrated EDI for communication	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Latest port IT systems
Integrated IT to share data	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Collaborate with channel members for channel optimization
Integrated IT to share data	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Latest port IT systems
Collaborate with channel members for channel optimization	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Latest port IT systems

7. For the "SUSTAINABLE GROWTH" performance measurement, there are 4 PPIs in the level 3: *safety and security, environment and social engagement*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons																		
PPIs	High			Average		Low			Equal	Low			Average		High			PPIs
Safety and security	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Environment
Safety and security	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Social engagement
Environment	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Social engagement

7-1. For the "SAFETY AND SECURITY" performance measurement, there are 4 PPIs in the level 5: *"identifying restricted areas and access control", "Formal safety and security training program", "Adequate monitoring and threat awareness" and "safety and security officers and facilities (port security officer, port security committee, security manual, fencing, lighting, secured gates, communication equipment, closed circuit TV monitoring equipment and detection devices)".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Identifying restricted areas and access control	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Formal safety and security training program
Identifying restricted areas and access control	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Adequate monitoring and threat awareness

Identifying restricted areas and access control	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Safety and security officers and facilities
Formal safety and security training program	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Adequate monitoring and threat awareness
Formal safety and security training program	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Safety and security officers and facilities
Adequate monitoring and threat awareness	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Safety and security officers and facilities

7-2. For the "ENVIRONMENT" performance measurement, there are 5 PPIs in the level 4: *"carbon footprint", "total water consumption", "total energy consumption", "waste recycling" and "existence of environment management programmes"*. Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Carbon footprint	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Total water consumption
Carbon footprint	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Total energy consumption
Carbon footprint	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Waste recycling
Carbon footprint	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment management programmes
Total water consumption	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Total energy consumption
Total water consumption	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Waste recycling
Total water consumption	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment management programmes
Total energy consumption	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Waste recycling
Total energy consumption	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment management programmes
Waste recycling	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment management programmes

7-3. For the "SOCIAL ENGAGEMENT" performance measurement, there are 2 PPIs in the level 4: *"employment opportunity", "regional GDP" and "disclose of information".* Please estimate its relative importance of each PPI based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Employment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Regional GDP
Regional GDP	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Disclose of information

PART B: DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company's name

2. Which category does your organization fall in?
   d. Shipping Line
   e. Port Operator
   f. Port Authority
   g. Central/local government
   h. Logistic Service provider
   i. Academic/research institute
   j. Other, please specify:

3. How many years have you been in the business?
   e. Less than 5 years
   f. Between 5 to 10 years
   g. Between 11 to 15 years
   h. More than 15 years

4. What is your position in the company?

< Thank you very much for your participation >

SURVEY for identifying Port Performance Indicators (PPIs) interdependency (DEMATEL)

INTERDEPENDENCY MEAUSREMENT ON MAIN SIX PPIs

The following questions based on pairwise comparisons, if you please, based on your experience, use the 5-scale to estimate to what extent each left-side factor affect the opposite factor; where:

0- No Influence

1- Very Low Influence

2- Low Influence

3- High Influence

4-Very High Influence

This survey aims to evaluate the causal relationships among the main six dimensions of the Port Performance Measurement framework (*core activities, support activities, financial strength, users' satisfaction, terminal supply chain integration, and sustainable growth*).

Core Activities (operational): output, productivity and lead-time

Support Activities: human capital, organisation capital and information capital

Financial Strength: profitability and liquidity and solvency

Port Users' Satisfaction: service fulfilment and service costs

Terminal Supply Chain Integration: intermodal transport systems, value added services and information/communication integration

Sustainable Growth: safety and security, environment and social and economic responsibility

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Core activities						Support activities
Core activities						Financial strength
Core activities						Users' satisfaction
Core activities						Terminal supply chain integration
Core activities						Sustainable growth
Support activities						Financial strength
Support activities						Users' satisfaction
Support activities						Terminal supply chain integration
Support activities						Sustainable growth
Financial strength						Users' satisfaction
Financial strength						Terminal supply chain integration
Financial strength						Sustainable growth

Users' satisfaction						Terminal supply chain integration
Users' satisfaction						Sustainable growth
Terminal supply chain integration						Sustainable growth

INTERDEPENDENCY MEAUSREMENT ON 16 PRINCIPAL - PPIs

Based on the causal relationships between the 6 dimensions, this survey aims to evaluate the causal relationships between the 16 Principal-PPIs of the Port Performance Measurement framework.

The following questions based on pairwise comparisons, if you please, based on your experience, use the 5-scale to estimate to what extent each left-side factor affect the opposite factor; where:

0- No Influence

1- Very Low Influence

2- Low Influence

3- High Influence

4-Very High Influence

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Output						Productivity
Output						Lead-time
Output						Human capital
Output						Organisation capital
Output						Information capital
Output						Profitability
Output						Liquidity and Solvency
Output						Service fulfilment
Output						Service costs
Output						Intermodal transport systems
Output						Value-added services
Output						Information/communication integration
Output						Safety and security
Output						Environment
Output						Social engagement
Productivity						Output
Productivity						Lead-time
Productivity						Human capital
Productivity						Organisation capital
Productivity						Information capital
Productivity						Profitability
Productivity						Liquidity and Solvency
Productivity						Service fulfilment
Productivity						Service costs
Productivity						Intermodal transport systems
Productivity						Value-added services
Productivity						Information/communication integration
Productivity						Safety and security
Productivity						Environment
Productivity						Social engagement
Lead-time						Output
Lead-time						Productivity

Lead-time						Human capital
Lead-time						Organisation capital
Lead-time						Information capital
Lead-time						Profitability
Lead-time						Liquidity and Solvency
Lead-time						Service fulfilment
Lead-time						Service costs
Lead-time						Intermodal transport systems
Lead-time						Value-added services
Lead-time						Information/communication integration
Lead-time						Safety and security
Lead-time						Environment
Lead-time						Social engagement

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Human capital						Output
Human capital						Productivity
Human capital						Lead-time
Human capital						Profitability
Human capital						Liquidity and Solvency
Human capital						Service fulfilment
Human capital						Service costs
Human capital						Intermodal transport systems
Human capital						Value-added services
Human capital						Information/communication integration
Human capital						Safety and security
Human capital						Environment
Human capital						Social engagement
Organisation capital						Output
Organisation capital						Productivity
Organisation capital						Lead-time
Organisation capital						Profitability
Organisation capital						Liquidity and Solvency
Organisation capital						Service fulfilment
Organisation capital						Service costs
Organisation capital						Intermodal transport systems
Organisation capital						Value-added services
Organisation capital						Information/communication integration
Organisation capital						Safety and security
Organisation capital						Environment
Organisation capital						Social engagement
Information capital						Output
Information capital						Productivity
Information capital						Lead-time
Information capital						Profitability
Information capital						Liquidity and Solvency
Information capital						Service fulfilment
Information capital						Service costs
Information capital						Intermodal transport systems
Information capital						Value-added services
Information capital						Information/communication integration
Information capital						Safety and security
Information capital						Environment
Information capital						Social engagement

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Profitability						Output
Profitability						Productivity

Profitability						Lead-time
Profitability						Human capital
Profitability						Organisation capital
Profitability						Information capital
Profitability						Safety and security
Profitability						Environment
Profitability						Social engagement
Liquidity and Solvency						Output
Liquidity and Solvency						Productivity
Liquidity and Solvency						Lead-time
Liquidity and Solvency						Human capital
Liquidity and Solvency						Organisation capital
Liquidity and Solvency						Information capital
Liquidity and Solvency						Safety and security
Liquidity and Solvency						Environment
Liquidity and Solvency						Social engagement

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Service fulfilment						Output
Service fulfilment						Productivity
Service fulfilment						Lead-time
Service fulfilment						Human capital
Service fulfilment						Organisation capital
Service fulfilment						Information capital
Service fulfilment						Profitability
Service fulfilment						Liquidity and Solvency
Service costs						Output
Service costs						Productivity
Service costs						Lead-time
Service costs						Human capital
Service costs						Organisation capital
Service costs						Information capital
Service costs						Profitability
Service costs						Liquidity and Solvency

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Intermodal transport systems						Output
Intermodal transport systems						Productivity
Intermodal transport systems						Lead-time
Intermodal transport systems						Human capital
Intermodal transport systems						Organisation capital
Intermodal transport systems						Information capital
Intermodal transport systems						Service fulfilment
Intermodal transport systems						Service costs
Value-added services						Output
Value-added services						Productivity
Value-added services						Lead-time
Value-added services						Human capital
Value-added services						Organisation capital
Value-added services						Information capital
Value-added services						Service fulfilment
Value-added services						Service costs
Information/communication integration						Output
Information/communication integration						Productivity
Information/communication integration						Lead-time
Information/communication integration						Human capital

Information/communication integration						Organisation capital
Information/communication integration						Information capital
Information/communication integration						Service fulfilment
Information/communication integration						Service costs

Pairwise comparisons						
PPIs	No influence	Low influence	Medium influence	High influence	Very High influence	PPIs
Safety and security						Output
Safety and security						Productivity
Safety and security						Lead-time
Environment						Output
Environment						Productivity
Environment						Lead-time
Social engagement						Output
Social engagement						Productivity
Social engagement						Lead-time

DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company's name

2. Which category does your organization fall in?
   k. Shipping Line
   l. Port Operator
   m. Port Authority
   n. Central/local government
   o. Logistic Service provider
   p. Academic/research institute
   q. Other, please specify:____

3. How many years have you been in the business?
   i. Less than 5 years
   j. Between 5 to 10 years
   k. Between 11 to 15 years
   l. More than 15 years

4. What is your position in the company?

< Thank you very much for your participation >

Port Performance Indicators (PPIs) Interdependent Weights (ANP)

PART A: WEIGHTS ASSIGNMENT (SIX DIMENSIONS)

There are 6 dimensions: *core (operational) activities (CA), support activities (SA), financial strength (FS), users' satisfaction (US), terminal supply chain integration (TSCI), and sustainable growth (SG)*. Please estimate its relative importance of each dimension based on simple pairwise comparisons.

1. Which dimension influences 'core activities (CA)' more: 'dimension A' or 'dimension B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Support activities
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users' satisfaction
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users' satisfaction
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users' satisfaction
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Users' satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Users' satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Terminal supply chain integration	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth

2. Which dimension influences 'supporting activities (SA)' more: 'dimension A' or 'dimension B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users' satisfaction
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users' satisfaction
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Users' satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Users' satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Terminal supply chain integration	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth

3. Which dimension influences 'financial strength (FS)' more: 'dimension A' or 'dimension B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Support activities
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth

4. Which dimension influences 'users' satisfaction (US)' more: 'dimension A' or 'dimension B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Support activities
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength

5. Which dimension influences ‘terminal supply chain integration (TSCI)’ more: ‘dimension A’ or ‘dimension B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Support activities
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users’ satisfaction
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users’ satisfaction

6. Which dimension influences ‘port performance (goal)’ more: ‘dimension A’ or ‘dimension B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Support activities
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users’ satisfaction
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Core activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Financial strength
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users’ satisfaction
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Support activities	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Users’ satisfaction
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Financial strength	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Users’ satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Terminal supply chain integration
Users’ satisfaction	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth
Terminal supply chain integration	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Sustainable growth

PART B: WEIGHTS ASSIGNMENT (16 PRINCIPAL PPIs)

1. With respect to output (OPC), which principal PPI influences ‘output (OPC)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement
Environment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement

2. With respect to productivity (PDC), which principal PPI influences 'productivity (PDC)' more: 'principal PPI A' or 'principal PPI B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement
Environment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement

3. With respect to lead-time (LTC), which principal PPI influences 'lead-time (LTC)' more: 'principal PPI A' or 'principal PPI B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement
Environment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement

4. With respect to human capital (HCS), which principal PPI influences 'human capital (HCS)' more: 'principal PPI A' or 'principal PPI B'? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement
Environment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement

5. With respect to organisation capital (OCS), which principal PPI influences ‘organisation (OCS)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement
Environment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Social engagement

6. With respect to information capital (ICS), which principal PPI influences ‘information capital (ICS)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Service fulfilment	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Service costs

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Value-added services

Intermodal transport systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration
Value-added services	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information and communication integration

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Safety and security	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Environment

7. With respect to profitability (PFF), which principal PPI influences ‘profitability (PFF)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

8. With respect to liquidity and solvency (LSF), which principal PPI influences ‘liquidity and solvency (LSF)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

9. With respect to service fulfilment (SFU), which principal PPI influences ‘service fulfilment (SFU)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Organisation capital
Human capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Information capital
Organisation capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Liquidity and Solvency

10. With respect to service costs (SCU), which principal PPI influences ‘service costs (SCU)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Organisation capital
Human capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Information capital
Organisation capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Liquidity and Solvency

11. With respect to intermodal transport systems (ITST), which principal PPI influences ‘intermodal transport systems (ITST)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8)(9)	Organisation capital

Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

12. With respect to value-added services (VAST), which principal PPI influences ‘value-added services (VAST)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

13. With respect to information and communication integration (ICIT), which principal PPI influences ‘information and communication integration (ICIT)’ more: ‘principal PPI A’ or ‘principal PPI B’? and how much more?

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Productivity
Output	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time
Productivity	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Lead-time

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Organisation capital
Human capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital
Organisation capital	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Information capital

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Profitability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Liquidity and Solvency

PART C: DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company’s name

2. Which category does your organization fall in?
    - r. Shipping Line
    - s. Port Operator
    - t. Port Authority
    - u. Central/local government
    - v. Logistic Service provider
    - w. Academic/research institute
    - x. Other, please specify:

3. How many years have you been in the business?
    - m. Less than 5 years
    - n. Between 5 to 10 years
    - o. Between 11 to 15 years
    - p. More than 15 years

4. What is your position in the company?

< Thank you very much for your participation >

Performance Improvement Strategies (TOPSIS)

I. PORT PERFORMANCE IMPROVEMENT STRATEGIES

Please judge the most appropriate linguistic term to indicate each of the questions below to your container terminal.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
CRANE PRODUCTIVITY IMPROVEMENT					
Improving cranes' capability (purchasing advanced crane) is required					
Optimising crane availability (crane numbers and hours) is required					
Training crane drivers is required					
YARD UTILISATION IMPROVEMENT					
Optimisation of yard stacking planning is required					
Permission to use any types of cargo (container box plus other cargo types) is required					
Utilising CY as a storage purpose for customers is required					
TRAINING AND EDUCATION IMPROVEMENT					
Formal training/education programs from external professionals are required					
Internal mentoring programme is required					
Participation in task forces is required					
Job rotation is required					
COMMITMENT AND LOYALTY IMPROVEMENT					
Increasing pay is required					
Individualised reward systems (including promotion) are required					
Increasing organisational support (welfare, training and education, etc.) is required					
Increasing job satisfaction is required					
ORGANISATIONAL CULTURE IMPROVEMENT					
Improving staffs or human capital driven culture is required					
Customer driven culture is required					
Clear organisational performance standard is required					
Accountability system is required					
LEADERSHIP IMPROVEMENT					
Essential role of moral judgement is required					
Executive coaching is required					
Emotional intelligence is required					
Cognitive intelligence is required					
DOCUMENTS & INFORMATION ACCURACY IMPROVEMENT					
Appropriate staff deployment is required					
Training and education programme (internal and external) is required					
Recognising frequent mistakes is required					
INCIDENCE OF SERVICE DELAY IMPROVEMENT					
Improving ship to shore (or vice versa) operations is required					
Improving berth to yard (or vice versa) operations is required					
Improving yard to gate (or vice versa) operations is required					
Preventing incidents and accidents (i.e. human incidents and accidents and machinery failures) is required					
SEA-SIDE CONNECTIVITY IMPROVEMENT					
Marketing to shipping liners/shippers is required					
Improving port reputation is required					
Expending and improving port facility and equipment are required					
VALUE-ADDED SERVICE TO CUSTOMERS IMPROVEMENT					
Identifying customers' requirements is required					
Collaborating with customers for service improvements is required					
Pursing customer oriented value-added service strategy is required					
PORT IT SYSTEMS IMPROVEMENT					
Purchasing advanced IT systems is required					
Updating the existing IT systems is required					
Improving management quality of information and data is required					

II. DEMOGRAPHIC/ COMPANY BACKGROUND

1. Please write your company's name:

2. What is your position in the company?

3. How many years have you been in the port industry?
   q. Less than 5 years
   r. Between 5 to 10 years
   s. Between 11 to 15 years
   t. More than 15 years

   < Thank you very much for your participation >

Weighting Assignment to Performance Improvement Strategies

1. In order to improve cranes' productivity in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

	Pairwise comparisons	
PPIs	High Average Low Equal Low Average High	PPIs
Improving cranes' capability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Optimising crane availability (crane numbers and hours)
Improving cranes' capability	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Training crane drivers
Optimising crane availability (crane numbers and hours)	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Training crane drivers

2. In order to improve yard utilisation in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

	Pairwise comparisons	
PPIs	High Average Low Equal Low Average High	PPIs
Optimisation of yard stacking planning	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Permission to use any types of cargo (container box plus other cargo types)
Optimisation of yard stacking planning	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Utilising CY as a storage purpose for customers
Permission to use any types of cargo (container box plus other cargo types)	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Utilising CY as a storage purpose for customers

3. In order to improve training and education practices in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

	Pairwise comparisons	
PPIs	High Average Low Equal Low Average High	PPIs
Formal training/education programs from external professionals	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7)(8)(9)	Internal mentoring programme
Formal training/education programs from external professionals	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7)(8)(9)	Participation in task forces
Formal training/education	(9)(8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7)(8)(9)	Job rotation

programs from external professionals		
Internal mentoring programme	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Participation in task forces
Internal mentoring programme	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Job rotation
Participation in task forces	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Job rotation

4. In order to improve staffs' commitment and loyalty in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Increasing pay	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Individualised reward systems
Increasing pay	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Increasing organisational support (welfare, training and education, etc.)
Increasing pay	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Increasing job satisfaction
Individualised reward systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Increasing organisational support (welfare, training and education, etc.)
Individualised reward systems	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Increasing job satisfaction
Increasing organisational support (welfare, training and education, etc.)	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Increasing job satisfaction

5. In order to improve organisational culture in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Improving staffs or human capital driven culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Customer driven culture
Improving staffs or human capital driven culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Clear organisational performance standard
Improving staffs or human capital driven culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Accountability system
Customer driven culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Clear organisational performance standard
Customer driven culture	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Accountability system
Clear organisational performance standard	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Accountability system

6. In order to improve leadership in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Essential role of moral judgement	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Executive coaching
Essential role of moral judgement	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Emotional intelligence
Essential role of moral judgement	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Cognitive intelligence
Executive coaching	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Emotional intelligence
Executive coaching	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Cognitive intelligence
Emotional intelligence	(9) (8) (7) (6) (5) (4) (3) (2) (1) (2) (3) (4) (5) (6) (7) (8) (9)	Cognitive intelligence

7. In order to improve document and information accuracy in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons

PPIs	High			Average		Low		Equal		Low		Average			High	PPIs
Appropriate staff deployment	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Training and education programme
Appropriate staff deployment	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Recognising frequent mistakes
Training and education programme	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Recognising frequent mistakes

8. In order to improve service delay in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Improving ship to shore operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving berth to yard operations
Improving ship to shore operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving yard to gate operations
Improving ship to shore operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Preventing incidents and accidents (HR and machinery errors)
Improving berth to yard operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving yard to gate operations
Improving berth to yard operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Preventing incidents and accidents (HR and machinery errors)
Improving yard to gate operations	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Preventing incidents and accidents (HR and machinery errors)

9. In order to improve sea-side connectivity in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Marketing to shipping liners/shippers	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving port reputation
Marketing to shipping liners/shippers	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Expending and improving port facility and equipment
Improving port reputation	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Expending and improving port facility and equipment

10. In order to improve value-added services to customers in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Identifying customers' requirements	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Collaborating with customers for service improvements
Identifying customers' requirements	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Pursing customer oriented value-added service strategy
Collaborating with customers for service improvements	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Pursing customer oriented value-added service strategy

10. In order to improve port IT systems in the Busan North Port container terminals, please estimate its relative importance of each criterion based on simple pairwise comparisons.

Pairwise comparisons		
PPIs	High Average Low Equal Low Average High	PPIs
Purchasing advanced IT systems	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Updating the existing IT systems
Purchasing advanced IT systems	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving management quality of information and data
Updating the existing IT systems	(9)(8)(7)(6)(5)(4)(3)(2)(1)(2)(3)(4)(5)(6)(7)(8)(9)	Improving management quality of information and data

< Thank you very much for your participation >