Efficiency Analysis of Major Container Ports in Asia: Using DEA and Shannon's Entropy

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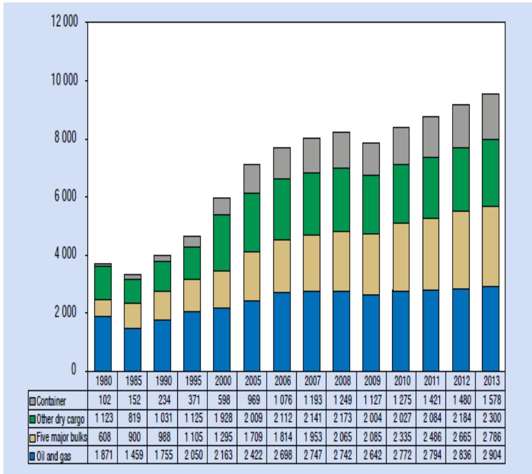
***Abstract*— This paper attempts to evaluate performance (i.e. efficiency) of Asia's container ports. Measurement of the port's performance is critical to increase the competitiveness of maritime transport, ultimately leading to one nation's competitive advantages over other countries. Data Envelopment Analysis (DEA), a non-parametric method widely used for assessing efficiency of units which have similar characteristics, was selected to analyze the data. Due to the limitations of the DEA method producing diverse results according to different models, and to the complexities of choosing a specific model among several DEA models, Shannon's Entropy was also employed. By including Shannon's Entropy, the efficiency results calculated from each model were integrated in order to rank the ports. This study contributes to our understanding of port efficiency by solving the difficulties to choose the suitable DEA models and provides port managers with valuable information to recognize the current status of Asia's container ports in terms of their efficiency.**

Keywords*—*Efficiency, DEA, Shannon's Entropy, Performance Measurement, Port, Asia

1. Introduction

International seaborne trade plays a key role in the economic development of a country, and it is diversified according to the patterns of trade as well as the size and the features of the cargoes. According to Ref. [1], the volume of international seaborne trade was increased at an estimated 4.3 percent in 2012. This trend was determined to be driven by the increased intra-Asian and South-South trade and by a growth in China's domestic demand. In particular, growth in volume of containerized trade (TEUs) in 2012 has slowed to 3.2 percent. This is significant reduction as compared to 13.1 percent in 2010 and 7.1 percent in 2011, as seen in Figure 1. This was primarily due to the decline in Europe's import demand as well as the consequent export volumes in Asia. In regards to region for both loading and unloading cargoes, Figure 2 illustrates Asia as being the most dominated area, followed by the Americas, Europe, Oceania and Africa on the loading side. For unloading, Europe, the Americas, Africa and Oceania are followed in descending order.



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Container	102	152	234	371	598	969	1 076	1 193	1 249	1 127	1 275	1 421	1 480	1 578
Other dry cargo	1 123	819	1 031	1 125	1 928	2 009	2 112	2 141	2 173	2 004	2 027	2 084	2 184	2 300
Five major bulks	608	900	988	1 105	1 295	1 709	1 814	1 953	2 065	2 085	2 335	2 486	2 665	2 786
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 836	2 904

Figure 1. International Seaborne Trade, Selected Years (Millions of tons loaded)

Source: Ref. [1]

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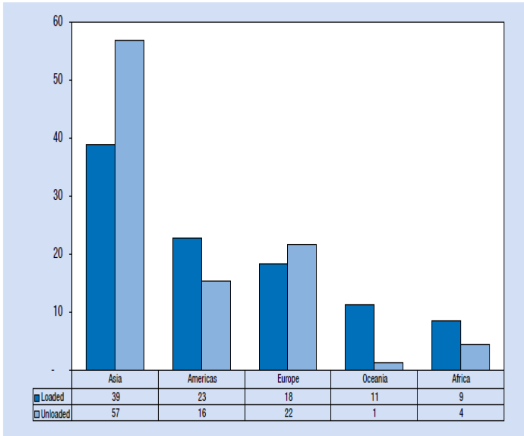
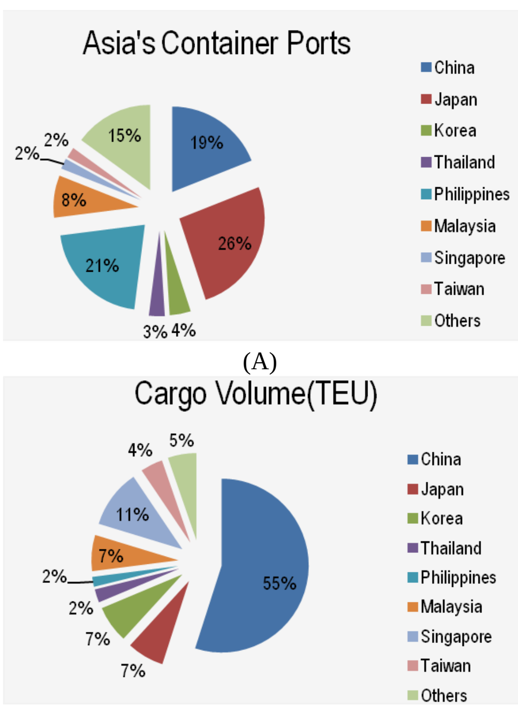


Figure 2. World Seaborne Trade, by Geographical Region (2012) (Percentage share in world tonnage)
Source: Ref. [1]

Regarding goods loaded in ports, around 9.2 billion tons were handled worldwide. Asia's container ports account for around 20% of the world container ports in 2012, showing that they handled 48% of the total volume of cargo. In particular, China managed 19% of Asia's container ports, accounting for around 55% of the total volume of cargo in Asia. Korea managed 4% and Japan managed 26% of the world container ports, accounting for 7% of the total volume of cargo, respectively (Figure 3).



(A)

(B)

Figure 3. Asia's Port Overview
Source: Ref. [14]

In addition, China handles almost 8 million TEUs on average, indicating that their volumes treated are twice as large as Asia's average of container volumes as illustrated in Table 1.

Table 1. Overview of Asian Ports

Country	Ports	Average TEU
China	19	7,774,961
Japan	26	709,367
Korea	4	4,628,882
Thailand	3	2,216,177
Philippines	21	235,513
Malaysia	8	2,256,058
Singapore	2	14,589,250
Taiwan	2	5,572,054
Others	15	948,541
Total	100	4,325,645

Source: Ref. [14]

As a crucial link in the whole trading chain inside a country as well as in the world, a port plays a pivotal role in supporting seaborne trade. The efficient flow of cargoes at ports is emphasized to improve not only ports, but also a nation's competitiveness in the world [2]. Technical innovation and the changes in the organization of ports have significantly affected the efficiency of ports' operations [3]. Therefore, during the last two decades there has been a growing interest in measuring performance of ports [4], [5]. Comparing overall performance between ports produces essential information which helps to reform the process and improve infrastructure of ports.

Data Envelopment Analysis (DEA), a non-parametric method, has been widely applied in order to assess the relative performance of organizational units, where manifold performance units are present, and which the measures have similar features. However, there exist several different DEA models which produce different results. Hence, the choice of the best model for assessing the efficiency of units is the main question in DEA application. To overcome this complexity, Shannon's Entropy can be applied for combining all the efficiency results of different DEA models in order to rank the units. This study, by employing DEA with Shannon's Entropy, aims to measure the overall efficiency of 21 container ports located in Asia (i.e., East, South-East and North-East Asia) whose volumes are more than a million TEU among the top 100 container ports in the world in 2011. The results of this research will provide useful information to assist managers' decision making for operational improvement of ports by referencing the practices used in efficient terminals.

This paper is organized as follows. Section 2 discusses the related prior studies which have influenced this research. Section 3 provides the findings of data analysis, and Section 4 concludes this study.

2. Literature Review

According to Ref. [6], since 2000, sixteen studies were found to measure port efficiency utilizing DEA. For instance, Ref. [2] undertook an empirical study with the aim of evaluating the relative efficiency of four major ports in Australia, in addition to twelve international container ports. By analyzing sample ports with two outputs including throughputs and ship working rate, and four inputs such as capital, labor, delay and land, it was identified that the ports of Melbourne, Rotterdam, Yokohama and Osaka are the least efficient ports. Ref. [7] used DEA in order to assess the total productivity of eleven Portuguese ports assisted by capital between 1990 and 2000, which divided factors into technical efficiency and technological change. It was suggested that only improvements in technical efficiency were identified in almost all ports, while no technological change was determined. Notably, the study concluded that there was no significant impact of monetary contribution by revealing that small ports are more efficient. Ref. [8] attempted to evaluate the technical efficiency of 57 container ports by comparing DEA and Stochastic Frontier Analysis (SFA) with five input variables related to land and equipment, and with one output variable, throughput. Similar results regarding the port ranking based on the estimation were discovered in two different ways. In line with Ref. [7], small ports were identified to be more efficient in terms of scale. By analyzing the relative efficiency of operations in container terminals from three Mercosur countries, Ref. [9] demonstrated that 75% of the terminals achieved 100% efficiency in 2002, while this ratio had decreased to 65% in 2004.

Furthermore, Shannon's Entropy has been combined with DEA so as to rank the DMUs [10], [11], [12] and [13]. For instance, Ref. [13] aggregated and determined the ultimate cross-efficiency scores for DMUs by taking into consideration of the concept of Shannon's entropy. Shannon's Entropy is a general concept which corresponds to the uncertainty in a proposition. The following 4 steps are needed to be taken for combining DEA and Shannon's entropy: 1) Normalization; 2) Certainty value calculation; 3) Determining uncertainty value; and 4) Determining significance degree.

1) $$\overline{E_{ij}} = \frac{E_{ij}}{\sum_{i=1}^{n} E_{ij}} \qquad i=1,2\cdots,n\,;\; j=1,2\cdots m$$

2) $$e_j = -k\sum_{i=1}^{n} \overline{E_{ij}} ln \overline{E_{ij}} \qquad i=1,2,\cdots,n\,;\; j=1,2,\cdots,m$$

$$k = \left(\frac{1}{l_n n}\right)$$

3) $$d_j = 1 - e_j \qquad j=1,2,\cdots,m$$

4) $$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \qquad j=1,2,\cdots,m$$

This process is useful as various models of DEA suggest different rankings. Consequently, it is complicated to choose the best approach and to combine methods from such models in ranking units [11].

3. Empirical Analysis

3.1 Data and Method

Of the world's top 100 container ports which handled volumes of over one million TEU in 2011, twenty one ports were selected for the analysis. Three ports in China, which met the criteria of this study, namely, Lianyungang, Taicang and Yingkou were excluded due to the difficulties of data collection. Ref. [14] was used to obtain the details of data, including the ports' ranking as well as their cargo volumes.

Container cargo volumes were employed as an output variable to evaluate port efficiency. For input variables, three infrastructure factors related to ports including length of berth, Gantry Crane (G/C) and terminal areas were used. These variables have been widely employed as popular standard indicators that reflect the containerization of ports when measuring the ports' efficiency. Brief information on these input and output variables of the 21 ports are given in Table 2.

Table 2. Basic statistics

	No. of Berth	Length of berth (m)	Terminal area (m^2)	No. of G/C	Cargo Volume (TEU)
Min	8	2,370	409,900	15	1,305,429
Max	59	17,410	8,569,837	206	31,700,000
Average	21	6,474	2,970,668	62	11,076,585
S.t	12	3,845	2,165,567	45	9,314,837

The big difference between the minimums and maximums of basic statistics is notable in Table 2. This is mainly attributed to the fact that the size of container ports is getting bigger by increasing water depth and also by increasing the number of container terminals and the related equipment in response to the transformed patterns of container shipping lines, including a reduction to a port of call and the employment of larger containerships to benefit from economies of scale.

3.2 The Results of Empirical Analysis

In this study, five DEA models, CCR-I, BCC-I, BCC-O, CRS-SBM (Slacks-Based Measure), without consideration of input and output variables, and VRS-SBM (Ref. [15]) were employed together utilizing Shannon's entropy in order to evaluate the overall efficiency. Table 3 demonstrates the outcomes of this study.

Table 3. DEA Analysis Result

Port	CCR-I	BCC-I	BCC-O	CRS-SBM	VRS-SBM
Shanghai	1	1	1	1	1
Singapore	0.5931	1	1	0.559	1
Hong Kong	1	1	1	1	1
Shenzhen	0.8137	0.8636	0.8826	0.694	0.6982
Busan	0.5498	0.5498	0.571	0.4664	0.4664
Ningbo	0.7012	0.7139	0.7217	0.5929	0.593
Guangzhou	0.8283	1	1	0.7809	1
Qingdao	1	1	1	1	1
Tianjin	0.865	1	1	0.7832	1
Kaohsiung	0.5697	0.6617	0.5868	0.5338	0.5338
Tanjung Pelepas	0.6336	0.9305	0.8467	0.6008	0.7437
Xiamen	0.4755	0.5989	0.4755	0.3833	0.3833
Dalian	0.5016	0.7848	0.6453	0.4455	0.542
Laem Chabang	0.263	0.3736	0.2678	0.2182	0.2182
Tokyo	0.4967	0.7181	0.5443	0.3931	0.4859
Yokohama	0.2867	0.5771	0.3007	0.2269	0.2542
Tanjung Perak	0.5837	1	1	0.3882	1
Keelung	0.5956	1	1	0.3265	1
Gwangyang	0.4975	1	1	0.3183	1
Osaka	0.4259	1	1	0.3148	1
Bangkok	0.3075	1	1	0.1985	1

According to this table, the ports of Shanghai, Hong Kong and Qingdao have been revealed to be most efficient, reflecting the growth of their own domestic cargoes in China. As several different ports were identified to be efficient depending on each model, the integrated model was required in order to analyze the overall efficiency.

Table 4. Comparison Results

Port	Average of 5 DEA models		Integrated Model of DEA and Shannon's Entropy	
	Efficiency	Ranking	Efficiency	Ranking
Shanghai	1.000	1	1.000	1
Singapore	0.830	6	0.777	6
Hong Kong	1.000	1	1.000	1
Shenzhen	0.790	8	0.764	7
Busan	0.521	18	0.507	17
Ningbo	0.665	14	0.646	13
Guangzhou	0.922	5	0.895	5
Qingdao	1.000	1	1.000	1
Tianjin	0.930	4	0.903	4
Kaohsiung	0.577	16	0.561	15
Tanjung Pelepas	0.751	11	0.709	9
Xiamen	0.463	19	0.435	19
Dalian	0.584	15	0.541	16
Laem Chabang	0.268	21	0.248	21
Tokyo	0.528	17	0.487	18
Yokohama	0.329	20	0.287	20
Tanjung Perak	0.794	7	0.719	8
Keelung	0.784	9	0.701	10
Gwangyang	0.763	10	0.680	11
Osaka	0.748	12	0.664	12
Bangkok	0.701	13	0.603	14

As shown in Table 4 as well as Figure 4, the integrated model of DEA and Shannon's entropy has also suggested that Shanghai, Hong Kong and Qingdao ports are the most efficient ports. However, some differences were found between the two models, the average of 5 DEA models and the integrated model of DEA and Shannon's

Entropy. For example, the rank of Shenzhen port went up one rank from 8th to 7th, while Tanjung Pelepas port went up from 11th to 9th rank. On the contrary, the efficiency of Tanjung Perak port (from 7th to 8th) and Bangkok port (from 13th to 14th) have gone down. This may be attributed to the information uncertainty when using the entropy.

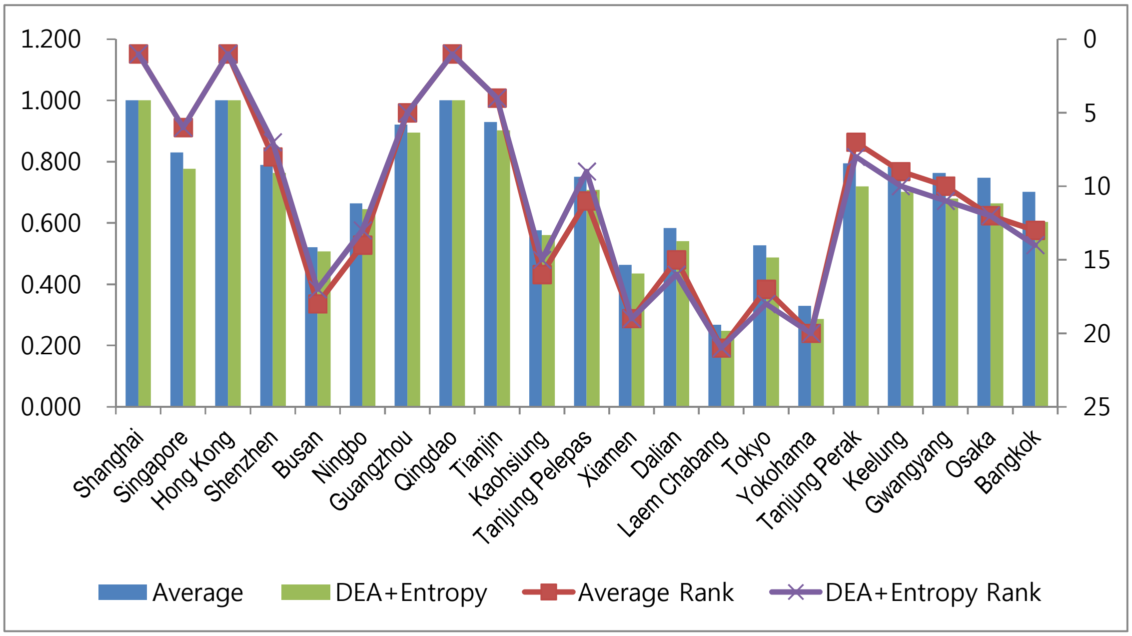


Figure 4. Average 5 DEA Models Vs Integrated Model of DEA & Shannon's Entropy

To further compare the efficiency of the Chinese ports, which occupy a large portion of the world ports in this study compared to other Asian ports, the Wilcoxon Rank-Sum-Test (also called Wilcoxon–Mann–Whitney test) was also conducted. According to the results, it can be concluded that the efficiency of 9 ports in China is higher than the 12 other Asian ports (p value = 0.02, 5% significance level). Additional analysis on the comparison of East Asian ports with other ports suggested that the ports in East Asia are more efficient than the ones in other areas (p value = 0.03, 5% significance level). These results are because of growing demands for raw materials essential to manufacturing, and because of increasing exports for finished goods to and from China and East Asia. Moreover, most ports in China and East Asia are on the main trunk routes, which allow them to take advantage on cargo shipping.

4. Conclusion

By employing DEA with Shannon's Entropy, this research measured the overall efficiency of 21 container ports located in Asia (i.e., East, South-East and North-East Asia) included in the top 100 container ports in the world whose volumes were over a million TEU in 2011. Shannon's Entropy was considered since each DEA model provides different analysis results. In this study, the overall efficiency results were analyzed and the results demonstrated that ports in Shanghai, Hong Kong and Qingdao are the most efficient. This research is valuable in that it has scrutinized the overall efficiency of major ports in Asia by applying Shannon's Entropy, which has not yet been applied in the port context. Secondly, by comparing the efficiency between nations and regions, China and the East Asia were disclosed to be more efficient than others. Therefore, based on the results of this research, it is possible to benchmark the efficient ports' operating strategies. However, further research should be conducted by expanding research periods, by using more input and output variables, and also the methodology used in this research can be applied in other contexts.

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