DigitalCommons @WayneState

Journal of Transportation Management

Volume 22 | Issue 1 Article 5

4-1-2011

The selection of transshipment ports using a hybrid data envelopment analysis/analytic hierarchy process

Byung-In Park
Chonnam National University, byungin.park@gmail.com

Hokey Min
Bowling Green State University, hmin@bgsu.edu

Recommended Citation

Park, Byung-In, & Min, Hokey. (2011). The selection of transshipment ports using a hybrid data envelopment analysis/analytic hierarchy process. Journal of Transportation Management, 22(1), 47-64. doi: 10.22237/jotm/1301616240

THE SELECTION OF TRANSSHIPMENT PORTS USING A HYBRID DATA ENVELOPMENT ANALYSIS/ANALYTIC HIERARCHY PROCESS

Byung-In Park
Chonnam National University

Hokey Min
Bowling Green State University

ABSTRACT

The accelerated globalization of logistics activities over the last several decades has spurred a rapid expansion of port facilities all cross the world. However, the recent slowdown of international trade, coupled with a global financial crisis, has created an on-going glut of international port facilities throughout the world. Although the abundance of port facilities provides more transshipment options for carriers and shippers, it makes the port selection decision more complex and difficult. To cope with this new set of challenges, this paper proposes a hybrid data envelopment analysis (DEA)/ analytic hierarchy process (AHP) model that is designed to identify factors specifically influencing transshipment port selection, evaluates the extent of influence of those factors on a transshipment port selection decision, and then determines the most critical ones among various factors. To illustrate the usefulness of the proposed hybrid DEA/AHP model, major container hub ports in Far-East Asia were analyzed.

INTRODUCTION

As a severe public debt crisis in developed economies including the Unites States, Great Britain, Spain, Portugal, and Greece continues, the global economy has struggled to slip out of ongoing recession. Impacted by this slumping global economy, international trade in 2009 experienced the sharpest decline in more than 70 years. Although international trade grew somewhat in 2010, that growth has been slow-paced relative to the recent past. Slow growth in international trade has far reaching impacts on the maritime logistics industry, and most notably ports serving the ocean shipping industry (Toth, 2009). To make matters worse, many major ports across the world substantially expanded their capacity in the recent past with an expectation of a demand surge. For example, the port of Qingdao in China recently invested 1.4 billion dollars in its harbor, including 10 deep-water berths and expansion of the total dock length to 3,408 meters (DredgingToday.Com, 2010). Similarly, the Port of Tianjin in China and the Port of Mundra in India poured billions of dollars of investment into capacity expansion.

On the surface, the above port capacity expansion sounds beneficial for shippers and carriers because the surplus of port capacity can lower port charges for ocean carriers. However, the reduced port charges may increase the number of vessels anchored at the port and can considerably slow the loading/unloading process at the port. A delay at the port caused by an excessibe number of vessels will lead to an increase in lead time and the subsequent deterioration of services for shippers. Considering this dilemma, the ocean shipping industry needs to develop an efficient and effective port selection strategy that will help carriers and shippers cope with the misalignment of port demand and supply.

Generally, a port selection decision is extremely challenging due to a multitude of influencing factors. These factors include (Murphy et al., 1992 and Chang et al., 2008), geographical location, terminal handling charges, port dues, feeder connections, inland intermodal connections, port reputation, water draft, information technology capabilities, convenience of customs processes, and labor-management relationships. Factors often conflict with each other thereby complicating the goal of selecting the most desirable port. For instance, a port in an ideal location may incur higher costs due to high terminal charges and port dues or vice versa. Also, since the comparative performance of ports relative to other competing ports can influence the port selection decision, the relative attractiveness of ports should be factored into the port selection decision. This attractiveness, in turn, is influenced by the relative importance of port selection factors. Considering this complexity of the port selection decision, this paper develops a systematic decision tool for selecting the most desirable port in dynamic business environments. More specifically, the main objectives of this paper are to:

1. Identify key determinants that significantly influence the transshipment port selection decision from the perspective of both port users (carriers) and port service providers (port authorities and operating companies);
2. Determine the relative importance of those determinants to the port selection decision;
3. Analyze the trade-offs among those determinants;
4. Evaluate the extent of influence of each determinant on port selection;
5. Develop a port competitive strategy or port policy that can attract more carriers to the port and then strengthen port competitiveness under various what-if decision scenarios.

PRIOR LITERATURE

A transshipment port plays an important role in linking the global supply chain, since it is often used as a point of transfer from international (open-sea) to domestic (inland) transportation or from one mode of transportation to another. The transshipment port is also regarded as a collection center for cargoes moving from a feeder port to an inland destination. Due to its critical role in a global supply chain, the choice of a transshipment port has a long lasting impact on supply chain efficiency. Despite its significance, relatively few studies have been conducted to address the issue of how a port is selected and who selected the port given the conflicting interests of multiple-stakeholders (i.e., port authority, carriers, and shippers). Some of the prior works on transshipment port selection include studies performed by Lim (2003, 2004), Ng (2006), and Park and Sung (2008). All of these studies built upon the findings of earlier pioneering studies (Bardi, 1973; Willingale, 1981; Murphy et al., 1992; and Malchow and Kanafani, 2001) on generic port selection which attempted to identify key determinants for port selection from the perspectives of multiple stakeholders. The following subsections elaborate on the key objectives, findings, and methodologies of these prior studies.

Generic Port Selection

Earlier studies on port selection were primarily concerned with the identification of port selection criteria/factors using empirical surveys of carriers and/or shippers. Examples of these studies include Willingale (1981), Branch (1986), Browne et al. (1989), and Murphy et al. (1988, 1989). They identified port infrastructure, cargo safety, port service quality, and port charges as the key influencing factors for port selection. Following up on these studies, Murphy et al. (1992), Hayuth (1995), Thomas (1998), and Villalon (1998) continued to examine which factors significantly affect port selection. In particular, they examined whether socio-political stability, geographical location, and cargo (including bulk cargo and odd-sized cargo) handling capability affect port selection decisions. Their findings indicated that port services, lead time (including loading/unloading time), equipment availability, and information technology support were considered most important for selecting a port. These exploratory studies, however, are not designed to analyze trade-offs among a host of conflicting factors and help the policy/decision maker to choose the best available port among alternative ports.

To overcome such an inherent shortcoming of exploratory studies based on survey questionnaires, a series of fairly recent studies on port selection proposed mathematical techniques. One of the most popular techniques is an analytic hierarchy process (AHP) which is helpful for selecting the best available port among a set of alternatives with various pros and cons. Examples of the studies which used AHP for port selection include Brooks (2000), Cullinance and Toy (2000), Song and Yeo (2004), Kim (2005), Guy and Urli (2006), and Lee et al. (2007). To summarize, these earlier studies on port selection revealed that port infrastructure, port capacity, port service quality, port charges, information technology support, and geographical location are key influencing factors, although their perceived relative importance may differ from one stakeholder to another (see Table 1). It is also noted that, with the increasing automation of port handling processes and electronic transmission of port-related data, the information technology capability of a port seems to have gained more importance for port selection.

Transshipment Port Selection

Generally, ports are points of convergence between two domains of freight circulation; the *land* and *maritime* domains. In a broad sense, key roles of the port include the provision of: (1) *maritime access* to navigational waters, (2) *maritime interface* to support maritime access through

TABLE 1
A SUMMARY OF THE SELECTED PORT LITERATURE

Problem scope		Author (year of publication)	Survey respondents or methodologies	Key determinants
Transshipment port selection		Lim et al. (2003, 2004)	Experts and carriers	Port/freight charge, port infrastructure, geographical location
		Ng (2006)	Carriers	
		Park & Sung (2008)	Carriers and port authorities	
Generic port selection	1980's	Willingale (1981)	Carriers	Port facility, docking frequency, port safety, port service, port/freight charge,
		Branch (1986)	Literature reviews	
		Browne et al. (1989)	Literature reviews	
		Murphy et al. (1988, 1989)	Carriers and port authorities	
	1990's	Murphy et al. (1992)	Carriers, shippers, forwarders, port authorities	Port service, lead time, equipment availability, shipment information technology
		Hayuth (1995)	Literature reviews	
		Thomas (1998)	Literature reviews	
		Villalon (1998)	Carriers	
	21st	Cullinane and Toy (2000)	Literature reviews	Port location, port/freight charge, port size, port facility, port management
		Brooks (2000)	Literature reviews	
		Song and Yeo (2004)	Experts	
		Kim (2005)	Carriers	
		Guy and Urli (2006)	Literature reviews	
		Lee et al (2007)	Carriers and shippers	

dedicated space (capacity), (3) *infrastructure* (e.g., piers, basins, stacking or storage areas, warehouses, terminals) and *equipment* (e.g., cranes), and (4) *land access* to inland transportation (e.g., rail, trcusk) (Rodrigue et al., 2009). In addition, one of the emerging roles of the large ports includes the transshipment of cargoes from one port to another. A port that plays the role of a transshipment point is often considered a hub port where cargoes are either consolidated or break-bulked for a final leg of the journey (Min and Guo, 2004). In this type of port, a multiple array of commodities including dry or liquid bulks are handled with a link to a wide variety of transportation modes and containers. Examples of well-known transshipment ports are: Rotterdam, Netherlands; Singapore; Hong Kong; Shanghai, China; Kaoshung, Taiwan; Busan, Korea; Yokohama, Japan. Although factors influencing transshipment ports may be similar to those affecting typical ports, a transshipment port selection decision is more complex than a generic port selection decision due to its expanded roles. Recongnizing such added complexity, Lirn et al. (2003, 2004), Ng (2006) and Park and Sung (2008) initiated studies focusing on transshipment port selection from the perspectives of either carriers or port authorities as recapitulated in Table 1.

To elaborate, Lirn et al (2003) identified a total of 47 factors affecting a choice of Taiwan's transshipment ports using two rounds of "Delphi" surveys of port experts. Among these, they discovered that geographical location was the most important determinant for transshipment port selection. They also proposed an AHP model for final selection of the most desirable port. A year later, Lirn et al. (2004) extended their study to include transshipment ports across the globe. They found that both geographical location and port charges were two dominant factors for transshipment port selection. Built upon the earlier studies of Lirn et al. (2003, 2004), Ng (2006) identified 46 different factors influencing transshipment port selection using a survey questionnaire. Among these, he observed that lead time turned out to be most important factor. More recently, Park and Sung (2008) further extended these earlier works by soliciting feedback from multiple stakeholders including the port authority for identifying transshipment port selection criteria in Far Eastern countries. Their study revealed that port/freight charges and the subsequent port operating expenses were considered most important for transshipment port selection.

As the review of this prior literature reveals, the perception of key factors, and their relative importance, seems to vary from one study to another due in part to the conflicting interests of multiple stakeholders. This indicates that a majority of the prior studies summarized in Table 1 failed to reflect the differing views of multiple stakeholders such as carriers, port authorities, shippers, port operating companies, and forwarders. To overcome this drawback, the current study attempts to solicit feedback from both carriers and port operators (port authorities/ operating companies) and identify differences in their perception of key determinants and their relative importance. Also, none of the prior studies measures the extent of influence of port selection determinants on a port selection decision relative to other determinants. Thus, this paper attempts to not only identify key determinants of transshipment port selection, but also evaluates the extent of contribution of each determinant to a port selection decision. In other words, this paper helps port policy makers understand how carriers arrive at the final port selection decision in the presence of multiple port selection determinants and alternative ports.

RESEARCH METHODOLOGY

The primary database for this study came from a survey questinnaure of both carriers (e.g., ocean carriers) and port operators (e.g., container operating companies, port authorities). A sample of carriers were targeted as survey respondents from a list of the top 30 carriers designated by *Containerization International* 2009 and 2010 as well as other major carriers serving shippers globally. Also, a sample of 50 carriers and 30 port operators in Far-East Asia were targeted for a survey. During the period of March 2009 through June 2009, the questionnaire was sent to this sample of carriers and port operators. Since the initial survey produced a total of only 20 valid responses, a second wave of questionnaires was sent to these target respondents with a reminder during the periods of December 2009 and February of 2010. Overall, 39 valid responses from the carriers and 9 valid responses from port operators were received. These responses represent a 78% response rate for the carriers and a 30% response rate for the port operators. Comparing early and late responses, a non-reponse bias error was checked for but no such error was found.

Based on these survey results and a review of prior literature, we identified a total of 46 different factors which may influence a transshipment port selection decision. These fators are summarized in Table 2. Since the simultaneous consideration of all of these factors can overwhelm the decision maker and some of these factors may be redundant with each other, we broke down these factors into 13 different categories and then these categores were aggregated into four distinctive groups: (1) port infrastrucre; (2) port location; (3) port management; and (4) carrier operating expenses as summarized in Table 3. The grouping of these factors was based on Lirn et al. and input from a panel of experts comprised of three university professors in the maritime logistics fields, three port administrators in the Ports of Busan and Gwangyang, and five executives representing liner shipping companies.

These grouped factors were re-organized as a hierarchical structure shown in Figure 1 for an application of analytical hierarchy process (AHP) techniques. AHP is a systematic scoring method that was designed to synthesize the perceived degree of importance of each port selection criterion/category into an overall evaluation of each candidate port with respect to such a criterion/category (see Saaty, 1980 for the conceptual foundation of AHP). Accordingly, AHP helps the carrier assess the strengths and weaknesses of candidate ports relative to competiting ports, but also helps the carrier identify the most viable alternative port in the port selection process. Furthermore, AHP can enhance the carrier's ability to make tradeoffs among various quantitative (port charges, container handling cost, ship turnaround time, a proximity/distance to a feeder port, quick response time) and qualitative port selection categories (port service quality, port security, cargo safety) for port selection (Saaty, 1988; Min and Min, 1996). In addition, data envelopment analysis (DEA) was employed to assess the extent of contribution of each category to the port selection decision so that the most essential categories would be identified. In measuring the extent of influence of transshipment port selection categories, we chose DEA over other alternative techniques, such as Cobb Douglas functions, because DEA does not require an explicit *a priori* determination of input and output functional relationships and provides valuable insights as to comparative "influence efficiency" (extent of influence) of each port selection category relative to other categories. Generally, DEA is referred to as a linear programming (non-parametric) technique that converts multiple incommensurable inputs and outputs of each decision-making unit (DMU) into a scalar measure of operational efficiency, relative to its competing DMUs. Put simply, DEA examines the resources available to each DMU and monitors the "conversion" of these resources into desired outputs (Cook and Zhu, 2008). Herein, DMUs refer to the collection of private firms, non-profit organizations, departments, administrative units, and groups with the same (or similar) goals, functions, *standards* and market segments (Charnes et al., 1978). Though uncommon, transshipment port selection categories are considered DMUs in our study because they represent port selection *standards*. Combining the complementary traits of both AHP and DEA, the application of hybrid DEA/AHP to transshipment port selection involves four major steps:

(1) Break down the port selection process into a manageable set of criteria (e.g., four criteria in this study) and categories and

TABLE 2
A LIST OF TRANSSHIPMENT PORT SELECTION FACTORS

Factors	M(89)	M(92)	T(98)	V(98)	B(00)	C(00)	L(3,4)	S(04)	Yeo(04)	Kim(05)	G(06)	N(06)	L(07)
Water depth				o			o		o	o	o		o
Port size	o	o	o			o	o	o	o	o	o		o
Port infrastructure			o	o			o			o		o	o
Port information technology	o	o				o	o	o	o	o		o	o
Quality of port superstructure	o	o	o		o	o	o	o		o	o	o	
Inland transporation cost						o	o	o	o				o
Port access							o	o	o	o			
Port service range					o		o					o	
The size of local/regional market							o	o	o	o	o		o
Intermodal links/networks				o			o	o	o	o	o		o
Cargo handling capacity	o			o		o	o	o	o				
Container cargo rate			o				o						
Geographical location				o	o		o			o		o	
Container hub				o			o			o			
Feeder frequency					o		o						o
Routing diversity									o				o
Port competitiveness							o	o					
Access to alternate ports							o			o		o	
Access to major shipping routes					o		o	o	o	o	o		o
Short transshipment time					o		o			o	o		
Socio-political stability							o	o	o	o			o
Port organization							o	o					
Customs procedure							o		o			o	
Port policy and regulation							o		o			o	
Container handling efficiency				o			o					o	
Operational flexibility							o	o					
Port operating time	o	o	o		o	o	o	o	o				
Shipment schedule	o	o				o	o	o	o				
Port marketing									o			o	o
Cargo safety						o		o	o			o	o
Feeder service							o		o				
A length of port berthing time			o				o						o
Port productivity							o		o		o		o
Port security	o	o				o	o	o	o				
Port labor quality									o	o		o	o
Port reputation									o	o		o	o
Immediate user service									o			o	o
Supporting service									o			o	
Government support				o			o						
Port exspense	o	o	o	o	o	o	o	o		o		o	o
Free dwell time on the terminal							o		o				
Related business operations							o						
Privileged ownership contract for carriers							o					o	o
Cargo balancing													o
Alliance member's calling													o
Competitor's calling													o

Note: M(89)-Murphy et al.(1989), M(92)-Murphy et al.(1992), T(98)-Thomas(1998), V(98)-Villalon(1998), B(00)-Brooks(2000), C(00)-Cullinane & Toy(2000), L(3,4)-Lim et al.(2003,2004), S(04)-Song & Yeo (2004), Yeo(04)-Yeo et al.(2004), Kim(05)-Kim(2005), G(06)-Guy & Urli(2006), N(06)-Ng(2006), L(07)-Lee

TABLE 3
GROUPING OF TRANSSHIPMENT PORT SELECTION FACTORS

Criteria	Categories	Examples of detailed factors
Port infrastructure	Basic infrastructure	Depth space of the port,size of port and terminal(quay length, no. of berths, container yards and CFS area), container handling capacity
	Information technology infrastructure infrastructure	information system (system integration, VTS, vessel/cargo information), port EDI, port RFID
	Intermodal links	Access to inland transportation, port service coverage (e.g., pilotage, towing and mooring), rail sidings, intermodal terminal access, competitiveness and diversity of other modes,
Port location	Proximity to import/export businesses	Traffic volume and throughput, containerized cargo proportion, geographical advantage (to the manufacturer), availability of free trade zones
	Feeder service access	Frequency and network of feeder service, variety of service routes, proximity to alternative port
	Access to major shipping routes	Deviation to trunk routes, short transit time
Port management	Port management efficiency	National stability (politics, society, labor, etc.), port reputation, quality of customs handling, port authority policy and regulations, container handling efficiency (delays), port operating / working hours, reliability of berth scheduling and cargo handling, port marketing, cargo handling safety & flexibility
	Ship turn-around time	Idle time (e.g., no congestion), length of berthing time, loading/unloading time
	Port security	Port physical security (CCTV systems, fences), personal security (security guards, employee background checks), information security (privacy, hacking prevention)
	Port service quality	Quality and availability of staff, port recognition and reputation, prompt response to claim and request, Supporting services (e.g. warehousing, insurance, fresh water, fuel oil and ship's stores provision, etc.)
Carriers operating expenses	Container handling cost	State aided incentives, cost for handling & storage of containers, free dwell time
	Terminal contract cost	Related business operating expenses, privileged ownership contract for carriers
	Carriers bargaining opportunity	Cargo balancing, alliance member's calling, competitor's calling

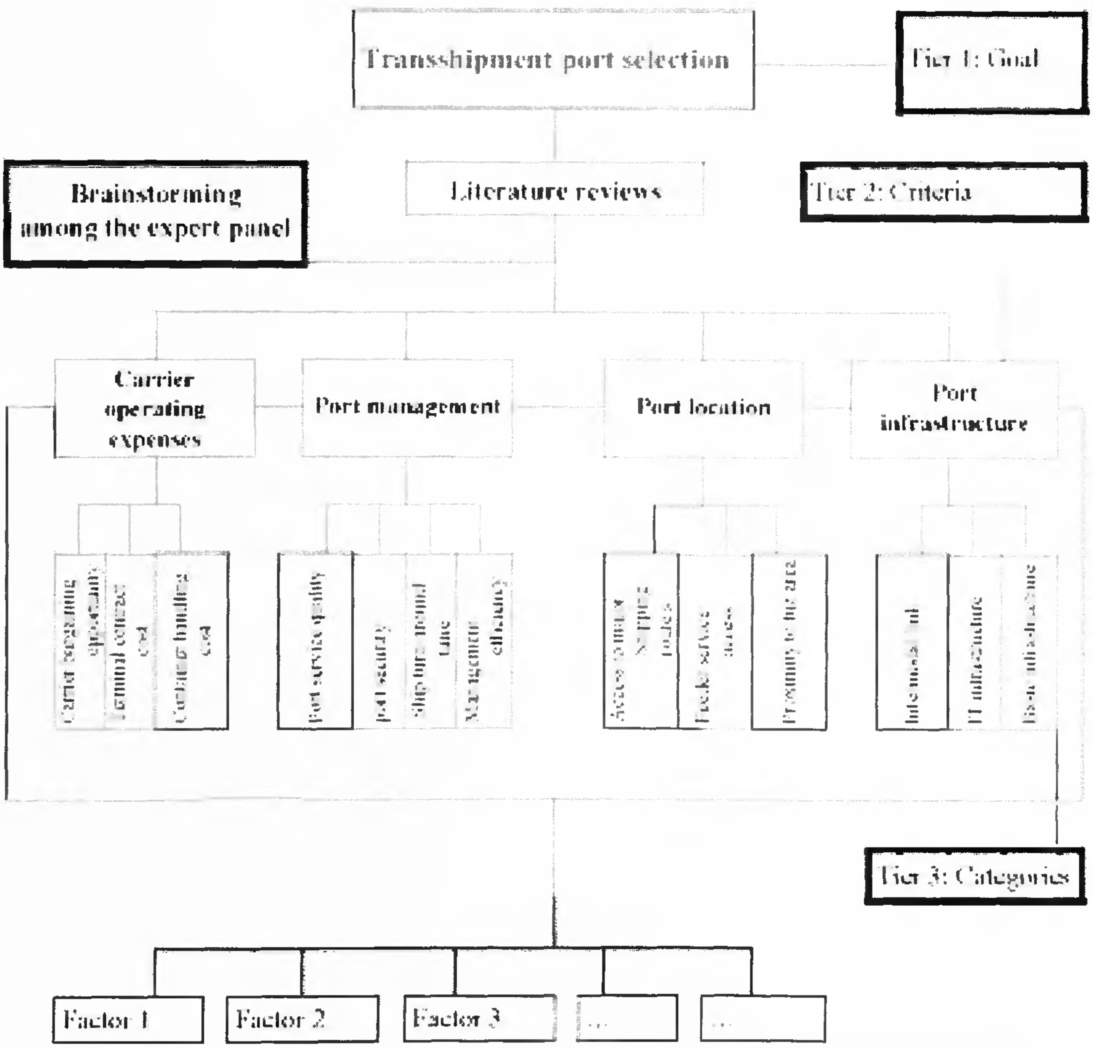
then structure these into a hierarchical form as displayed in Figure 1;

(2) Make a series of pairwise comparisons among the criteria and categories according to the survey respondent's perceived importance of each criterion and category;

(3) Estimate the relative weights of service criteria and categories based on the panel of experts' perceived importance of those criteria and categories. Also, determine the local priority scores of the respective transshipment port selection categories using AHP;

(4) Aggregate these local priority scores and synthesize them for the overall evaluation of each port selection category. Then, identify the most influencial port selection categoties among various determinants using DEA.

FIGURE 1
A HIERARCHICAL STRUCTURE OF THE TRANSSHIPMENT PORT SELECTION CRITERIA



RESULTS AND DISCUSSION

To deteremine both the carriers's and the port operators' perceived importance of transshipment port criteria and categories, their relative weights and priority scores were first calculated through a series of pairwaise comparisons made by a panel of experts and survey respondents. Using the Expert Choice program (2009), the weights and priority scores were derived. These scores, however, are not absolute measures (raw scores), but relative measures that represent the relative importance or priority of each criterion and category. Thus, pairwise comparisons were intended to derive numerical values (relative measures) from a set of experts and survey respondents' judgments, rather than arbitrarily assigning numerical values to criteria and categories. These pairwise comparisons produced relative weights of the four transshipment port selection cariteria summarized in Table 4. As shown in Table 4, port operating expenses turned out to be most important in selecting a transshipment port. Overall, the second most important cariteria is port infrastructure. However, there is a marked difference in its relative importance between the carrier and the port operator. Indeed, the port operators regarded port infrastructure as the least important criterion, whereas the carriers valued port infrastructure almost as much as port operating expenses. Especially, the port operators did not seem to fully understand how much the carriers appreciate good basic infrastructure (port size, water depth) and convenient access to intermodal links (piggybacks, rails, barges). This result indicates that port operators should invest more in the improvement of port infrastructure to attract more carriers and

TABLE 4
RELATIVE IMPORTANCE OF PORT SELECTION CRITERIA/CATEGORIES

Criteria Categories	Overall	Carriers	Port Operators
Port instratsructure	0.271	0.304	0.128
Basic infrastructure	0.384	0.381	0.417
Information tech. infra-structure	0.212	0.208	0.253
Intermodal links	0.404	0.412	0.330
Sub-total	1.000	1.000	1.000
Port location	0.240	0.231	0.275
Proximity to imp-exp. businesses	0.291	0.306	0.236
Feeder service access	0.226	0.235	0.192
Access to major shipping routes	0.483	0.459	0.572
Sub-total	1.000	1.000	1.000
Port management	0.140	0.143	0.130
Management efficiency	0.332	0.350	0.248
Ship turnaround time	0.267	0.253	0.335
Port security	0.122	0.120	0.131
Port service quality	0.279	0.277	0.286
Sub-total	1.000	1.000	1.000
Port operating expenses	0.349	0.322	0.467
Container handling cost	0.540	0.518	0.606
Terminal contract cost	0.182	0.189	0.160
Carrier bargaining opportunity	0.278	0.293	0.234
Sub-total	1.000	1.000	1.000
Total	1.000	1.000	1.000

TABLE 5
TRANSSHIPMENT PORTS UNDER EVALUATION

Port	2009		2008		Country
	1,000 TEU	Ranking	1,000 TEU	Ranking	
Shanghai	25,000	2	27,980	2	China
Hong Kong	20,980	3	24,490	3	China
Busan	11,950	5	13,180	5	Korea
Tianjin	8,700	11	8,500	14	China
Kaohsiung	8,580	12	9,680	12	Taiwan
Tokyo	3,740	26	4,160	24	Japan
Gwangyang	1,810	53	1,810	65	Korea

Source: CI Yearbook, 2010

subsequently generate more revenue. Another noticeable discrepancy between the opinions of the carriers and the port operators is the relative importance of port management efficiency. As shown in Table 4, the carriers are more concerned with port management efficiency than the port operators. However, in a competitive environment, the measure of port management efficiency should be relative rather than absolute. In other words, to properly factor port management efficiency into a port selection decision, we should compare its relative importance to that of other port selection categories. The same analolgy can be made regarding the comparative evaluation of other port selection categories. Such evaluation called for the use of DEA, since a standalone AHP is not designed to assess the comparative efficiency. Thus, there is a need to combine AHP with DEA.

For illustrative purposes, we considered seven major transshipment/hub ports in Far-East Asia: (1) Shanghai; (2) Hong Kong; (3) Busan; (4) Tianjin; (5) Kaohsiung; (6) Tokyo; (7) Gwangyang for comparative evaluation. All but Gwangyang were listed on top 30 ports in the world in terms of their cargo handling volume (see Table 5). Although Gwangyang is relatively young and unknown, it is growing rapidly thanks to heavy investment in the development of large-scale free economic zones due for completion in 2011. Therefore, we included it in the DEA evaluation.

Prior to DEA applications, we solicted the opinions of both carriers and port operators regarding their perceived importance of 13 port selection categories identified earlier. Their combined and respective opinions are summarized in Tables 6, 7, and 8. These raw data were later fed into the DEA model for comparative evaluation of these categories for port selection. With respect to all of these categories, larger and sourthen location hub ports such as Busan, Shanghai, and Hong Kong are considered more favorable whereas smaller or northern location ports such as Tianjin and Tokyo are considered less favorable. However, as shown in Tables 7 and 8, opinions between the carriers and the port operators somewhat differ in that the carriers tend to favor southern location ports whereas the port operators tend to favor larger ports.

A careful identification of inputs and outputs is critical to the successful application of DEA to any decision-making process (Yeh, 1996; Thanassoulis, 2001). Thus, the assessment of the extent of influence of port selection categories using DEA begins with the selection of appropriate input and output measures that can be aggregated into a composite index of overall performance standards. Although any resources utilized by DMU could be included as input, we selected the performance rating (1: the least favorable scale, 5: the most favorable scale) of each transshipment

TABLE 6
TRANSSHIPMENT PORT EVALUATION SCORES WITH RESPECT TO OVERALL CATEGORIES

Data	(O) Overall priority score	(I) Gwangyang	(I) Busan	(I) Tokyo	(I) Shanghai	(I) HongKong	(I) Kaohsiung	(I) Tianjin	Average
Basic infrastructure	0.104	3.4	3.8	3.4	3.9	3.9	3.2	3.1	3.5
Information tech. infrastructure	0.057	3.4	3.8	3.6	3.7	3.9	3.4	3.0	3.5
Intermodal link	0.110	2.9	4.0	3.3	3.6	3.8	3.2	3.0	3.4
Proximity to businesses	0.070	2.9	4.1	3.3	3.9	3.8	3.2	3.2	3.5
Feeder service access	0.054	2.9	4.1	3.2	3.6	3.8	3.2	2.9	3.4
Access to major shipping routes	0.116	3.1	4.1	3.3	3.8	4.0	3.5	3.0	3.5
Management efficiency	0.047	3.4	3.7	3.4	3.6	3.8	3.4	3.1	3.5
Ship turnaround time	0.037	3.3	3.8	3.3	3.6	3.8	3.4	3.0	3.5
Port security	0.017	3.6	3.8	3.8	3.6	3.8	3.5	3.2	3.6
Port service quality	0.039	3.4	3.8	3.5	3.6	4.0	3.5	3.1	3.6
Container handling cost	0.189	3.7	3.6	2.8	3.7	3.3	3.2	3.4	3.4
Terminal contract cost	0.063	3.2	3.4	3.1	3.7	3.5	3.3	3.0	3.3
Carrier bargaining opportunity	0.097	3.0	3.7	3.1	3.9	3.9	3.2	3.1	3.4
Port evaluation score	Average	3.26	3.84	3.22	3.74	3.73	3.28	3.11	3.45
	Ranking	5	1	6	3	2	4	7	

TABLE 7
THE TRANSSHIPMENT PORT EVALUATION SCORE WITH RESPECT TO CATEGORIES
(CARRIER'S OPINIONS)

Data	(O) Carriers	(I) Gwangyang	(I) Busan	(I) Tokyo	(I) Shanghai	(I) HongKong	(I) Kaohsiung	(I) Tianjin	Average
Basic infrastructure	0.116	3.5	3.8	3.3	3.9	3.9	3.1	3.0	3.5
Information tech. infrastructure	0.063	3.5	3.8	3.5	3.6	3.8	3.3	3.0	3.5
Intermodal link	0.125	3.1	3.9	3.3	3.5	3.7	3.2	2.9	3.4
Proximity to businesses	0.071	3.1	4.1	3.1	3.7	3.7	3.1	3.2	3.4
Feeder service access	0.054	3.1	4.2	3.2	3.6	3.7	3.1	2.8	3.4
Access to major shipping routes	0.106	3.1	4.1	3.2	3.7	3.9	3.3	3.0	3.5
Management efficiency	0.050	3.5	3.7	3.4	3.6	3.7	3.2	2.9	3.4
Ship turnaround time	0.036	3.4	3.9	3.3	3.6	3.8	3.3	2.9	3.5
Port security	0.017	3.6	3.7	3.7	3.4	3.7	3.4	3.0	3.5
Port service quality	0.040	3.6	3.7	3.5	3.4	3.9	3.4	3.0	3.5
Container handling cost	0.167	3.7	3.7	2.8	3.6	3.4	3.1	3.3	3.4
Terminal contract cost	0.061	3.3	3.4	3.0	3.5	3.4	3.2	3.0	3.2
Carrier bargaining opportunity	0.094	3.1	3.8	3.1	3.9	3.8	3.1	3.1	3.4
Port evaluation score	Average	3.33	3.84	3.18	3.65	3.71	3.18	3.04	3.42
	Ranking	4	1	6	3	2	5	7	

TABLE 8
THE TRANSSHIPMENT PORT EVALUATION SCORE WITH RESPECT TO CATEGORIES
(OPERATOR'S OPINION)

Data	(O) Operators	(I) Gwangyang	(I) Busan	(I) Tokyo	(I) Shanghai	(I) HongKong	(I) Kaohsiung	(I) Tianjin	Average
Basic infrastructure	0.053	3.1	3.8	3.6	4.0	3.8	3.4	3.6	3.6
Information tech. infrastructure	0.032	3.0	3.9	3.6	4.3	4.3	3.5	3.1	3.7
Intermodal link	0.042	2.1	4.5	3.6	4.0	3.9	3.3	3.5	3.6
Proximity to businesses	0.065	2.3	4.4	3.9	4.6	4.1	3.8	3.5	3.8
Feeder service access	0.053	1.9	4.1	3.3	4.0	4.0	3.8	3.3	3.5
Access to major shipping routes	0.157	3.3	4.4	3.6	4.0	4.5	4.3	3.0	3.9
Management efficiency	0.032	2.8	3.4	3.4	4.0	4.0	4.1	3.5	3.6
Ship turnaround time	0.044	2.9	3.5	3.5	3.6	3.8	4.3	3.5	3.6
Port security	0.017	3.6	4.1	4.1	4.1	3.9	4.0	3.8	3.9
Port service quality	0.037	2.9	4.0	3.5	4.6	4.4	3.9	3.6	3.8
Container handling cost	0.283	3.9	3.3	3.0	3.9	3.0	3.8	3.8	3.5
Terminal contract cost	0.075	3.0	3.5	3.3	4.4	4.0	3.6	3.4	3.6
Carrier bargaining opportunity	0.109	2.4	3.4	3.5	4.1	4.0	3.5	3.1	3.4
Port evaluation score	Average	3.07	3.74	3.39	4.06	3.79	3.79	3.43	3.61
	Ranking	7	4	6	1	2	3	5	

Note 1: Likert scale of 1: Least favorable, 5: Most favorable
Note 2: Port evaluation score = Perceived importance of category × Port performance rating

Note 3: (O) Operators = Operators' priority scores based on AHP port as input. Since the port performance rating with respect to each port selection category reflects the port efficiency and subsequently increases the chance of a particular port being selected, it can be regarded as input. Given seven different ports to evaluate, there were a total of seven inputs. On the output side, the overall performance of the port can be measured by its diverse service offerings weighed by each port selection category. Thus, the priority score of each port selection category was used as the output. As indicated earlier, this priority score ranging from a small fractional value to a maximum of 1.0 was generated by AHP. By calculating a ratio of the priority score of each port selection category to each port performance rating relative to other priority scores, an estimate of the extent of contribution of each port selection category to port attractiveness and the subsequent port selection can be developed.

Overall, nine different port selection categories that affected the port selection decision "significantly" (using the threshold value of 95% for a DEA model with varying returns to scale - BCC) were found. As shown in Table 9, these categories are: (1) basic port infrastructure; (2) intermodal links; (3) feeder service access; (4) access to major shipping routes; (5) ship turnaround time; (6) port security; (7) container handling cost; (8) terminal contract cost; and (9) carrier bargaining opportunity. Among these, four categories (intermodal links, a proximity to major shipping routes, container handling cost, and carrier bargaining opportunity) are considered primary port selection factors with 100% DEA scores ("full" efficiency"), while five others (basic port infrastructure, feeder service access, ship turnaround time, port security, and terminal contract cost) are considered secondary port selection factors with less than 100% DEA scores. However, the results differ somewhat in that the carriers' port selection decision was affected by ten different categories including the port's proximity to import/export businesses, whereas the operators factored nine categories into the port selection decision. The most striking differences in the extent of impact of categories on port selection happen to be the port's proximity to businesses involved in import/export activities (carriers' 99.98% versus operators' 67.63%), port security (carriers' 99.66% versus operators' 6.70%), port service quality (carriers' 99.72% versus operators' 22.14%), and port management

TABLE 9
SUMMARY OF FINAL DEA RESULTS

	Overall		Carriers		Operators	
	CCR	BCC	CCR	BCC	CCR	BCC
Basic infrastructure	60.04%	99.98%	76.55%	100.00%	23.39%	99.94%
Information technology infrastructure	34.36%	68.49%	42.10%	53.27%	14.78%	29.63%
Intermodal link	73.25%	100.00%	87.93%	100.00%	27.22%	99.98%
Proximity to businesses	47.20%	99.93%	50.99%	99.98%	39.50%	67.63%
Feeder service access	37.25%	99.98%	38.82%	99.98%	38.56%	100.00%
Access to major shipping routes	73.28%	100.00%	76.02%	100.00%	69.48%	100.00%
Management efficiency	27.31%	57.47%	33.35%	49.24%	16.05%	98.31%
Ship turnaround time	22.33%	99.83%	24.63%	99.79%	20.74%	99.96%
Port security	9.69%	99.64%	11.17%	99.66%	6.43%	6.70%
Port service quality	22.50%	33.97%	26.07%	99.92%	17.71%	22.14%
Container handling cost	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Terminal contract cost	38.85%	38.85%	41.06%	99.98%	34.10%	99.70%
Carrier bargaining opportunity	63.97%	63.97%	66.36%	100.00%	63.00%	100.00%

efficiency (carriers' 49.24% versus operators' 98.31%). These discrepancies illustrate significant gaps between the opinions of carriers and that of operators in the perceived importance and the extent of influence of port selection categories. From a port policy standpoint, these gaps may be the sources of port failure in attracting more carriers to a particular port.

CONCLUSSIONS AND MANAGERIAL IMPLICATIONS

In increasingly fierce port competition, port attractiveness is playing a pivotal role in sustaining the competitiveness of transshipment ports serving carriers (liner ships) all across the world. Also, from a carrier's viewpoint, the selection of a particular transshipment port has a long-lasting impact on its global supply chain links and subsequent supply chain efficiency. Thus, port attractiveness and selection are intricately interwoven. The common premise is that port operating cost single-handedly dictates the port attractiveness and subsequently becomes a dominant factor for influencing the carrier's port selection decision. Although cost turned out to be one of the most influential factors for port selection according to many prior studies and this study, it is not the only one significantly influencing the carrier's port selection decision. To identify other factors for port selection, we conducted a three-stage research process involving (1) an empirical study based on a survey identifying a host of port selection factors; (2) an AHP model determing the relative weights (importances) of port selection factors; (3) and a DEA model assessing the extent of contribution of each factor to port selection. Unlike prior studies that focused on the identification of port selection factors, this study not only identified port selection factors, but also assesses the extent of influence of those factors on port attractiveness and the subsequent port selection decision. In other words, this paper is one of the first to propose a hybrid DEA/AHP model that is useful for evaluating the extent of impact of each port selection factor. From a practical standpoint, some findings of this study are noteworthy.

First, port operating cost such as container handling cost is not the only factor which significantly influences port selection. That is to say, the port authority's attempt to offer volume discounts and monetary incentives alone may not increase port attractiveness. As observed by Bennathan and Walters (1979), non-monetary qualitative factors such as intermodal links and feeder service access could play a significant role in increasing port attractiveness.

Second, we found substantial discrepancies in the perceived importance of some port selection factors such as a port's proximity to import/export businesses, port service quality, port security, and port management efficiency between the carriers (port users) and the operators (port service providers). Disregarding these discrepancies may have contributed to the failure of port strategy to attract more liner ships to a particular port. In particular, it is somewhat surprising to find that the port operators (authority) tended to overlook the growing importance of port security to the carriers' port selection decision in the wake of 9/11 events. Also, the port operators did not seem to take port service quality and the port's proximity to import/export businesses as seriously as their customers (carriers). On the other hand, the port operators tended to think that port management efficiency would attract carriers to their port, whereas the carriers did not consider it to be a major factor for choosing their port. As such, the port operators need to change their port policy and strategy in accordance with changing preferences of the carriers.

Finally, despite the increasing use of advanced information technology such as RFID and EDI among carriers and port operators, neither carriers nor port operators regarded information technology infrastructure as an essential element for port selection. The possible explanation for this tendency is that information technology infrastructure is almost considered a necessity for every port and thus may not be considered a differentiator.

To summarize, this paper intended to help carriers develop a wise port selection strategy, while aiding port operators in formulating more user-friendly and effective port competitive strategy using novel hybrid DEA/AHP techniques. Despite its merits, this paper has some limitations. These limitations include the consideration of seven transshipment ports located in the Far East Asian region only. Also, this study is confined to a cross-sectional study targeting both carriers and port operators. Appropriate platforms for further research include:

- Consideration of other major hub ports in Europe and North American regions and comparisons of these ports in terms of their attractiveness and competitiveness;
- Extension of the current study to include shippers' perspectives;
- Development of multi-year databases for a longitudinal study with a DEA window analysis.

Acknowledgments
The authors wish to thank the Korea Ocean Research & Development Institute (KORDI) for partly funding this research project. In particular, the authors would like to express sincere gratitude to the President of KORDI, Dr. Jeung-Keuck Kang; Director General of the Maritime & Ocean Research Institute (MOERI), Dr. Yong-Kon Lim; and the KORDI Researcher, Dr. Jong-Won Park for their continuous support and encouragement throughout this research project.

REFERENCES

Bardi, E.J. (1973), "Carrier Selection From One mode," *Transportation Journal*, 13(1): 23–29.

Bennathan, E. and A.A. Walters (1979), *Port Pricing and Investment Policy for Developing Countries*, Oxford, Great Britain, Oxford University Press.

Branch, A.E. (1986), *Elements of Port Operation and Management*, London, Great Britain: Champman & Hall.

Brooks, M. (2000), *Sea Change in Liner Shipping - Regulation and Managerial Decision-Making in a Global Industry*, Oxford, England: Elsevier Science.

Browne, M., Doganis, R. and S. Bergstrand (1989), *Transhipment of UK Trade*, London, Great Britain: British Ports Federation.

Charnes, A., Cooper W. W., and E. Rhodes (1978), "Measuring the Efficiency of Decision Making Units," *European Journal of Operational Research*, 2: 429-444.

Chang, Y-T, Lee, S-Y and J. L. Tongzon (2008), "Port Selection Factors in Shipping Lines: Different Perspectives Between Trunk Liners and Feeder Service Providers," *Maritime Policy*, 32: 877-885.

Cook, W.D. and J. Zhu (2008), "*Data Envelopment Analysis: Modeling Operational Processes and Measuring Productivity*," Lexington, KY, www.deafrontier.com/deatext.

Cullinane, K. and N. Toy (2000), "Identifying Influential Attributes in Freight Route/Mode Choice Decisions: A Content Analysis," *Transportation Research Part E: Logistics and Transportation Review*, 36(1): 41-53.

DredgingToday.Com (2010), "*2nd Annual China Port Expansion and Efficiency Summit,*" http://www.dredgingtoday.com/2010/06/16/2nd-annual-china-port-expansion-and-efficiency-summit/, (June 16, 2010), retrieved on October 12, 2010.

Expert Choice (2009), *Advanced Decision Support Software*, Pittsburgh, PA: Expert Choice, Inc.

Guy, E. and B. Urli (2006), "Port Selection and Multicriteria Analysis: An Application to the Montreal-New York Alternative," *Maritime Economics & Logistics*, 8: 169-186.

Hayuth, Y. (1995), "Container Traffic in Ocean Shipping Policy," *Proceedings of International Conference 'Ports for Europe' Conference*, Europacollege, Zeehaven Brugge, November 23-24.

Kim, Y. (2005), *A Model of Container Carriers' Port Selection*, Unpublished Doctorial Dissertation, Korea Maritime University.

Lee, S. Y., Chang Y. T. and P.T.W. Lee (2007), "Determinants of Port Selection: Heterogeneity among Major Market Players," *International Conference on Logistics, Shipping and Port Management*, Taiwan.

Lirn, T. C., Thanopoulou, H. A., and A.K.C. Beresford (2003), "Transshipment Port Selection and Decision-Making Behavior: Analysing the Taiwanese Case," *International Journal of Logistics: Research and Application*, 6(4): 229-244.

Lirn, T. C., Thanopoulou, H. A., and A.K.C. Beresford (2004), "An Application of AHP on Transshipment Port Selection: A Global Perspective," *Maritime Economics & Logistics*, 6(1): 70-91.

Malchow, M. and A. Kanafani (2001), "A Disaggregate Analysis of Factors Influencing a Port's Attractiveness," *Maritime Policy & Management*, 28(3): 361–373.

Min, H. and Z. Guo (2004), "The Location of Hub-Seaports in the Global Supply Chain Network Using a Corporate Competition Strategy," *International Journal of Integrated Supply Management*, 1(1): 51-63.

Min, H. and H. Min (1996), "Competitive Benchmarking of Korean Luxury Hotels Using the Analytic Hierarchy Process and Competitive Gap Analysis," *Journal of Services Marketing*, 10(3): 58-72.

Murphy, P. R., Dalenberg, D. R., and J.M. Daley (1988), "A Contemporary Perspective of International Port Operations," *Transportation Journal*, 28(2): 23-32.

Murphy, P. R., Dalenberg, D. R., and J.M. Daley (1989), "Assessing International Port Operations," *International Journal of Physical Distribution and Materials Management*, 19(9): 3-10.

Murphy, P. R., Daley, J. M. and D. R. Dalenberg (1992), "Port Selection Criteria: An Application of A Transportation Research Framework," *Transportation Research Part E: Logistics and Transportation Review*, 28(3): 237-255.

Ng, K. Y. A. (2006), "Assessing the Attractiveness of Ports in the North European Container Transshipment Market: An Agenda for Future Research in Port Competition," *Maritime Economics & Logistics*, 8: 234-250.

Park, B. and S. Sung (2008), The Decision Criteria on the Transshipment Container Ports," *Journal of Korea Port Economic Association*, 24(1): 41-60.

Rodrigue, J-P, Comtois, C. and B. Slack (2009), *The Geography of Transportation Systems*, 2nd edition, London, United Kingdom: Routledge.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, (1980), New York, NY: McGraw-Hill.

Saaty, T.L. (1988), *Decision Making for Leaders*, Pittsburgh, Pennsylvania: RWS Publications.

Song, D.W. and K.T. Yeo (2004), "A Competitive Analysis of Chinese Container Ports Using the Analytic Hierarchy Process," *Maritime Economics & Logistics*, 6(1): 34-52.

Thanassoulis, E. (2001), *Introduction to the Theory and Application of Data Enevlopment Analysis: a Foundation Text with Integrated Software*, Norwell, MA, Kluwer Academic Publishers.

Thomas, B.J. (1998), "Structure Changes in the Maritime Industry's Impact on the Inter-Port Competition in Container Trade," *Proceedings of the International Conference on Shipping Development and Port Management*, Kaohsiung, March 26-29.

Toth, D. (2009), *"Maritime Piracy and the Devastating Impact on Global Shipping,"* http://www.examiner.com/x-18100-Pittsburgh-Foreign-Policy-Examiner~y2009m7d31-Maritime-piracy-and-the-devastating-impact-on-global-shipping, retrieved on October 22, 2009.

Villalon, W. (1998), "Smarter Beats Bigger, World Economic Development Congress," Transportation Infrastructure Summit, excerpted and edited by *the Journal of Commerce* (hppt://www.containtheport.com/contain/info/jocv.htm), retrieved on December 8, 2010.

Willingale, M. C. (1981), "The Port Routing Behavior of Short Sea Ship Operators: Theory and Practice," *Maritime Policy and Management*, 8: 109-120.

Yeh, Q. (1996), "The Application of Data Envelopment Analysis in Conjunction with Financial Ratios for Bank Performance Evaluation," *Journal of Operational Research Society*, 47: 980-988.

AUTHOR BIOGRAPHIRS

Byung-In Park is a Professor in the Department of Logistics and Transportation at Chonnam National University in Yeosu, Chonnam, Korea. E-mail: byungin.park@gmail.com

Hokey Min is the James R. Good Chair in Global Supply Chain Strategy and Research Director of the Supply Chain Management Institute. He is in the Department of Management, College of Business Administration Bowling Green State University in Bowling Green, Ohio. E-mail: *hmin@bgsu.edu*