한국항해항만학회지 제40권 제5호
J. Navig. Port Res. Vol. 40, No. 5 : 317-328, October 2016 (ISSN:1598-5725(Print)/ISSN:2093-8470(Online))
DOI : http://dx.doi.org/10.5394/KINPR.2016.40.5.317

An Empirical Study on the Efficiency of Container Terminals in Russian and Korean Ports using DEA models

Mariia Den · Ho-Soo Nah** · † Chang-Hoon Shin*

* *Graduate school of Korea Maritime and Ocean University, Busan, 49112, Korea*
** *Professor, Division of International Trade and Economics, Korea Maritime and Ocean University, Busan, 49112, Korea*
† *Professor, Department of Logistics Engineering, Korea Maritime and Ocean University, Busan, 49112, Korea*

Abstract : *The steady growth of seaborne trade has resulted in the further development of container ships, ports, and container terminals, and the operating efficiency of a container terminal is a decisive element for its competitive ability in international markets. The aim of this research is to evaluate the relative efficiency of Russian and South Korean container terminals. For this purpose, the output-oriented DEA was applied to 31 container terminals of Russian and South Korean seaports for the years from 2012 to 2014. The results indicate that Korean container terminals exhibited higher efficiency scores than their Russian counterparts.*

Key words: *Container terminals, Efficiency, Data envelopment analysis (DEA), Windows Analysis (WDEA), Technical efficiency, Pure technical efficiency, Scale efficiency, Tiered data envelopment analysis (TDEA)*

1. Introduction

In general the indicators for trade and economic relationships between Russian Federation and Republic of Korea look positive. The foreign trade turnover values increased from $2.9 billion in 2000 to $ 26.6 billion in 2014. In 2014 Russian exports to Korea reached $17.68 billion, imports from Korea to Russia reached $8.92 billion. However, the bilateral trade volumes in 2014 ($26.6 billion) were much less than Russia-China ($95.28 billion) or Russia-Japan ($30.6 billion) turnovers (source: Rusexporter).

The gap in investment volumes is even more revealing. According to the Export-Import Bank of Korea (KEXIM) in 2014 South Korea invested $113.6 million in Russian economy and $3.16 billion in Chinese projects. The total amount of investment accumulated in Russian Economy in 2014 was $22 billion - i.e. South Korean share was only 0.5% (source: Bank of Russia). Russian investment values into Korean economy reached $29 million (source: Ministry of Trade, Industry and Energy). While total volumes of Russian foreign direct investments reached $57 billion in 2014 (source: Bank of Russia).

Besides, the structure of mutual trade stays conservative and archaic: Russia supplies mainly oil and minerals, Korea - engineering products, electronics, and consumer goods. The current trade structure is quite vulnerable to all sorts of crises. In 2015, for instance, the trade turnover between two countries decreased significantly. There is a real threat of a slowdown in the development of trade and economic cooperation between Russia and South Korea, if it is not raised to a higher level, with a focus on intensive innovations and investment exchanges.

According to the "Concept of long-term socio-economic development of the Russian Federation until 2020", the cooperation with the Republic of Korea should be concentrated in hi-tech spheres. It is necessary to form strong technological and industrial alliances, implement large infrastructure projects.

The multilateral cooperation of countries of East Sea: Far Eastern part of Russia, Japan, South Korea, North Korea, and Chinese three north-eastern provinces (Liaoning, Jilin and Heilongjiang) plays a very significant role for the whole region. In 2015 the container land-sea route connecting Suifenhe (China) - port Vostochny (Russia) - port Busan (Korea) was opened. Hunchun (China) - port Zarubino (Russia) - port Busan (Korea) and Tianjin (China) - Busan

---

† Corresponding author, chshin@kmou.ac.kr 051)410-4333
* maria_den@naver.com 051)410-4930
** nhs1030@kmou.ac.kr 051)410-4403
Note) This paper was presented on the subject of "An Empirical Study on the Efficiency of Container Terminals in Russian and Korean Ports using DEA model" in the KINPR proceeding of 2016 KAOSTS Joint Conference (Bexco, Busan, 19th May-20th May, 2016, pp.60-61).

(Korea) – Vostochny (Russia) – Trans-Siberian Railway (Russia) – Finland routes are already operating.

Also, a very promising project is a trilateral cooperation: a railroad trade route from Russia (Khasan) to the North Korean port of Rajin, then by sea to the ports of South Korea, further to South Korean Ports, Although, it was suspended because of U.N. Security Council's sanctions against North Korea.

Another area of cooperation is the transport corridor between the countries of the Asian-Pacific region, Central Asia, and Europe. The project of President of South Korea Park Geun-hye "Eurasian Initiative" project, in particular, assumes the creation of a single transport, logistics and cultural corridor from Korea to Europe. This project aims to enhance cooperation through the establishment of integrated logistics and energy systems. Likewise, both Russia and South Korea expressed a wish to participate actively in research of the Arctic region to find out the possibilities of using the Northeast Passage for freight transportation.

The development of these areas will provide the modernization of port infrastructure and port facilities in general. In March 2015 the Korean Minister of Maritime Affairs and Fisheries announced the intention to direct investments in the development and modernization of the Russian Far East ports to create anchor points for Korean vessels maintenance. Simultaneously, at the sixth meeting of the "Russian-Korean business dialogue" the President of Russian Federation Vladimir Putin specifically noted the development of infrastructure as an important factor. In June 2015 the Russian-Korean scientific research center for the analysis of transport and logistics complex and port infrastructure of the Far East and the Arctic was opened. The project was prepared by the Russian Maritime State University and the Korea Maritime Institute (KMI).

Of some interest are free ports and territories of priority development, already operating in the Far East of Russia. Korean special experience was taken into account when a free port of Vladivostok was created in October 2015. But in order to convert common ports into transport and logistics centers, tax privileges alone are not enough – it is necessary to create a highly developed infrastructure. Thus, it is very important to study the experience of other countries, adopt advanced technology, and use the best mechanisms to reach a new level of production. South Korea has accumulated rich experience in the construction of container terminals and ports. In January 2014 in Moscow, the Ministry of Transport of the Russian Federation and the Ministry of Maritime Affairs and Fisheries of the Republic of Korea signed a Memorandum of Understanding on the cooperation in the field of the port infrastructure development and modernization.

Competition and dynamic development of transport are the major motivating factors for ports to improve their infrastructure, berths, and unloading terminals, which allow passing a large turnover operatively. Many container ports must frequently review their capacity in order to ensure that they can provide satisfactory services and maintain their competitive edge. Sometimes, the necessity to build a new terminal or increase the existing capacity is inevitable. However, before a port implements such a plan, it is of great importance to know if it has fully used its existing facilities and the output is maximized, given the input (Cullinane et al., 2004).

Using the frontier approach to efficiency estimation, the management of ports or terminals that are deemed inefficient can benchmark themselves against ports that are deduced to operate on the efficient frontier for the industry. Ports may also use the results from this sort of analysis to benchmark the performance of individual terminals.

The general purpose of the current research paper is to evaluate the efficiency of container handling and port industry, to understand whether the container terminals in Russia and South Korea operate efficiently or not. We are particularly interested in finding out what factors contributed to the significant growth of Korean container terminals, what strategies were adopted, and what did they brought in terms of effectiveness.

We address this objective from a quantitative standpoint by evaluating the relative efficiency of container terminals, as well as by examining the physical characteristics that may affect the efficiency.

2. Theoretical Review

Data Envelopment Analysis (DEA) is a mathematical programming technique that enables the determination of a unit's efficiency based on its inputs and outputs, and compares it to other units involved in the analysis. The DEA can be described as data-oriented as it effects performance evaluations and other inferences directly from the observed data (Daraio and Simar, 2007). The focus of the research is evaluating the technical efficiencies of a collection of Decision Making Units (DMUs) (e.g. ports, container terminals, bank branches, enterprises), which consume common inputs to generate common outputs (Charnes et al., 1994). DEA determines the efficiency of each

DMU by maximizing the ratio of a weighted sum of its outputs to a weighted sum of its inputs, while ensuring that the efficiencies of other units do not exceed 100%.

Within the family of DEA models, there is one initially proposed by Charnes, Cooper and Rhodes (CCR) in 1978. This model used constant returns to scale (CRS) concept to assess relative productive efficiencies of DMUs with multiple inputs and outputs. In 1984 Banker, Charnes, and Cooper (BCC) assumed variable returns to scale (VRS) for the model and evaluated technical efficiency and scale efficiency of a DMU.

Technical efficiency is defined as the ratio of the input usage of a fully efficient firm, producing the same output vector, to the input usage of the firm under consideration.

In current research, the model assumes I inputs, J outputs and N container terminals – DMUs. In addition, xi represents the amount of inputs employed, yi represents the amount of output produced by the i-th container terminal. Thus, the data in the sample are represented by $J*N$ output matrix, Y and $I*N$ input matrix, X. Since, there are N container terminals, the linear programming problem is solved N times, once for each container terminal in the sample.

To simplify the problem, in the DEA-CRS Technical Efficiency model, we consider that N container terminals operate under CRS and employ seven inputs (Xj, j=1,2,3,4,5,6,7) to produce single output (Y). The formal problem for technical efficiency (TE) can be conveniently expressed in following way:

Min TE, W TEi
s.t. $Y * wi \geq yi,$
$Xj * wi \leq TEi * xi,\ j$ = 1,2,3,4,5,6,7
$wi \geq 0,$

where, TEi is a scalar and represents the technical efficiency measure for the i-th container terminal; w – is the $I*N$ vector of the intensity weights, defining the linear combination of efficient container terminal to be compared with the i-th container terminal. The inequality ($Y * wi \geq yi$) implies that observed outputs must be less or equal to the linear combination of outputs of the container terminals that form the efficient frontier. The inequality ($Xj * wi \leq TEi * xi$) assures that the usage of inputs of efficient container terminals must be less or equal to the use of inputs of i-th container terminal. It will satisfy: $TEi \leq 1$. According to Farrell(1957), an index value of 1 refers to a point on the frontier and thus to technically efficient container terminals.

The CRS assumption is only appropriate when all DMUs are operating at an optimal scale. Otherwise, the CRS specification will bias the estimation of the technical efficiency by confounding scale effects.

In the VRS Technical Efficiency (DEA-VRS) model the substitution of CRS with VRS assumption brings about the estimation of the pure technical efficiency (PTE), i.e. TE devoid of scale effects.

This can be achieved by adding a convexity constraint (NI*wi=1) as demonstrated below:

Min TE, W TEi
s.t. $Y * wi \geq yi,$
$Xj * wi \leq TEi * xi,\ j$ = 1,2,3,4,5,6,7
NI*wi=1
$wi \geq 0,$

where, NI is an I*N vector of ones. The VRS frontier, obtained this way, envelops the data more tightly than the CRS frontier and, thus, generates efficiency scores which are greater than or equal to those obtained from the CRS frontier.

If there is a difference between CRS technical efficiency (CRSTE) and VRS technical efficiency (VRSTE) for a specific container terminal, then that terminal has scale efficiency. Scale efficiency for a container terminal can be computed from the difference between CRSTE and VRSTE. Since, CRSTE = VRSTE*SE, then SE = CRSTE / VRSTE (Coelli et al., 2005).

Under DEA, the input and output data of DMUs are compared with each other for one selected time period. Therefore, the number of data sets corresponds to the number of chosen DMUs. In contrast, the Window DEA forms 'time windows' over several time periods (Jahn et al, 2013). This approach allows to regard the DMUs as if it were a different DMUs in each of the periods, examined within one time window, and monitoring the efficiency changes during the selected time period.

The Tiered data envelopment analysis (TDEA) classifies the sampled units into rank-ordered peer groups. DMUs located on the same frontier have comparable levels of efficiency (Barr et al, 1994). As DMUs on the highest efficiency frontier have DEA scores of 1 – this group is "Tier 1". Dropping the most efficient units from the set for benchmarking, DEA scores are recalculated for each of the remaining units. Those with a score of 1 are on the second frontier – "Tier 2". The procedure continues until all DMUs are assigned to a frontier.

Recently, there has been a significant growth of interest in DEA among the specialists, who research the efficiency and performance of ports and container terminals. So, DEA became the dominant analysis technique in port research to measure the efficiency (Woo et al., 2011). Tongzon(2001), Valentine and Gray(2001), Wang et al.(2003), Song and Sin(2005), So et al.(2007), Park et al.(2007), D'agostini et al.(2015), Li et al.(2015) proposed DEA method with CCR, and BCC models for efficiency study. The output of the analyzed seaports and container terminals included annual container throughput, while the inputs could include berth length, total terminal area, number of container gantries, quay cranes, floating cranes, mobile cranes; number of straddle carriers, forklifts, reach stackers, top lifter; container freight station area.

On the contrast, in Russian economic literature the DEA method is relatively rare, especially in port industry. Kharchenko(2013) described only general concepts of DEA method in her research paper "Benchmarking of Russian ports. Case study from ports of Vladivostok and Nakhodka". Kuznetsov and Kozlova(2007) showed the possibility of applying DEA for evaluating container terminals' efficiency, using Korean container terminals' data for 1999-2002 (Busan, Sebang, Hanjin, Hutchison and Korex) as an example. Thus, this topic is greatly underdeveloped, moreover, no one has ever tried to compare the relative efficiency of Russian container terminals by means of DEA.

Hence, Russian versus Korean container terminals' efficiency comparison was never conducted before. This paper should be seen as an attempt to expand this topic.

3. Characteristics and Analysis of Ports and Container Terminals

3.1 Distinctive Features of Ports and Container Terminals in Russia

The State Register of Seaports holds 63 seaports in five marine basins, located on the shores of 13 seas: Azov & Black sea basins – 12 ports; Baltic basin – 7 ports; Caspian basin – 3 ports (Figure 1); Far East basin – 22 ports; Arctic basin – 19 ports (Figure 2). The main share of throughput goes through the Baltic, Azov and Black Sea basins – 36% and 31% of the total volume in 2014, respectively. Far Eastern basin accounts for 26%, Arctic basin – 6% and Caspian basin – 1%. Due to their small share in total turnover, Arctic and Caspian basins were not included in this study.

The development of ports in each sea basin has its own characteristics, formed by the specifics of the economic areas and natural conditions of navigation. Even so, most of the Russian ports are multipurpose; they can handle all kind of cargo – liquid bulk, dry bulk, general cargo, containers. Moreover, the share of containers in the structure of Russian seaports cargo turnover is about 7%.

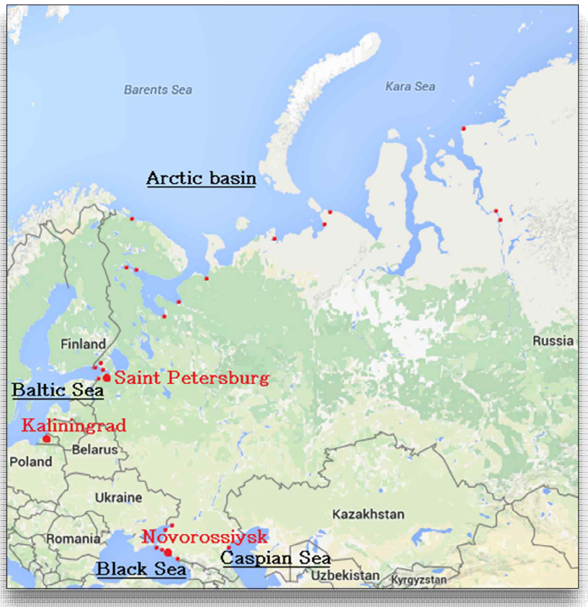

Fig. 1 Seaports in European part of Russia.

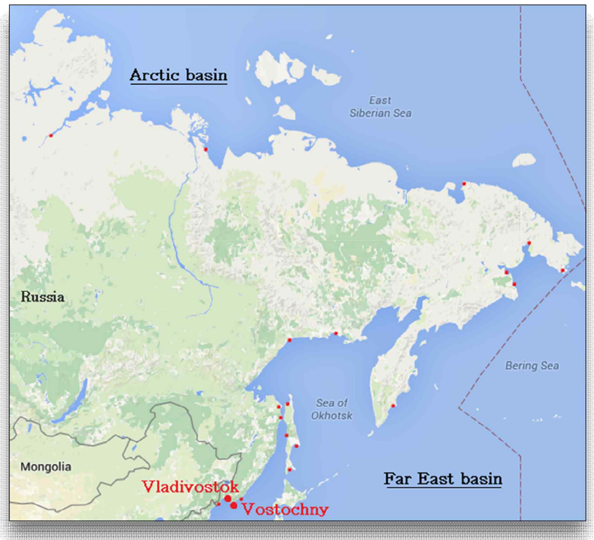

Fig. 2 Seaports in Russian Far Eastern.

This situation was determined by historical background. Global container boom coincided with the collapse of the Soviet Union. At that time, container infrastructure of the country was quite modern. Specialized terminals worked in all major ports. However, their capacity only satisfied the requirements of that time, when container turnovers were measured in mere tens of thousands.

Transition process for containerization in Russia lags behind the world level. Today the level of containerization in

Russia is five times lower than in Europe and North America. The share of cargo, suitable for container transportation is only 30%, while containers represent only 3,5% of total cargo turnover by sea, air or land (source: Russian Federal Agency of Maritime and River transport).

However, according to Drewry, in 2000-2010, Russian container market had one of the highest growth rates globally, supported by the growth of Russian economy, growth in consumer demand and growth in imports.

Total Russian container turnovers, including container transit through Finland and the Baltic states, grew from approximately 748 thousand TEUs in 2000 to 4,126 thousand TEUs in 2010 demonstrating a CAGR (Compound Average Growth Rate) of 18.6% (source: Russian Federal State Unitary Enterprise Rosmortport).

In the past five years, the growth rate of container throughput showed a positive trend – it increased by 1.63 times from 3.48 million TEU in 2010 to 5.11 million TEU in 2014, excluding container transit through Finland and Baltic states (source: Russian Federal Agency of Maritime and River transport).

The development of container terminals in each sea basin has its own features, caused by the specifics of economic areas and natural conditions of navigation. Ports of the Baltic Sea basin handle approximately 55% of Russian container traffic. This is more than two times higher than the Far East Basin throughput (28%) and almost four times higher than the Black Sea Basin throughput (15%). Most of the cargo is processed in five Russian ports (Figure 1, 2). Saint Petersburg and Kaliningrad (Baltic Sea basin) handled 2375.5 and 325.2 thousand TEU in 2014 respectively; Novorossiysk (Black Sea basin) processed 721.2 thousand TEU; Vladivostok and Vostochny (Far East basin) 870.1 and 474.7 thousand TEU respectively (source: Russian Federal State Unitary Enterprise Rosmortport).

3.2 Distinctive Features of Ports and Container Terminals in South Korea

In South Korea 30 seaports are located on the shores of two seas and the Korea Strait, eight of them handled approximately 87% of total Korean cargo throughput (Figure 3). The main share of all cargo throughput goes through Busan port – 24% of the total volume in 2014, Gwangyang Port accounts for 18%, Ulsan Port – 14%, Incheon Port – 11%, Pyeongtaek-Dangjin Port 8% (source: SP-IDC).

South Korea has achieved significant economic growth over the last decades, largely due to the adoption of export-oriented economic policies. The economic development has resulted in rapid increase in export and import cargoes and, since the foreign trade of Korea is carried predominantly by sea transport, ports play a crucial role in this process. Korea's economic growth depends mainly upon the import of raw materials and export of processed and finished products. As a result, the volume of containers handled in Korea has also risen sharply (Cullinane and Song, 1998). The container throughput increased from 19.37 million TEU in 2010 to 24.80 million TEU in 2014. Rapid growth of Chinese economic, accompanied by increase in its inbound/outbound cargo volumes, has triggered an increase in container transshipment. Thus, South Korea, advantageously located between Japan, China, and South-East Asia, became a one of the key logistics centers of Asia. The transshipment volume increased from 6.64 million TEU in 2010 to 9.99 million TEU in 2014. Along with economic opportunities, South Korea has proactively developed its ports and maritime logistic infrastructure in order to play a leading role. The biggest share of the container traffic is handled by the port of Busan, the principal port of Korea, which was the sixth (as of 2014) largest container port in the world, after Shanghai, Singapore, Shenzhen, Hong Kong, Ningbo-Zhoushan. The share of Busan port in Korea's total turnover volume was 75 % (18683 thousand TEU) in 2014, the port of Gwangyang handled 10% (2338 thousand TEU), Incheon port handled 9% (2334 thousand TEU), Pyeongtaek and Ulsan – 2% (546 and 392 thousand TEU, respectively). South Korean terminals are large-scaled, advanced, complex areas of value-added logistics, located in highly urbanized

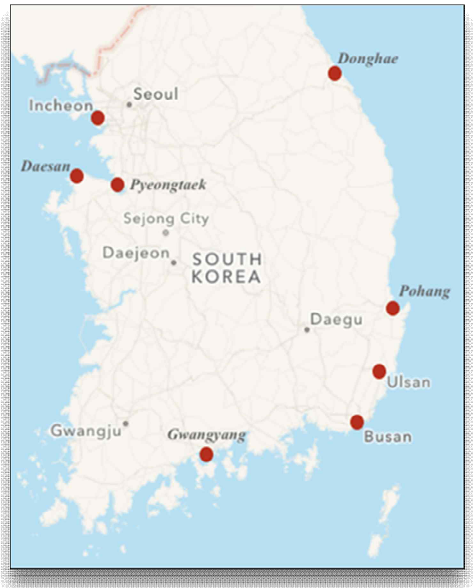

Fig. 3 Seaports in South Korea.

areas and in close proximity to main transport intersections (source: SP-IDC).

4. DEA Empirical Analysis

In this paper, we assume seven inputs and one output. Output: Annual container throughput. Inputs: Total terminal area; Total quay length; Quay equipment; Yard equipment; Storage capacity; Depth alongside; Handling capacity. These inputs are the key factors of container terminal operations, and are closely related to container throughput of ports. To confirm the correlation between selected inputs and outputs, this paper applied analysis of Pearson correlation coefficients, which showed that the output variable highly correlates with the inputs. The p-value indicates that the correlation is significant.

We selected 12 container terminals in Russia and 19 container terminals in South Korea, see Table 1. To ensure comparability, only terminals specialized in container handling are included, thus, multipurpose terminals are excluded (Jahn et al., 2013; Cullinane and Wang, 2006).

All the data were collected from annual reports for 2012-2014, Port-MIS, and ports' official web sites. Table 2 shows the summary statistics of the data used.

In the first step the output-oriented Window DEA was performed for Russia DMUs. Terminal operators can influence the production level, but they cannot easily influence and change the production inputs. Therefore, we consider that the output-oriented model represents the maximum output that can be obtained for a given input level.

For the purposes of this study, the data was obtained for 12 container terminals ($n = 12$) over a three-year period from 2012 to 2014. According to Cooper et al.(2007) the number of data points can be determined as: $w = k - p + 1$, where, k = number of periods, p = length of window, w = number of windows.

Number of windows (w) = $3 - 2 + 1 = 2$

Number of data points = $n * p * w = 12 * 2 * 2 = 48$

Thus, there are 48 different data points; the first window was formed by the 2-year period 2012-2013 and comparative analysis of 24 DMUs ($n * w = 12 * 2 = 24$) was applied; in the second window, in this manner, the analysis is carried out for the next 24 DMUs of the set from 2013-2014.

Table 1 Decision making units selected for the analysis

Port	Container terminal	DMU
Saint Petersburg	First Container Terminal (FCT)	DMU 1
	Petrolesport (PLP)	DMU 2
	Container Terminal St. Petersburg (CTSP)	DMU 3
	Moby Dik	DMU 4
Kaliningrad	Kaliningrad Sea Commercial Port (KSCP)	DMU 5
	Baltic Stevedore Company (BSC)	DMU 6
Novorossiysk	Novoroslesexport	DMU 7
	Novorossiysk Commercial Sea Port (NCSP)	DMU 8
	NUTEP Container Terminal (NUTEP)	DMU 9
Vladivostok	Vladivostok Container Terminal (VCT)	DMU 10
	Vladivostok Sea Container Terminal (VSCT)	DMU 11
Vostochny	Vostochnaya Stevedoring Company (VSC)	DMU 12
Busan North Port	Jaseongdae Container Terminal (HBCT)	DMU 13
	Shinseondae Container Terminal (CJKBCT)	DMU 14
	Gamman Container Terminal (BIT)	DMU 15
	Singamman Container Terminal (DPCT)	DMU 16
Busan New Port	Phase 1-1 (New pier 1) (PNIT)	DMU 17
	Phase 1-2 (New pier 2) (PNC)	DMU 18
	Phase 2-1 (New pier 3) (HJNC)	DMU 19
	Phase 2-2 (New pier 4) (HPNT)	DMU 20
	Phase 2-3 (New pier 5)	DMU 21
Gwang Yang Port	Phase 2-1 (HSGT)	DMU 22
	Phase 2-2 (KIT)	DMU 23
	Phase 3-1 (CJKE)	DMU 24
Incheon Port	ICT	DMU 25
	SICT	DMU 26
	E1CT	DMU 27
	CJKE	DMU 28
Pyeongtaek·Dangjin Port	East Pier	DMU 29
Ulsan Port	Ulsan New Port	DMU 30
	Jungil Container Terminal	DMU 31

In the current research, we used DEA-Solver (LV 8.0) software to solve DEA-CRS model (Cooper et al., 2007). It is worthwhile to say that, to avoid potential imbalance in data magnitudes, Cooper et al.(2007) have recommended that within an input or output item, the ratio min/max of data should be greater than 10^{-4} on average. The data set, under evaluation, for each inputs and output meets this requirement. The ratio min/max of data measures up from 0.006 till 0.389, that is more than 0.0001.

The results of Window analysis of Russian DMUs are arranged in Table 3. The average of the DEA efficiency scores per window is presented in the column denoted "mean." The column labeled GD denotes the greatest difference in a DEA scores for the entire period, negative quantity means decline in efficiency. The DMU with efficiency score equal to 1 is considered to be efficient amongst the DMUs included in the analysis. The DMU with efficiency score less than 1.000 is deemed to be relatively inefficient. Set of efficient DMUs used as reference set

Table 2 Summary statistics

for sample of Russian container terminals					
Description	Unit	Average	Min	Max	SD
Annual container throughput	TEU	393,922	138,500	1,100,000	256,677
Total terminal area	m2	308,533	41,700	890,000	248,681
Total quay length	m	677	168	1,433	359
Quay equipment	unit	5	1	9	3
Yard equipment	unit	24	11	66	15
Storage capacity	TEU	15,118	4,100	34,705	8,885
Depth alongside	m	10	7	14	2
Handling capacity	TEU	532,500	150,000	1,250,000	313,106
for sample of Korean container terminals					
Description	Unit	Average	Min	Max	SD
Annual container throughput	TEU	1,123,205	136,138	3,895,202	904,208
Total terminal area	m2	531,627	7,691	1,202,000	362,823
Total quay length	m	1,059	220	2,000	506
Quay equipment	unit	8	2	17	4
Yard equipment	unit	32	8	74	19
Storage capacity	TEU	37,379	2,200	112,319	26,474
Depth alongside	m	15	8	18	2
Handling capacity	TEU	1,131,930	100,000	2,730,000	708,453

Table 3 Window DEA-CRS model results, Russia.

DMUs	2012	2013	2014	Mean per window	Total mean (by DMU)	GD
DMU 1	1	0.985		0.993	0.963	-0.132
		1	0.868	0.934		
DMU 2	1	0.860		0.930	0.904	-0.155
		0.913	0.845	0.879		
DMU 3	0.509	0.618		0.563	0.578	0.077
		0.599	0.585	0.592		
DMU 4	0.607	0.588		0.598	0.592	-0.009
		0.574	0.598	0.586		
DMU 5	0.740	0.617		0.679	0.636	-0.166
		0.614	0.574	0.594		
DMU 6	0.510	0.614		0.562	0.593	0.136
		0.600	0.646	0.623		
DMU 7	0.881	1		0.940	0.960	0.080
		1	0.961	0.980		
DMU 8	0.736	1		0.868	0.925	0.264
		0.964	1	0.982		
DMU 9	0.624	0.805		0.714	0.747	0.137
		0.796	0.761	0.779		
DMU 10	0.788	0.824		0.806	0.824	0.085
		0.811	0.874	0.842		
DMU 11	0.965	1		0.983	0.986	0.019
		0.995	0.984	0.990		
DMU 12	0.702	0.840		0.771	0.805	0.137
		0.839	0.839	0.839		

(benchmarks) for each inefficient DMU.

The first row (with values of 1, 0.985) shows the relative technical efficiency of the DMU 1 in 2012, 2013, respectively. The second row (with values of 1, 0.868) shows the relative technical efficiency of DMU 1 in 2013, 2014, respectively, and so on. The scores in different years within the same windows show how the efficiency changes from year to another.

The result shows that none of the DMUs from Russian sample, were efficient during the entire period. The DMU 8 has the positive and highest quantity of GD (0.264), that means improving efficiency. Thus, this container terminal reached 1 by the end of the period and became efficient. DMU 7, DMU 11 have positive GD (0.080, 0.023, respectively) and were efficient in 2013 (efficiency score equals to 1), in 2014 they had a relatively high efficiency score (0.961, 0.988, respectively).

The next DMUs show minimum efficiency score by years: DMU 3 (0.509), DMU 6 (0.510) in 2012, DMU 4 - 0.574 in 2013 and DMU 5 - 0.574 in 2014.

As can be seen in the rows (by windows), 67% (GD) of all Russian DMUs show increasing efficiency trend, but during the whole period of study DMU 6, DMU 8, DMU 10, DMU 12 have showed increasing efficiency.

On the contrary, 33% of DMUs show decreasing efficiency trend: DMU 5 (highest negative quantity of GD), DMU 2, DMU 1, DMU 4. Among them, DMU 1 and DMU 2 have reduced their efficiency significantly - from efficiency (score equals 1) in 2012 to 0.868, 0.845, respectively, in 2014.

A DMU can have different efficiency scores for the same year in different windows. A unit that is efficient in one year, regardless of the windows, is said to be stable in its efficiency rating relative to other units (Cooper et al., 2007). DMU 5, DMU 7, DMU 11, DMU 12 were the most stable in their efficiency. Besides, all studied DMUs have small difference between scores for the same years.

According to the analysis of the average efficiency, none of the studied DMUs have an efficiency score of 1. Five container terminals (DMU 1, DMU 2, DMU 7, DMU 8, and DMU 11) are close to the efficiency frontier, ranking average scores of above 90%. Four terminals (DMU 5, DMU 9, DMU 10, and DMU 12) showed highest scores from 60 to 89%. And three terminals (DMU 3, DMU 4, and DMU 6) showed average scores above 50%. This may indicate a shortage of about half of their respective potential throughputs.

None of the studied DMUs were highly inefficient (with average scores below 50%).

In the second step Window DEA was performed for Korean DMUs. In the above mentioned manner, the data was obtained for 19 container terminals; there are 76 different data points; two windows are formed by the 2-year periods (2012-2013 and 2013-2014); in each window the comparative analysis is applied for 38 DMUs. The results of Window analysis of Korean DMUs are arranged in Table 4.

Comparative analysis of Korean container terminals shows that none of the DMUs were efficient during the

Table 4 Window DEA-CRS model results, S.Korea.

DMUs	2012	2013	2014	Mean per window	Total mean (by DMU)	GD
DMU 13	0.638	0.678		0.658	0.660	0.049
		0.636	0.688	0.662		
DMU 14	0.954	0.702		0.828	0.772	-0.158
		0.634	0.796	0.715		
DMU 15	0.967	0.870		0.918	0.824	-0.330
		0.821	0.637	0.729		
DMU 16	1	0.904		0.952	0.944	0
		0.871	1	0.936		
DMU 17	0.660	0.945		0.803	0.839	0.207
		0.885	0.867	0.876		
DMU 18	0.994	1		0.997	0.960	0.006
		0.847	1	0.924		
DMU 19	1	0.973		0.986	0.984	0
		0.963	1	0.981		
DMU 20	0.831	1		0.916	0.942	0.169
		0.937	1	0.969		
DMU 21	0.272	0.649		0.460	0.564	0.452
		0.610	0.724	0.667		
DMU 22	0.552	0.531		0.542	0.515	-0.069
		0.495	0.483	0.489		
DMU 23	0.543	0.598		0.571	0.569	0.031
		0.560	0.574	0.567		
DMU 24	0.547	0.615		0.581	0.585	0.058
		0.574	0.605	0.589		
DMU 25	0.932	0.918		0.925	0.873	-0.086
		0.796	0.845	0.821		
DMU 26	0.917	1		0.959	0.942	0.083
		0.850	1	0.925		
DMU 27	0.627	1		0.814	0.833	0.373
		0.704	1	0.852		
DMU 28	0.980	0.962		0.971	0.801	-0.488
		0.770	0.493	0.631		
DMU 29	0.594	0.596		0.595	0.585	-0.006
		0.559	0.589	0.574		
DMU 30	0.300	0		0.302	0.293	-0.013
		0.282	0.287	0.284		
DMU 31	0.935	1		0.968	0.939	-0.020
		0.903	0.915	0.909		

entire period. According to the analysis of the average efficiency, seven Korean container terminals: DMU 16, DMU 18, DMU 19, DMU 20, DMU 26, DMU 31 are close to the efficiency frontier, ranking average scores of above 90%. Among the terminals that showed high average scores from 60 to 89%, there are DMU 13, DMU 14, DMU 15, DMU 17, DMU 25, DMU 27, DMU 28. The DMUs 21～24, and DMU 29 showed only half of their respective potential throughputs with scores ranging above 50%. DMU 30 is highly inefficient with average scores 0.293. As can be seen in the rows (by windows), 58 % of all Korean DMUs show increasing efficiency trend. Thus, the DMU 16, DMU 18, DMU 19, DMU 20, DMU 26 and DMU 27 have reached 1 by the end of the period. Thus, the aforementioned container terminals have become efficient. Although, DMU 27 was highly inefficient in 2012 (0.627), but growth of the efficiency was notable (the GD equals 0.373).

DMU 21 and DMU 17 showed highest positive quantity of GD (0.452 and 0.207, respectively) and increased its efficiency significantly – DMU 21 from 0.272 in 2012 to 0.724 in 2014, DMU 17 from 0.660 in 2012 to 0.867 in 2014. On the contrary, 42% of all Korean DMUs show decreasing efficiency trend. DMU 15, DMU 22, and DMU 28 have shown a decreasing efficiency trend during the entire period. Among them, DMU 28 reduced its efficiency significantly – from 0.980 in 2012 and 0.866 in 2013 (mean) to 0.493 in 2014 (the GD equals -0.488). DMU 30 showed continuous low efficiency scores, in 2013 and 2014 years it showed the lowest score among all Korean DMUs (0.282 and 0.287, respectively); the GD value of this DMU is also negative that means a decline in efficiency.

None of the Korean DMUs were stable in their efficiency – no one was efficient in one year, regardless of the windows. DMU 19 has the smallest difference in a DEA scores – 0.0099, the DMU 27 has the largest difference in a DEA scores – 0.296. This variation in DEA scores of each unit reflects both the performance of that unit over time as well as that of the other unit.

In the third step Window DEA was performed for both Russian and Korean DMUs. It should be mentioned that all the data that are used to evaluate the model, are assumed to be homogeneous. That means that DMUs: (1) perform the same tasks, with similar objectives, (2) perform under the same set of market conditions (3) are identical, except for differences in intensity or magnitude (Sarkis, 2000). Therefore, we decided to compare Far eastern Russian and small Korean container terminals.

In the above mentioned manner, the data set was obtained for 13 container terminals. There are 52 different data points, two windows have been formed by the 2-year period (2012-2013 and 2013-2014). In each window the comparative analysis was applied for 26 DMUs.

The results of Window analysis of Russian and Korean DMUs are arranged in Table 5. Among Korean DMUs, six container terminals showed the highest efficiency scores – average scores of above 90% – DMU 23, DMU 24, DMU 25, DMU 26, DMU 29, DMU 31. None of the Russian DMUs showed the highest efficiency scores. Other Korean terminals – DMU 22, DMU 27, DMU 28, and DMU 29 – showed an average score above 70%. Among Russian DMUs, two container terminals – DMU 10 and DMU 12 – showed such score. Russian DMU 11 and Korean DMU 30 show only half of its respective potential – average scores above 50%.

As can be seen in the rows (by windows), most of the

Table 5 Window DEA-CRS model results, Russian and Korean container terminals.

DMUs	2012	2013	2014	Mean per window	Total mean (by DMU)	GD
DMU 10	0.768	0.803		0.79	0.77	0.004
		0.717	0.772	0.74		
DMU 11	0.574	0.595		0.58	0.538	-0.086
		0.493	0.488	0.49		
DMU 12	0.650	0.777		0.71	0.73	0.093
		0.742	0.742	0.74		
DMU 22	0.845	0.814		0.83	0.788	-0.11
		0.756	0.737	0.75		
DMU 23	0.909	1		0.95	0.97	0.091
		0.975	1	0.99		
DMU 24	0.890	1		0.94	0.96	0.110
		0.949	1	0.97		
DMU 25	1	0.985		0.99	0.98	0.000
		0.942	1	0.97		
DMU 26	0.917	1		0.96	0.94	0.083
		0.850	1	0.93		
DMU 27	0.627	1		0.81	0.83	0.373
		0.704	1	0.85		
DMU 28	0.980	0.962		0.97	0.82	-0.432
		0.770	0.549	0.66		
DMU 29	0.997	1		1.00	0.981	-0.01
		0.939	0.989	0.96		
DMU 30	0.487	0.493		0.49	0.467	-0.04
		0.440	0.448	0.44		
DMU 31	0.935	1		0.97	0.939	-0.02
		0.903	0.915	0.91		

Korean container terminals have reached 1 by the end of the period and have become efficient, unlike Russian terminals.

Among Korean DMUs, there are two terminals that displayed relatively erratic behavior - one showed great improvement in efficiency (DMU 27), the other - great decline in efficiency (DMU 28) from 2012 to 2014.

Among Russian DMUs, the container terminals display more stable behavior over the entire period. Most of Korean DMUs show increasing efficiency trend, as well as Russian DMUs.

The efficiency measures of DEA-VRS model (Table 6) are higher than those of CRS, which can be evident from the definition of VRS. DEA model with CRS assumption provides information on pure technical efficiency and scale efficiency (SE) taken together, while DEA model with VRS assumption identifies technical efficiency alone. Two Russian terminals scored gently better in the BCC analysis. For DMU 10 score of 0.765 in the CCR analysis (avg. for all years) became as high as 0.827 (avg. for all years) in the BCC analysis.

As well, differences in DEA scores were found with the Korean container terminals between the CCR and BCC model applications. For DMU 28 and DMU 30 (in the second window), which became efficient under VRS assumption, but have been found to be inefficient under CRS, we can infer that the CRS inefficiency in container terminals is not caused by poor input utilization (managerial inefficiency), but is rather caused by inappropriate scale size.

Table 6 Window DEA-VRS model results and SE, Russian and Korean container terminals.

DMUs	DEA-VRS model			Scale efficiency		
	2012	2013	2014	2012	2013	2014
DMU 10	0.826	0.863		0.930	0.930	
		0.779	0.839		0.921	0.921
DMU 11	0.584	0.605		0.983	0.984	
		0.554	0.547		0.890	0.891
DMU 12	0.667	0.798		0.975	0.975	
		0.744	0.744		0.997	0.997
DMU 22	0.878	0.850		0.962	0.958	
		0.800	0.774		0.945	0.952
DMU 23	0.909	1		1	1	
		0.975	1		1	1
DMU 24	0.890	1		1	1	
		0.949	1		1	1
DMU 25	1	0.985		1	1	
		0.942	1		1	1
DMU 26	0.917	1		1	1	
		0.850	1		1	1
DMU 27	0.627	1		1	1	
		0.704	1		1	1
DMU 28	1	0.981		0.980	0.980	
		1	0.846		0.770	0.649
DMU 29	0.997	1		1	1	
		0.939	0.989		1	1
DMU 30	0.494	0.501		0.986	0.986	
		0.446	0.454		0.986	0.986
DMU 31	0.935	1		1	1	
		0.987	1		0.915	0.915

The scale efficiency (SE) (Table 6) indicates how close the production size of a DMU is to the most productive scale. The fact that VRS efficiency scores are higher than SE scores implies that the inefficiency takes place primarily due to scale inefficiency - DMU 28 and DMU 31 in second window.

Table 7 Container terminals efficiency peer groups according to TDEA

Tier	DMUs	Reference set
Tier 1 Most efficient N= 7	DMU 23	
	DMU 24	
	DMU 25	
	DMU 26	
	DMU 27	
	DMU 29	
	DMU 31	
Tier 2 N= 5	DMU 10	DMU 24, DMU 25, DMU 26
	DMU 11	DMU 26
	DMU 12	DMU 24, DMU 25
	DMU 22	DMU 23, DMU 24, DMU 25, DMU 26
	DMU 28	DMU 25, DMU 26
Tier 3 Most inefficient N= 1	DMU 30	DMU 10, DMU 22, DMU 28

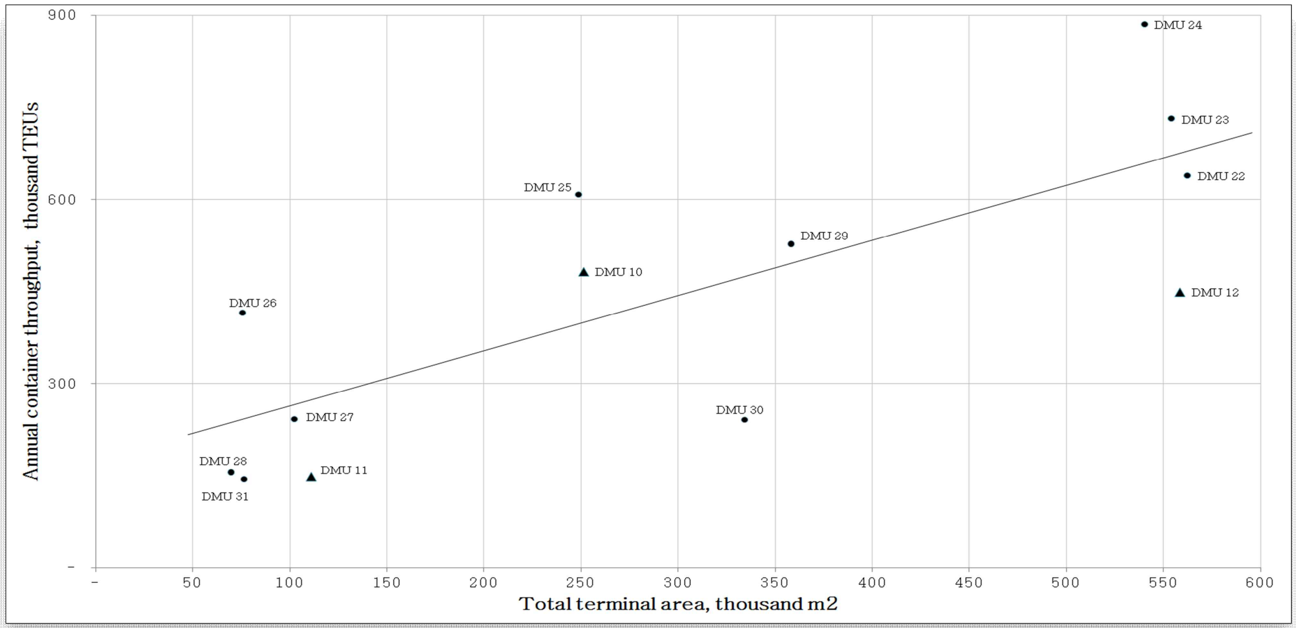

Fig. 4 Container throughput per square meter

As for the rest of the DMUs, their VRS inefficiency scores are lower than SE scores; it indicates that inefficiency takes place mainly due to technical factors rather than scale factors.

The Tiered data envelopment analysis (TDEA) allows ranking of DMUs without having the subjectivity of the classification. By adopting this approach, a group of units can be compared with other peer groups, instead of having unit-by-unit comparisons.

Table 7 illustrates how TDEA procedures generate three Tier groups of container terminals efficiency.

The most efficient group (Tier 1) consists of Korean container terminals and this result is in line with previous conclusions. The terminals in the first Tier include: the port of GwangYang - Phase 2-2 (KIT) and Phase 3-1 (CJKE), the port of Incheon - ICT, SICT, E1CT, the port of Pyeongtaek Port - East Pier, the port of Ulsan - Jungil Container Terminal.

The DMUs in Tier 2 have not been evaluated as the best performers in the previous study. All Russian container terminals are categorized in this Tier 2.

If we compare DMUs with their reference sets we can notice the relative excess of total terminal area. The Russian DMUs from Tier 2 have low “Annual container throughput”-to-“Total terminal area” ratio: DMU 10 has 2 TEU/m2, DMU 11 - 1.34 TEU/m2, DMU 12 - 0.85 TEU/m2. As well as Korean DMUs from Tier 2: DMU 22 - 1.10 TEU/m2, DMU 28 - 1.97 TEU/m2. Whereas DMUs from Tier 1 have the significantly higher values: DMU 26 - 6.24 TEU/m2, DMU 27 - 3.30 TEU/m2, DMU 26 - 6.2 TEU/m2, DMU 25 - 2.53 TEU/m2.

Figure 4 illustrates the correlation between throughput and terminal area. The majority of DMUs from Tier 2 are below the trend line, indicating a sub optimal use of available terminal area.

The same situation can be observed with the number of quay cranes (QCs) and yard equipment (eq). The DMUs from Tier 1 occupy the five highest positions of “Annual container throughput”-to-“Number of QCs (eq.)” ratio ranking. As a example we may compare DMU 27 (168’819 TEU/QCs and 37’515 TEU/eq) with DMU 28 (68’495 TEU/QCs and 17’123 TEU/eq). All the Russian terminals are low enough: DMU 11 (24’697 TEU/QCs and 12’348 TEU/eq), DMU 12 (59’375 TEU/QCs and 13’970 TEU/eq).

This is likely to mean that potential throughput of DMUs from Tier 2 has not yet been attained and they have resources for throughput increase.

Again, if we compare “Annual container throughput”-to-“Total quay length” ratio, we can see the insufficient quay length utilization. DMU 27, DMU 26, DMU 25 from Tier 1 has 1304, 1162, 1048 TEU/m of quay length, respectively.

In contrast, Korean DMU 22 from Tier 2 have 539 TEU/m of quay length, and DMU 28 - 608 TEU/m of quay length. But, the Russian DMU 11 have only 247 TEU/m of quay length, and DMU 12 have 370 TEU/m of quay length.

Moreover, the major part of deep-water ports (15-18 m) is found among Korean container terminals. The average depth alongside of all Russian ports is 10 m. Typical Panamax-class container vessel, handling 3,000-5,000 TEUs, requires a berth depth of more than 12 meters; under such circumstances, many Russian ports are inaccessible to Panamax container ships. Furthermore, nowadays the Panamax containerships have no longer meet the requirements of modern market. Vessels with 10,000 TEU capacity save 37% of operating costs per container, in comparison with 4,000 TEU vessels (Ilnitski, 2008). Post-Panamax container ships, handling above 10,000 TEUs, require a berth depth of more 15 meters.

So, there is no escape from the conclusion that depth restrictions can directly linked with aforementioned insufficient quay length utilization. In modern circumstances, container ports must overcome the disadvantages of their small depth alongside in order to stay effective and competitive.

Ulsan New Port container terminal in Tier 3 has one of the smallest annual throughput, but its terminal area, storage capacity, quay cranes and yard equipment ranks relatively high among the studied DMUs. This terminal have a necessary and sufficient condition for efficient operation, but is characterized by proximity to main hubs of this region - Busan container terminals.

5. Summary and Conclusions

Data Envelopment Analysis does not make accommodation for statistical noise effects such as measurement error, force majeure and other events, which are beyond control of ports. However, DEA provides a suitable method for measurement of container terminal operating efficiency.

According to the research observations, Russian Vladivostok Sea Container Terminal, Novoroslesexport and Novorossiysk Commercial Sea Port showed the best results. An efficient container terminal in modern Russia is relatively small-scaled without excess of equipment and with low annual container throughput. However it cannot satisfy the demands of current state of global container market.

The development of multilateral cooperation between the East Sea countries and transport corridors to Europe/Central Asia would result in load increase. Since Russian container terminals, according to analysis results, show a shortage of about half of their respective potential throughputs, they have got plenty of potential area, equipment and storage capacity. Given such a situation, it is important to improve existing terminals by investing in quay wall, depth alongside, modern communication technologies and information systems.

The following Korean terminals demonstrated the best performance: Singamman Container Terminal in Busan North Port, New pier 2, 3, 4 in Busan New Port and SICT in Incheon Port. These results prove that Busan Port is highly ranked among the largest container ports in the world.

The comparison of Far-eastern Russian and small Korean container terminals showed the supremacy of Korean DMUs, which was expected, granting these terminals were planned and built for container specialization. The results partially prove that the development vector of Korean ports has brought positive results in the last few decades. Korean container terminals have significantly evolved, thanks to their container hub status achieving strategies. These terminals, over the years, invested heavily in expensive and advanced equipment in order to attract new container shipping lines, provide modern and complex services, be able to handle large vessels, etc., which enhanced the efficiency of their operations.

The inefficiency of Russian terminals can partly result from out-of-date production cycle and non-container specialization. Besides, Russian container terminals are motivated to increase the scale of their operations. Since a larger scale of operation invariably means greater network connectivity (mainline and feeder services) and attaining hub status (China-Europe and China-CIS routes). Russian ports need to consider establishing new large specialized container terminals, adopt advanced technology, and use the best mechanisms to reach a new level of production. Thus, the rich experience in the construction of container terminals of South Korea and common interest in the development of transport corridors are the major motivating factors for a big teamwork.

In conducting this research, we had several limitations: this study included only terminals from Russian Federation and Republic of Korea; therefore, the models' results do not reflect the actual position of studied DMUs in global industry and economic environment. The study focused mainly on measuring the relative efficiency of container terminals. The operating environment of each terminal such as governance, institutional factors and public policy, market characteristics, and physical location (access to the railroad, highway, etc.) were not taken into consideration.

References

[1] Barr, R. S., Durchholz, M. L. and Seiford, L.(1994), “Peeling the DEA onion: Layering and rank-ordering units using tiered DEA”, Southern Methodist University Technical Report, vol. 5., pp. 1-24.

[2] Charnes, A., Cooper. W., Lewin, A., and Seiford, L. (1994), Data Envelopment Analysis: theory, methodology and applications, Kluwer Academic Publishers.

[3] Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. and Battese, G. E.(2005), An Introduction to Efficiency and Productivity Analysis, Springer US.

[4] Cooper, W., Seiford, L. and Tone, K.(2007), Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software, Springer Science & Business Media, p. 313.

[5] Cullinane, K. and Song, D. W.(1998), “Container terminals in South Korea: problems and panaceas”, Maritime Policy & Management, Vol. 25, No.1, pp. 63-80.

[6] Cullinane, K., Song, D. W., Ji, P. and Wang, T. F.(2004), “An Application of DEA Windows Analysis to Container Port Production Efficiency”, The Review of Network Economics, Vol. 3, No. 2, pp. 184-206.

[7] Cullinane, K. and Wang, T. F.(2006), “The efficiency of European container ports: A cross-sectional data envelopment analysis”, International Journal of Logistics Research and Applications, Vol. 9, No. 1, pp. 19-31.

[8] D'agostini, E., Ryoo, D. K. and Jo, S. H.(2015), “Comparative Port Performance Analysis of Italian Ports”, Journal of Navigation and Port Research, Vol.. 39, No. 5, pp. 393-399.

[9] Daraio, C. and Simar, L.(2007), Advanced Robust and Nonparametric Methods in Efficiency Analysis. Methodology and Applications, Springer US.

[10] Farrell, M.(1957), “The Measurement of Productive Efficiency”, Journal of the Royal Statistical Society, No. 120, pp. 253-281.

[11] Golany, B. and Roll, Y.(1989), “An application procedure for DEA”, Omega, Vol. 17, No. 3, pp. 237- 250.

[12] Ilnitski, K.(2008), “The most deepest-water”, The port of Ukraine, Vol. 2, p. 120.

[13] Jahn, C., Flitsch, V. and Meissner, K.(2013), “Efficiency developments at European North Range container terminals”, Pioneering solutions in supply chain performance management: Concepts, technology and applications, pp. 3-35.

[14] Kharchenko, O.(2013), “Benchmarking of Russian ports. Case study from ports of Vladivostok and Nakhodka“, Vestfold University College, Faculty of Technology and Maritime Sciences, Master Thesis.

[15] Kuznetsov, A. and Kozlova, E.(2007), “DEA Method for Studying the Efficiency of Container Terminals”, Morflot, No. 4, pp. 52-55.

[16] Li, D., Kwak, K. S., Nam, K. C. and An, Y. M.(2015), “A Comparative Analysis of Terminal Efficiency in Northeast Asia Container Ports”, Journal of Navigation and Port Research, Vol. 39, No. 1, pp. 55-60.

[17] Park, B. K., Choi, M. S., Song, J. Y and Ryoo, D. K.(2007), “A Study on the Efficiency Analysis of Korean Container Terminal - Focus on Busan Port, Gwangyang Port”, Journal of Navigation and Port Research, Vol. 31, No. 1, pp. 89-97.

[18] So, S. H., Kim, J. J., Cho, G. and Kim, D. K.(2007), “Efficiency Analysis and Ranking of Major Container Ports in Northeast Asia: An Application of Data Envelopment Analysis”, International Review of Business Research Papers, Vol. 3, No. 2, pp. 486 - 503.

[19] Song, J. Y. and Sin, C. H.(2005), “A Empirical Study on the Efficiency of Major container Ports with DEA Model”, Journal of Navigation and Port Research, Vol. 29, No. 3, pp. 195-201.

[20] Tongzon, J.(2001), “Efficiency measurement of selected Australian and other international ports using data envelopment analysis”, Transportation Research Part A, Vol. 35, No. 2, pp 107-122.

[21] Trick, M.(1996), “DEA for Consultants”, http://mat.gsia.cmu.edu/classes/mstc/dea/dea.html

[22] Valentine, V. F. and Gray, R.(2001), “The Measurement of Port Efficiency Using Data Envelopment Analysis”, the 9th World Conference on Transport Research, Seoul, South Korea, July 22-27, 2001.

[23] Wang, T. F., Song, D. W. and Cullinane, K.(2003), “Container Port Production Efficiency: A Comparative Study of DEA and FDH Approaches”, Journal of the Eastern Asia Society for Transportation Studies, No. 5, pp. 698-713.

[24] Woo, S., Pettit, S., Kwak, D. W., and Beresford, A.(2011), “Seaport research: A structured literature review on methodological issues since the 1980s”, Transportation Research Part A, Vol. 45, pp 667-685.

Received 28 June 2016
Revised 26 October 2016
Accepted 26 October 2016