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DEA 방식을 활용한 한국과 러시아 콘테이너 항만의 효율성에 대한 실증연구

An Empirical Study on the Efficiency of Container Terminals in Russian and Korean Ports
– Using DEA model –

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DEA 방식을 활용한 한국과 러시아 콘테이너 항만의 효율성에 대한 실증연구

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Abstract

본 논문에서는 DEA 방식을 활용하여 러시아와 한국 컨테이너 터미널의 효율성을 평가한다. 시간주기는 2010~2014 년이다. 터미널의 효율성 측정을 위해 이전의 연구는 함께 두 나라 러시아와 한국을 연구하지 않았다. 그 결과는 한국 효율성 점수의 전평균이 높다는 것을 보여준다. 러시아에서 낮은 스케일 효율가치와 높은 VRS 효율가치를 리소스 사용률이 충분하다는 것을 나타낸다. 하지만 터미널 크기를 효율적으로 하지 않는다. 한국에서 높은 스케일 효율가치와 낮은 VRS 효율가치는 터미널 크기가 충분하다는 것을 나타낸다. 하지만 컨테이너 터미널은 효율적으로 자원을 사용하고 있지 않다. 러시아의 컨테이너 터미널은 IRS 을 보여준다. 한국의 컨테이너 터미널은 CRS 을 보여준다.

KEYWORDS: 해항; 컨테이너 터미널; 효율성; 기술효율성; 순수기술효율성; 규모의 효율성; 자료 포락 분석; Seaports; Container terminals, Efficiency; Data envelopment analysis; DEA; Technical Efficiency; Pure Technical Efficiency; Scale Efficiency.

An Empirical Study on the Efficiency of Container Terminals in Russian and Korean Ports – Using DEA model –

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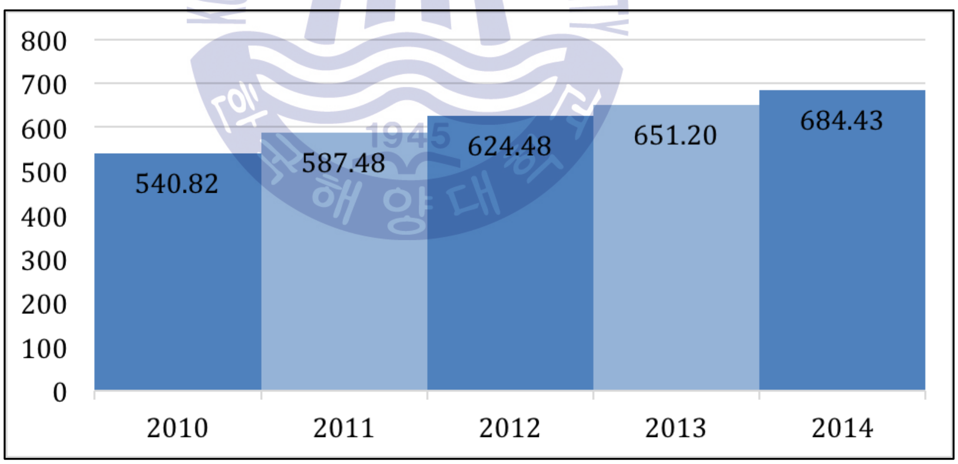
Abstract

The steady growth of seaborne trade has resulted in the increase of container ships, ports and their container terminals. The operating efficiency of a container terminal is the critical element for its competitiveness in the international market. The aim of this research is to evaluate the efficiency of container terminals and to study how to improve their scale efficiency. In this paper the efficiency and performance is evaluated for 31 container terminals in Russian and South Korean seaports in 2010-2014, using DEA (Data Envelopment Analysis), a non-parametric linear programming method, which evaluates relative efficiencies of a homogenous set of decision making units (DMUs) in the presence of multiple input and output factors. Similar comparative studies of Russian and Korean ports/terminals operating efficiency were not conducted previously. The results show that the total average of Korean terminals' operating efficiency scores is higher in both DEA-CCR and DEA-BCC models, in comparison with Russian efficiency scores. Russian terminals showed relatively low scale efficiency and relatively high VRS efficiency scores that may indicate that resource utilization is relatively efficient, but the operational sizes of the terminals are not proper. Korean terminals showed relatively high scale efficiency and relatively low VRS efficiency scores that may indicate that input level (the size of the terminals) is chosen correctly, but container terminals are not using their resources efficiently. Most Russian container terminals show increasing returns to scale, whereas Korean terminals show tendency to constant returns to scale.

KEYWORDS: Seaports; Container terminals, Efficiency; Data envelopment analysis; DEA; Technical Efficiency; Pure Technical Efficiency; Scale Efficiency.

Chapter 1. Introduction

The global market of containerization is one of the most rapidly developing markets. Currently in the world, more than 60% of all cargos are transported using containers. Containerization of general cargo in the world is close to almost 100%. Though the crisis has affected the global economy as a whole and, significantly, and reduced freight traffic volume, including container cargo, recently the recovery of regular container lines and the increase in turnover have already begun. In 2014, world container traffic comprised 684.43 million TEUs, according to UNCTAD [Figure 1]. Key drivers that contributed to the growth in global container throughput over period 2010-2014 were sustained growth in global trade, increased global sourcing and manufacturing, a shift from transporting cargo in bulk to transporting cargo in containers and growth in transshipment volumes[1].



[Figure 1] Global container throughput, annual, million TEUs.

With rapid expansion of global business and international trade, many container ports must frequently review their capacity in order to ensure that they can provide satisfactory services to port users and

[1] See UNCTAD review of maritime transport 2015

maintain their competitive edge. Sometimes, the need to build a new terminal or increase capacity is inevitable. However, before a port implements such a plan, it is of great importance for the port to know whether it has fully used its existing facilities and that output has been maximized given the input.

The objective of this research is to evaluate the efficiency of the container handling industry and to understand whether the container terminals in Russia and South Korea operate efficiently or not. The research also aims to examine the ways to improve the scale efficiency. We address these two objectives from a quantitative perspective by evaluating the technical and scale efficiencies of container terminals, and by examining the physical attributes that may affect the efficiency.

Since the operating efficiency of a container port is a mixture of multiple inputs and outputs, it is problematic to compare quantitative and qualitative indicators to assess the performance of each element and the entire system. Currently there are no universal algorithms and concepts, however, among the non-parametric methods, Data Envelopment Analysis (DEA) method is considered very promising. There are special features, which make DEA method more potent than typical statistical approach:

a) DEA can handle multiple input and multiple output models.

b) It does not require an assumption of a functional form for relating inputs to outputs.

c) DMUs are directly compared against a peer or combination of peers.

d) Inputs and outputs can have very different measurement units (units, tons, dollars in the same set).

This rest of the research is organized as following:

Chapter 2 presents a brief overview of theoretical aspect of the research. In which we survey the literature on efficiency and DEA, and explain the methods used in this study. Chapter 3 aims to make a brief introduction into Russian and Korean container terminals industries and their significance for the economy. Chapter 4 contains empirical research and data analysis. Finally, Chapter 5 discusses the conclusion.

Chapter 2. Theoretical Review

2.1. The concept of efficiency

2.1.1. The definitions of efficiency

The concept of efficiency is very similar to productivity. Even though, in relevant literature some authors do not make any difference between productivity and efficiency. According to the classic definition, productivity is the ratio between an output and factors that made it possible. In the same way, Lovell (1993) defines the productivity of a production unit as the ratio of its output to its input.

Alternatively, efficiency can be described as a distance between the quantity of input and output, and the quantity of input and output that defines a frontier, the best possible frontier for a firm in its cluster (industry).

Lovell (1993) defines the efficiency of a production unit in terms of a comparison between observed and optimal values of its output and input. The comparison can take the form of the ratio of observed to maximum potential output obtainable from the given input, or the ratio of minimum potential to observed input required to produce the given output. In these two comparisons, the optimum is defined in terms of production possibilities.

Koopmans (1951) provided a definition of what we refer to as technical efficiency: an input-output vector is technically efficient if, and only if, increasing any output or decreasing any input is possible only by decreasing some other output or increasing some other input.

Farrell (1957) and much later Charnes and Cooper (1985) go back over the empirical necessity of treating Koopmans' definition of technical efficiency as a relative notion, a notion that is relative to best observed practice in the reference set or comparison group. This provides a way of differentiating efficient from inefficient production units, but it offers no guidance concerning either the degree of inefficiency of an inefficient vector or the identification of an efficient vector or combination of efficient vectors against which an inefficient vector is compared.

Debreu (1951) offered the first measure of productive efficiency with his coefficient of resource utilization. Debreu's measure is a radial measure of technical efficiency. Radial measures focus on the maximum feasible equi-proportionate reduction in all variable inputs, or the maximum feasible equi-proportionate expansion of all outputs. They are independent of unit of measurement.

Applying radial measures to the achievement of the maximum feasible input contraction or output expansion suggests technical efficiency, even though there may remain slacks in inputs or surpluses in output. In economics, the notion of efficiency is related to the concept of Pareto optimality. An input-output bundle is not Pareto optimal if there remains the opportunity of any net increase in outputs or decrease in inputs. Pareto-Koopmans measures of efficiency (i.e., measures that call a vector efficient if and only if it satisfies the Koopmans definition reported above, coherent with the Pareto optimality concept) have been analyzed in literature.

Farrell (1957) extended the work initiated by Koopmans and Debreu by noting that production efficiency has a second component reflecting the ability of producers to select the "right" technically efficient input-output vector in light of prevailing input and output prices. This led Farrell to define overall productive efficiency as the product of technical and allocative efficiency. Implicit in the notion of allocative efficiency is a specific behavioral assumption about the goal of the producer; Farrell considered cost-minimization in competitive inputs markets, although all the behavioral assumptions can be considered. Although the natural focus of most economists is on markets and their prices and thus on allocative rather than technical efficiency and its measurement, he expressed a concern about human ability to measure prices accurately enough to make good use of allocative efficiency measurement, and hence of overall economic efficiency measurement. This worry expressed by Farrell (1957; p. 261) has greatly influenced the OR/MS work on efficiency measurement. Charnes and Cooper

(1985; p. 94) cite Farrell concern as one of several motivations for the typical OR/MS emphasis on the measurement of technical efficiency.

It is possible to distinguish different kind of efficiency, such as scale, allocative and structural efficiency.

The scale efficiency has been developed in three different ways. Farrell (1957) used the most restrictive technology having constant returns to scale (CRS) and exhibiting strong disposability of inputs. This model has been developed in a linear programming framework by Charnes, Cooper and Rhodes (1978). Banker, Charnes and Cooper (1984) have shown that the CRS measure of efficiency can be expressed as the product of a technical efficiency measure and a scale efficiency measure. A third method of scale uses nonlinear specification of the production function such as Cobb-Douglas or a translog function, from which the scale measure can be directly computed.

2.1.2. Measurement of port efficiency

The competitiveness of a container terminal is always determined by a combination of many factors: geographical location, physical characteristics, with respect to the placement of ground transportation and cargo traffic concentration centers[2].

Moreover, today the terminal should take into account the balance of influences of many new processes: globalization, privatization, deregulation, logistics, computerization. Otherwise, the port is in danger of not getting (or losing) a desired marketing position.

These factors force to improve the methods of operational management and thus improve their productivity, while the requirements of the preceding stages of development it was often possible to meet the extensive expansion.

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[2] See Kyznetsov, Pogodin, Serova (2006).

With the growth of traffic and economies of scale applied to maritime shipping, port terminals are facing pressures to improve their productivity and efficiency. A standard container port accommodating panamax and post-panamax containerships has a set of technical characteristics related to berthing depth, stacking density, crane productivity, dwell time, truck turnaround time and accessibility to rail services. A new generation of container port terminals is gradually coming online with significant improvements. This involves new infrastructures, equipment and procedures. It is also a matter of competitiveness, both on the maritime and inland sides since port terminals are competing with other port terminals to service continental hinterlands.

The capacity of the container terminal is determined by many factors, few of which are under the control of the operator of a container. This includes configuration of the terminal, placement of facilities, capital investments and labor productivity.

Outside the control terminal operator are the volume and structure cargo traffic, the balance of exports and imports, the performance of the ground distribution system (railway, road).

Every port and container terminal is an element of a distribution chain. In turn, the terminal itself is represented as a sequence of transmitting flow of cargo as shown in the [Figure 2].

[Figure 2] Terminal as a transportation chain

This chain includes maritime transportation system, marine cargo front of the terminal, the internal transport, storage, land transportation system. The capacity of each element in this circuit can be different, which determines a different coefficient (K) of its use[3].

[3] For more information about container terminal chain, see Kyznetsov, Pogodin, Serova (2006).

Each i-th element with a capacity of Pi for continuous work for a period of time T could process volume Qi = PiT. At the same time, the flow of goods through the entire chain of Qt determined by the capacity of the “weak“ link Qt = min {Q1, ..., Qn}. This flow of goods Qt goes through all the elements of a certain time, “idle“ is not fully using its power. Hence, for the entire chain of elements we have the ratio Qt = Pi T ki, which in turn gives Po ko = P1k1 = ... = Piki = ... = Pnkn

Specific elements that determine total capacity of the entire chain of cargo handling through the terminal, may be different: a warehouse, internal transport, the rear edge, the presence or the need for a particular cargo, cargo sea front.

To evaluate the performance of container terminals, various indicators are used, generally summarized in the [Table 1].

[Table 1] Common productivity measures of container terminals

Element of Terminal	Measure of Productivity	Measure
Crane	Crane Utilization Crane Productivity	TEU / Year / Crane Moves / Hour /Crane
Berth	Berth Utilization Service Time	Vessel/Year / Berth Vessel Service Time(Hour)
Storage	Land Utilization Storage Productivity	TEU /Year / hectare TEU / Storage hectare
Gate	Gate Throughput Truck Turnaround Time	Container / Hour / Lane Truck Time in Terminal
Gang	Labor Productivity	Moves/ Hour / Workman

The most common current practice of evaluation and comparison of terminals today are the following figure:

- TEU / meter quay / year (use of the quay wall)
- TEU / gantry crane / year (use of the quay crane)
- TEU / quay crane / hour (productivity of the quay crane)
- TEU / hectare of the terminal / year (performance of the area)

It should be noted that this list shows only a small part of existing indicators. Each terminal uses only those, which are necessary for the operation, in different sources indicator names may differ.

All the long, medium, and short-term decisions are usually based on corresponding indicators.

In the long-term decisions are made regarding the configuration of the terminals (borders, topology, replacement or purchase of handling equipment, capacity of container berth/area, contracts with new lines or creation of new multimodal interfaces. Medium and short-term decisions are made regarding changes in dock/container yard working schedule[4].

2.1.3. Port competitiveness and efficiency-related researches

Analysis of domestic and foreign publications shows that there is a significant growth of interest in measurement and comparison of ports and terminals performance.

[Table 2] Literature Review of DEA methods applications

Author	Data Description	Model Evaluation	Input/Output Variables
Valentine (2001)	Cross-sectional data 1998 of 2 Greek and 4 Portuguese	DEA-CCR and BCC	labour and capital / ships, movement of freight, cargo handled, container handled
Tongzon (2001)	Cross-section data 1996 of 4 Australian and 12 other international container ports	DEA with CCR model	number of cranes, number of container berths, number of tugs, terminal area, delay time, and labor / annual container throughput, and ship working rate
Wang, Song, and Cullinane (2003)	Cross-section data 2001 of 28 world ports with 57 container terminals	DEA with CCR, BCC, and FDH models	quay length, terminal area, and number of quayside gantry, yard gantry, and straddle carrier / container throughput
Barros (2003)	Panel data of 10 Portuguese seaports, 1990-2000	DEA-Malmquist index and a Tobit model	number of employees and book value of assets / ships, movement of freight, break-bulk cargo, containerized freight, solid bulk, liquid bulk

[4] For more information see Grevenshikova E., 2013. Evaluation of the container terminal effectiveness. *Seaports* 1 (112), pp.52-54.

Park and De (2004)	11 Korean seaports for the year 1999	DEA-CCR and BCC	berth length, handling equipment, storage area / cargo throughputs, number of ship calls, revenue and consumer satisfaction
Lin, Tseng (2005)	27 international container ports from 1999 to 2002	DEA and SFA	container gantry cranes, container quay length, stevedoring equipment, container yard / container throughput
SoonHoo So, et al. (2007)	Cross-sectional data 2004 of 19 container ports in the Northeast Asia	DEA with CCR, BCC, and super- Efficiency models	berth length, terminal area, no of quay cranes, no of yard equipment / container throughput
Ahmed Salem Al-Eraqi, et al.(2008)	Panel data of 22 Middle East and East African ports from 2000 to 2005	DEA Using Window Analysis	berth length, storage area, handling equipment / ship's calls and cargo throughput in tons
Hermouche Toufik (2011)	Cross-sectional Data 2008 of 32 Mediterranean ports	DEA-CCR and BCC and super- Efficiency models	terminal area, storage capacity, total quay length, yard and quay equipment / containers annual throughput
Lu, Park (2012)	28 East Asian container terminals in 2008	DEA-CCR and RA	yard quay area/ crane/ berth terminal/ yard crane/ tractor/ berth length/ berth throughput

2.2. General concept of DEA

2.2.1. Meaning of DEA

Data Envelopment Analysis (DEA) is a technique of mathematical programming 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. DEA is a non-parametric method, as it does not require any assumption about functional form (e.g. a regression equation, a production function, etc.). The focus of considerable research, development and application is technique for 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.

A DMU is said to be 100% efficient if:

- None of the outputs can be increased without either
  - increasing one or more inputs; or
  - decreasing some of the other outputs; and
- None of the inputs can be decreased without either
  - decreasing some of its outputs; or
  - increasing some of its other inputs.

Since we usually have no way of establishing an absolute standard of efficiency, this definition must be adapted so that it refers to levels of efficiency relative to known levels of efficiency in other DMUs. We therefore say that a DMU is 100% efficient when comparisons with other DMUs do not provide evidence of inefficiency in the use of any input or output.

Based on this definition of efficiency, DEA is a mathematical optimization technique, which 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%.

Besides determining relative efficiency measures for each DMU, DEA also identifies efficient peer DMUs for each inefficient DMU and quantifies the required increase in outputs or decrease in inputs required to transform an inefficient DMU into an efficient DMU.

Within the family of the DEA models, the one initially proposed by Charnes, Cooper and Rhodes in 1978 (CCR). The CCR model used constant returns to scale (CRS) concept to assess relative productive efficiencies of decision making units with multiple inputs and outputs.

In 1984, since CCR model assumed DMU to be constant returns to scale for restriction of production possible set, the Banker, Charnes, and Cooper (BCC model) relaxes this restriction to be variable returns to scale (VRS) model, and evaluates technical efficiency and scale efficiency of DMU.

Technical efficiency for the given firm is defined as the ratio for 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 input employed, *yi* represents the amount of output produced by the *i-th* container terminals. Thus, the data of the container terminals 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 terminals in the sample.

- The DEA-CRS technical efficiency (DEA-CRS Model)

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

$\text{Min}_{TE,\ W}\ TE_i$

s.t. $Y * w_i \geq y_i$

$X_j * w_i \leq TE_i * x_i,\ j = 1,2,3,4,5$

$wi \geq 0,$

where, TEi is a scalar and represents the technical efficiency measure for the i-th container terminal. wi 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 ($Y * w_i \geq y_i$) implies that the observed outputs must be less or equal to the linear combination of outputs of the container terminals forming the efficient frontier. The inequality ($X_j * w_i \leq TE_i * x_i$) assures that the use of inputs at the linear combination of the efficient container terminals must be less or equal to the use of inputs of the i-th container terminals. The formulation will show that TEi ≤ 1. According to the Farrell (1957), an index value of 1 refers to a point on the frontier and thus to a technically efficient container terminals.

- The VRS technical efficiency (DEA-VRS Model)

The CRS assumption is only appropriate when all DMU’s are operating at an optimal scale. The CRS assumption will be incorrect if all container terminals are not operating at an optimal scale. In this case, the CRS specification will bias the estimation of the technical efficiency by confounding scale effects. However, the substitution of the CRS with variable returns to scale (VRS) assumption brings about the estimation of the pure technical efficiency (PTE), i.e. TE devoid of the scale effects. This can be achieved by adding a convexity constraint ($N_I * w_i = 1$) to DEA-CRS Model which allows VRS as demonstrated below:

$\text{Min}_{\ TE,\ W}\ TE_i$

s.t. $Y * w_i \geq y_i$

$X_j * w_i \leq TE_i * x_i, \quad j – 1,2,3,4,5$

$N_I * w_i = 1$

$wi \geq 0,$

where, N_I 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 technical efficiency scores which are greater than of equal to those obtained from the CRS frontier.

- The Scale Efficiency

If there is a difference between the CRS technical efficiency (CRSTE) and the VRS technical efficiency (VRSTE) for a specific container terminal, then this means that the container terminal has scale efficiency. The scale efficiency for the container terminals can be compute from the difference between the CRSTE and the VRSTE. Since, CRSTE = VRSTE*SE, then SE = CRSTE / VRSTE.

2.2.2. An Application Procedure for DEA

DEA and its appropriate applications are heavily dependent on the data set that is used as an input to the productivity model[5]. In addition, there are certain characteristics of data that may not be acceptable for the execution of DEA models.

Some data requirements and characteristics that may ease the execution of the models and the interpretation of results are the following:

i. Definition and selection of DMUs to enter the analysis.

ii. Determination of input and output factors, which are relevant and suitable for assessing the relative efficiency of the selected DMUs.

Each of these phases comprises several steps.

- Selection of DMUs

DEA is a technique for assessing the relative efficiency of ‘comparable’ units, with a view to improving their performance. This implies a basic assumption that differences in performance among ‘like’ units exist and are measurable.

Even under quite similar conditions, one always finds differences in the way units are managed, if only because they are led by different decision makes. Thus, on the one hand we look for a ‘homogeneous’ set of units, where comparison makes sense, and on the other, we try to identify the differences between them. These contradicting considerations accompany every step of a DEA application. They are, however, most prominent during the stages of choosing the DMUs to be compared and identifying the factors affecting them.

A homogeneous group of units, for our purposes, is one where:

- the units under consideration perform the same tasks, with similar objectives;

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[5] For more information see Golany, Roll (1988).

- all the units perform under the same set of 'market conditions' (this is of special importance in the analysis of non-profit organizations such as schools, army units, state hospitals, courts, etc.);
- the factors (both inputs and outputs) characterizing the performance of all units in the group, are identical, except for differences in intensity or magnitude.
- The next step is to determine the size of the comparison group. There are two conflicting considerations: one consideration is to include as many DMUs as possible because with a larger population there is a greater probability of capturing high performance units that would determine the efficient frontier and improve discriminatory power; the other conflicting consideration is that the homogeneity of the data set may decrease, meaning that some exogenous impacts of no interest to the analyst or beyond control of the manager may affect the results.

A. Boussofiane, R.G. Dyson and E. Thanassoulis (1991) stipulate that to get good discriminatory power the lower bound on the number of DMUs should be the multiple of the number of inputs and the number of outputs. This reasoning is derived from the issue that there is flexibility in the selection of weights to assign to input and output values in determining the efficiency of each DMU. That is, in attempting to be efficient a DMU can assign all of its weight to a single input or output. The DMU that has one particular ratio of an output to an input as highest will assign all its weight to those specific inputs and outputs to appear efficient. The number of such possible inputs is the product of the number of inputs and the number of outputs. For example, if there are 3 inputs and 4 outputs the minimum total amount of DMUs should be 12 for some discriminatory power to exist in the model.

Golany and Roll (1989) establish a rule of thumb that the number of units should be at least twice the number of inputs and outputs considered. Bowlin (1998) mentions the need to have three times the number of DMUs as there are input and output variables. Dyson et al. (2001) recommend a total of two times the product of the number of input and output variables. For example, with a 3 input, 4 output model Golany and Roll recommend using 14 DMUs, while Bowlin recommends 21 DMUs, and Dyson et al. recommend 24.

These rules of thumb attempt to make sure that the basic productivity models are more discriminatory. If the analyst still finds that the discriminatory power is lost due to a small number of DMUs, they can either reduce the number of input and output factors.

The determination of DMUs to enter the DEA evaluation process is affected by two kinds of boundaries: one comprises the organizational, physical or regional boundaries, which define the individual units; the other relates to the time periods used in measuring the DMU's activities. Preferably, the time periods to be considered should be 'natural' ones, corresponding to seasonal cycles and budgeting or auditing periods. Regarding the length of such periods, it should be borne in mind that long periods may obscure important changes occurring within them, while short periods may give an incomplete picture of the DMU's activities.

A final step in determining the set of units is sifting out DMUs which may be considered as outliers, i.e. units or time periods deviating from the general characterization of the group to be analyzed.

One should bear in mind that efficiency is measured with respect to the DMUs and factors selected. There is no guarantee that the initial selection is 'correct' in the sense that it serves best the purposes of the analysis. Thus, the considerations may require the application of parts of the proposed procedure in an iterative fashion.

Selection of input and output factors.

The initial list of factors to be considered for assessing DMU performance should be as wide as possible. Every dimension, the changes in which may affect the DMUs to be evaluated, should be included in the initial list. Such factors could be either fully or partially controllable by the DMUs, or they may be 'environmental' factors outside the control of the DMUs. Some of the factors would be quantitative (i.e. readily available), while other factors may be qualitative in nature, with different degrees of difficulty to be accorded numerical values.

The factors could be inputs or outputs, or factors placed on either side of a production relationship. All the factors which may possibly have any bearing on the performance of the DMUs to be analyzed should be listed (at this stage, without any numerical treatment). Clearly, this may result in quite a large number of factors in the initial list.

The introduction of a large number of factors into the analysis will result in 'explaining away' a larger portion of the differences among DMUs. This will tend to shift the compared units towards the efficiency frontier, resulting in a relatively large number of units with high efficiency scores. In the following procedure, it is proposed to introduce initially only a limited number of carefully selected factors, thus accentuating the basic differences among units. At a later stage, while analyzing the outcomes, additional factors can be brought into the model to examine whether they explain some of the differences.

Thus, the next steps are directed towards the reduction of the (typically lengthy) initial list to one that includes only the most relevant factors. The factors chosen should distinguish clearly among the compared units and serve effectively the objectives of the analysis.

This refinement of the list can be carried out in three stages:

- Judgmental screening;

The first stage in reducing the list of factors is its critical examination by expert decision makers in the field where the DMUs operate. Since a large list of 'relevant' factors is usually compiled, some may be repeating virtually the same information, some may not be regarded as crucial, while others may appear to be conflicting or confusing.

A problem often encountered at this stage is the proper distinction between factors determining efficiency and factors explaining efficiency gaps. For example, tabor input may serve to determine efficiency while the scale at which the unit operates may be an explaining factor. Entering such explaining factors into the initial analysis may blur the overall picture and reduce the distinction between compared units. It may also obscure our understanding of the way in which some factors affect performance and generally diminish the usefulness of efficiency analyses as tools for improving performance. In public sector units or in non-profit organizations, where factors governing performance are not always well defined, special care should be exercised to distinguish between 'inputs' and 'explaining factors'.

Judgment may be exercised, inter alia, along the following lines:

- Is the factor related to, or contributing to, one or more of the objectives set for the application?
- Is the factor conveying pertinent information not included in other factors?
- Does the factor contain elements (e.g. price) which interfere with the notion of technical efficiency?
- Are data on the factor readily available and generally reliable?

  - non-DEA quantitative analysis;

The first step here is to assign *numerical values* to the various factors. For many of these factors, the 'natural' choice would be the physical units by which they are measured. Such measures can be in dollar terms (for economic factors), in number of persons, KWH of generated electricity, gallons of fuel, etc. A nontrivial consideration in this regard is whether to aggregate all (or some) factors, which can be measured in economic terms into one 'dollar' factor (in other words, assign fixed relations among the weights of these factors). Whether or not to do such aggregations depends strongly on the objectives of the analysis. Another issue concerning quantitative factors is the handling of cases where zero values are encountered for some factors (in some DMUs or some time periods). This may happen if the periods chosen do not correspond to 'natural' cycles of operation, or for reasons stemming from the data-gathering procedure. In such cases, periods could be redefined or data accumulated across several periods. In principle, the DEA models can handle cases with zero values for some of the factors, as long as there exists at least one input and one output for each DMU, which is non-zero. However, such cases should be handled with care, as the computational algorithms may be sensitive to zero values. A final remark concerns the 'isotonicity' relations, which are assumed for DEA, i.e. an increase in any input should not result in a decrease in any output. Consequently, the values of some factors may have to be inverted before they are entered into the analysis.

Another group of factors is the *qualitative* ones. Indeed, the inclusion of such factors is one of the novelties of DEA. Nevertheless, they have to be assigned numerical values in order to participate in the mathematical evaluation of efficiency. The usual practice, here, is to locate some measurable surrogate variable which is assumed to bear a known relation to varying levels of the qualitative factor. Typically, several possible surrogates may be tried out for each qualitative factor until a suitable one is located. Criteria for the choice of surrogate factors are:

- the degree of correspondence between variations in the surrogate data and the examined factor;
- the ability to express this correspondence in a functional form and the general compliance of the results to the analysis objectives.

The next step within this stage is to describe the production relations governing the DMUs to be analyzed, and classify the factors into inputs and outputs. Resources utilized by the units or conditions affecting their operation are typical inputs, while measurable benefits generated constitute the outputs. In most cases, this distinction is straightforward. However, some factors may be interpreted in both ways, their classification depending on the analyst' s point of view. A useful procedure here may be to carry out a series of regression analyses, of such factors, one at a time, on the factors known to be inputs and outputs. A weak relation to inputs and strong relation to outputs indicates a preference towards classifying the factor as an input, while a reversed outcome will point towards viewing the factor as an output. A weak relation to all the factors may indicate a need to reexamine the factor and possibly delete it. Alternatively, strong relations may indicate that the information contained in that factor is already represented by other factors and, again, its deletion should be considered.

However, one should not regard these one-at-a-time regression tests as reliable rules but merely as indicators for a need to examine some of the factors more closely. It may be useful, at this stage, to use each factor separately to rank order all the DMUs. These rankings can then be aggregated into a single ranking which best describes them all. Factors with rankings which differ sharply from the others are again candidates for possible deletion. Throughout this stage, attempts can be made to refine or replace the surrogates selected earlier for the qualitative factors.

- DEA based analysis.

The last step in the process of examining and refining the list of factors consists of trial runs of DEA models. Factors, which have remained in the list so far, are now entered into the model and outcomes are examined closely. Factors which are consistently associated with very small multipliers (i.e. have little impact on the efficiency scores) may be dropped. We seek the ability to discriminate between the DMUs, using the selected factors. Hence, factors, which do not contribute to this end, are candidates for elimination. To test the "discriminating power" of the different factors, the model is run with a series of combinations of these factors. Then, various grouping techniques can be applied to the DMUs, using the resulting efficiency scores. Factors, which do not alter such groupings significantly, should be examined closely. Special attention should be given to factors, which could not be easily classified as inputs or outputs. They can be tried at both sides of the efficiency ratio and classified, finally, according to the results. Some factors (typically, the non-discretionary ones) can be used to rescale all other factors in the analysis. Thus, non- discretionary factors are accounted for in an indirect manner and the total number of factors reduced. Following a series of such iterations, the list of factors to enter the analysis is decided upon. Outcomes of the final iteration provide, at the same time, the first and basic set of efficiency scores for the compared DMUs.

Chapter 3. Characteristic and analyze of ports and terminals

3.1. Features of the Port and Container Terminals in Russia.

3.1.1. Infrastructure of Seaports.

The State Register of Seaports[6] holds 63 seaports in five marine basins, located on the shores of 13 seas [Figure 3]:

- Azov & Black sea basins – 12 ports;
- Baltic basin – 7 ports;
- Caspian basin – 3 ports;
- Far East basin – 22 ports;
- Arctic basin – 19 ports.

Due to their small share in total turnover, Arctic and Caspian basins are not included in this study.

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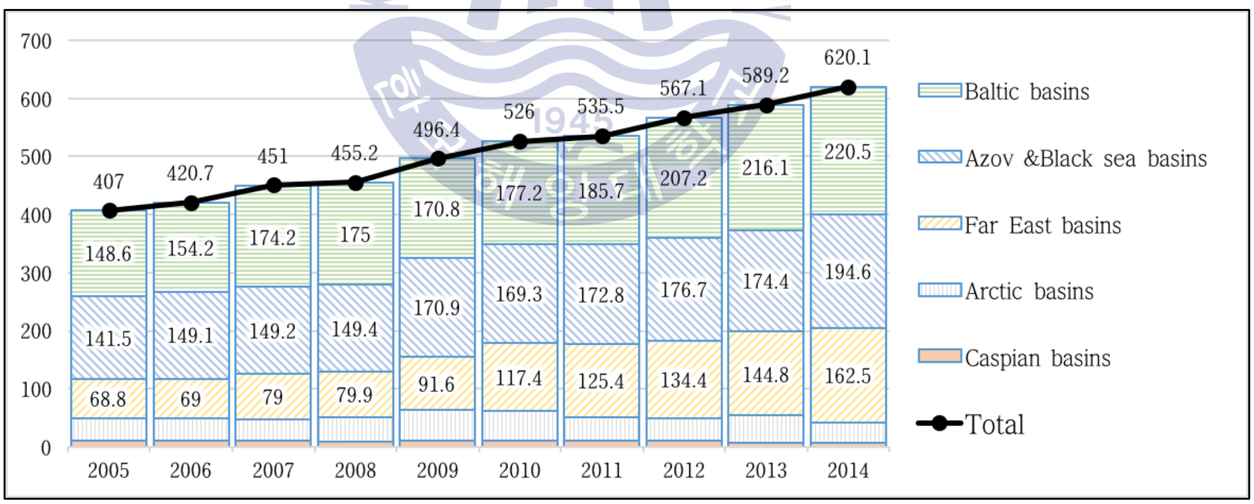
[6] Federal Law №.261-FZ "On seaports in the Russian Federation" defines seaports as government agencies engaged in transportation of passengers, baggage, and cargo by sea. Such institution must receive state registration, have approved limits and title. A registered seaport is added in the official State Roster of Seaports.

The State Roster of Seaports is a unified and systematic compilation of data on seaports, established in the territory of the Russian Federation.

[Figure 3] Russian sea transport system geography.

The main share of throughput [Figure 4] goes through the Baltic, Azov and Black Sea basins – in 2014, respectively 36% and 31% of the total volume. Far Eastern basin accounts for 26%, Arctic basin - 6% and Caspian basin - 1%.

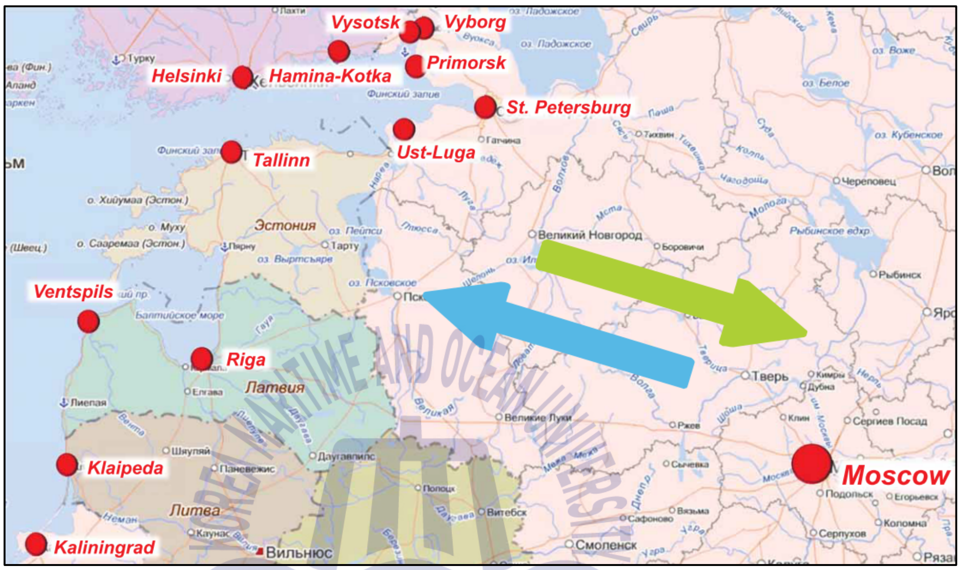


[Figure 4] Russian ports cargo throughput basin-wise, 2005-2014, million tons[7].

[7] Here and further statistics about Russian ports from Association of Sea Commercial Ports (ASOP).

The development of ports in each sea basin has its own characteristics, caused by the specifics of the economic areas and natural conditions of navigation.

As noted before, Baltic Sea ports rank first among the ports of other basins on total cargo turnover. Thet are located in economically developed and densely populated area. Proximity to the European countries also favours the cargo transportation.

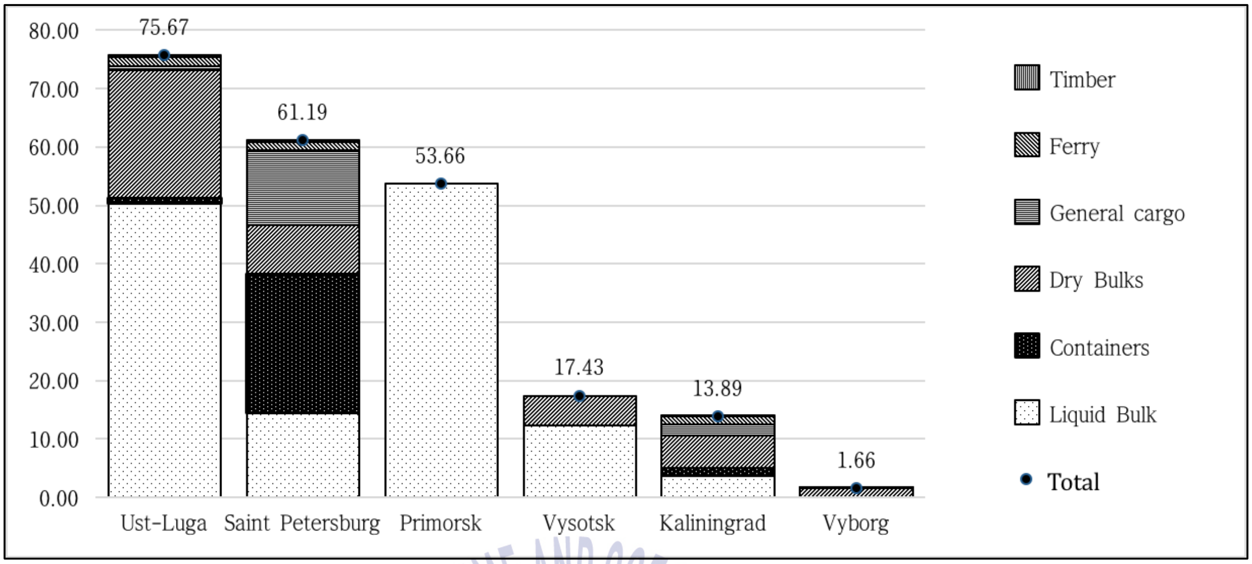


[Figure 5] Geography of Baltic basin seaports

There are seven seaports in the basin: Big Port Saint Petersburg, Primorsk, Vysotsk, Vyborg, Ust-Luga, Kaliningrad and the Passenger Port Saint Petersburg [Figure 5]. Baltic ports manage mostly international trade and transit shipments. Cabotage is less than 1% of their turnover. Baltic ports handle 42% of liquid bulk and 30% of dry bulk of the overall national turnover.

Containers take place in cargo turnover structure of Saint Petersburg (39%), Kaliningrad port (10%) and Ust-Luga 1.2% [Figure 6].

The Baltic Sea basin processes the majority of Russia's inbound and outbound container transportation, including Finland and Baltic countries cargo transit. It operates with largest part of Russian container traffic (56% of Russian container throughput, almost two times more than in Far East basin and three times more than in Black Sea basin). Container terminals of the Baltic Sea basin are located in close proximity to the key transit hubs, such as Hamburg and Rotterdam.



[Figure 6] Throughput of Russian ports of the Baltic Sea basin in 2014, million ton[8].

In total national cargo turnover, the Black Sea ranks second after the Baltic Sea. Black Sea basin ports handle all kind of cargo (liquid bulk, dry bulk, general cargo). Black Sea ports manage mostly foreign trade and transshipment. Cabotage is about 1% of their turnover.

There are 12 seaports in the basin [Figure 7]. They may be divided into three unequal groups. The first group includes the ports located on the Black Sea coast – they are ice-free, able to handle large-capacity vessels and have the potential for further development. The second group includes ports of the Azov Sea, freezing and shallow, these ports are generally located in underdeveloped cities without any perspectives for turnover increase. The third group includes the ports located in resort cities.

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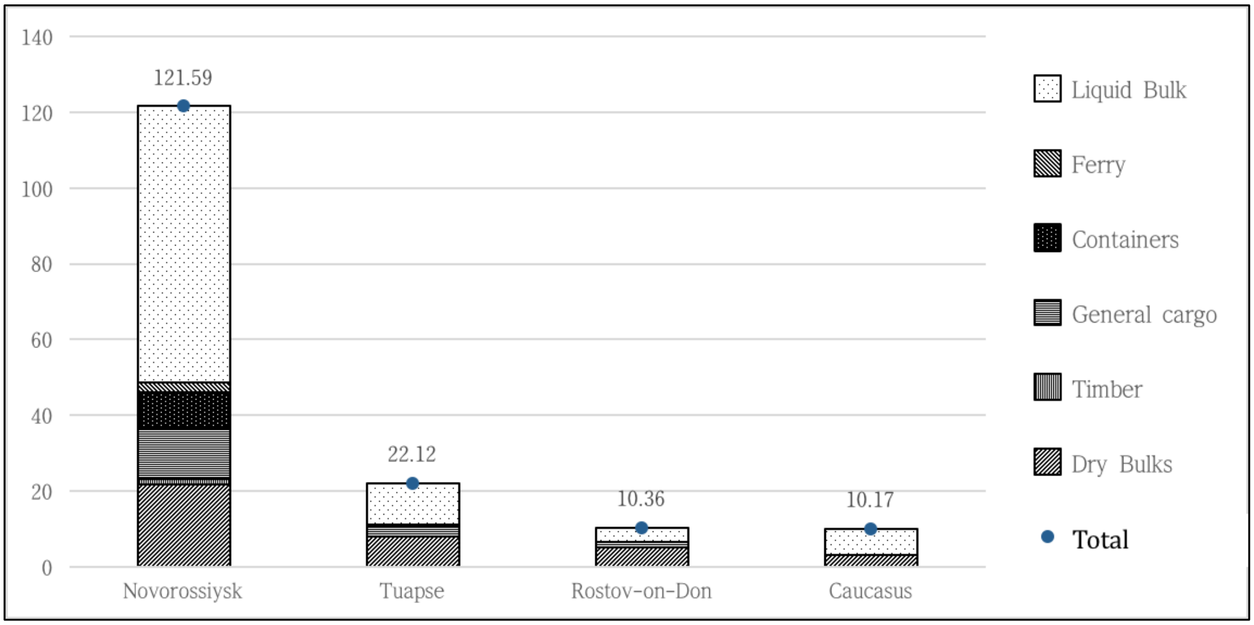
[8] Liquid bulk includes petroleum, gasoline, liquefied natural gas; Dry bulk includes coals and cokes, agricultural products, sand and gravel, etc.; General cargo includes furniture, machinery, motor- and military vehicles, etc.; Ferry (roll-on/roll-off) includes vehicles.

Most the cargo is processed in Novorossiysk (66.5%), Tuapse (10.1%), Rostov-on-Don (6.3%) and the Caucasus (5.3%). The rest of the basin processes only 11.9% of total turnover. Share of containers in the structure of Novorossiysk seaport is about 8% [Figure 8].

[Figure 7] Geography of seaports in Azov and Black sea basins.

The Black Sea Basin accounted for approximately 14% of the total Russian container terminals throughput in 2014, according to ASOP. Novorossiysk is Russia's largest and most important Black Sea container port with a throughput of approximately 722 thousand TEUs in 2013, which accounted for 13% of Russian container traffic in 2012, according to ASOP. This port's main strength is its ability to service the hinterland regions close to the port. However, transportation from the Novorossiysk port to Moscow and central parts of Russia involves higher inland transportation costs.



[Figure 8] Throughput of Russian ports of the Black Sea in 2014, million ton.

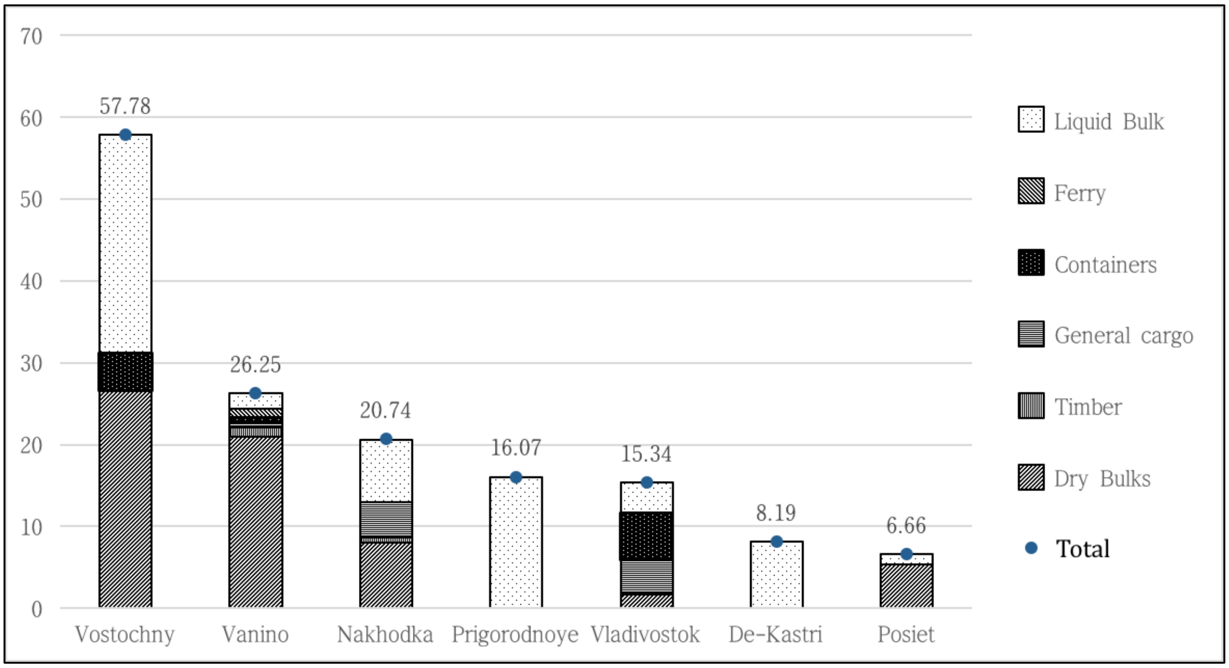
Figure 9 provides the geography of Far Eastern basin. There are 22 seaports, managing mostly foreign trade and cabotage. More than 75% of the basin turnover is being processed in main ports of Khabarovsk and Primorsky regions – Vostochny, Nakhodka, Vladivostok, Vanino and De-Kastri. Four of them serve as key elements of regional railroad and sea transport system and enter top ten largest ports in Russia. Far Eastern basin ports handle 17,7% of liquid bulk and 31.2% of dry bulks of national turnover.

Far East basin ports may be divided into three groups. The first group includes ports of Vostochny, Vanino, Vladivostok, Nakhodka and Posyet. These ports are connected with national rail transport system and major pipelines. The second group includes ports that are connected with offshore oil fields of Sakhalin – Prigorodnoye, De-Kastri, and serve the needs of oil companies. Their turnover represents more than 20% of total Far East basin turnover. The third group contains the remaining 15 ports that are located in areas where land transportation is difficult due to natural conditions, these ports mostly provide provision for settlements.

[Figure 9] Geography of seaports in Far Eastern basin.

Remoteness from the central regions of Russia has a significant influence on functioning and development of the Far Eastern ports. At the same time, Far Eastern ports are located in the fast-growing Asian-Pacific region (China, South Korea, Japan etc.), where Russia seeks to strengthen its economic position.

Vostochny and Vladivostok are of great interest for the current study. Demand for container transportation via Russian Far East ports derives largely from Urals and Central regions of Russia. The Far East basin is usually the fastest route from Asia to Central part of Russia. Far Eastern ports achieved a 24% share of Russian container market in 2014. In recent years, improvements in the reliability and frequency of block-train dispatches from major container terminals in Far East contributed to container transportation growth in this region. Shorter transit time is a key advantage for customers, who are shipping high valued and time-sensitive cargo.



[Figure 10] Throughput of Russian ports of the Far East basin in 2014, million ton.

3.1.2. Container Terminals in Russia.

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 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).

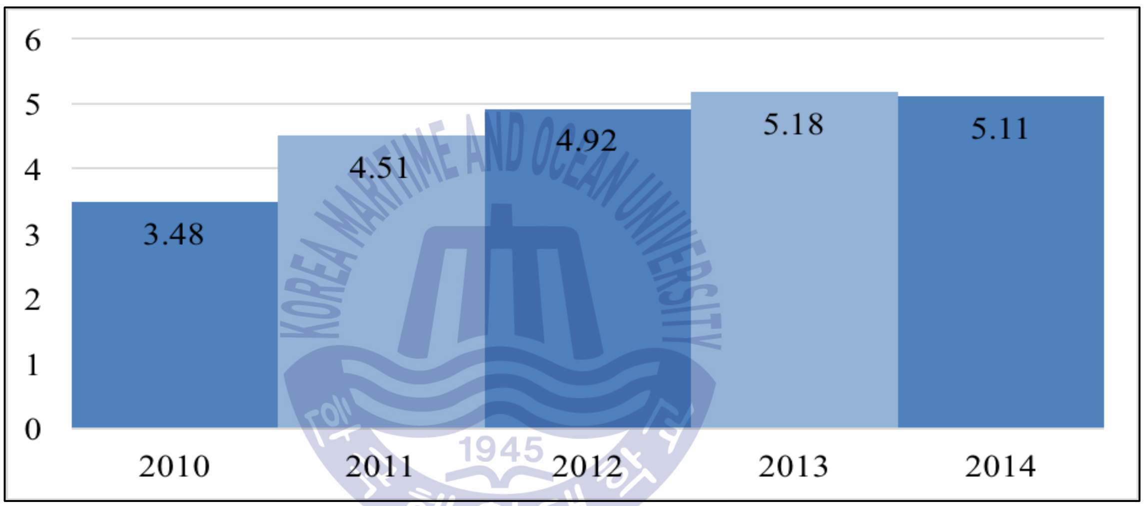
However, according to Drewry[9], in 2000-2010, Russian container market had one of the highest growth rates globally, supported by the growth of Russian economy, growth in consumer demand and

[9] Drewry is the specialist research and advisory organization for the maritime sector.

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%[10].

In the past five years, the growth rate of the container throughput showed a positive trend - increased by 1.63 times to 5.11 million TEU in 2014 (excluding container transit through Finland and the Baltic states). Flow of imported goods in containers grow faster than exported goods.

The main reason for the growth of containerization in Russia is the intensification of international trade, especially import of consumer goods - from food to automotive vehicles.

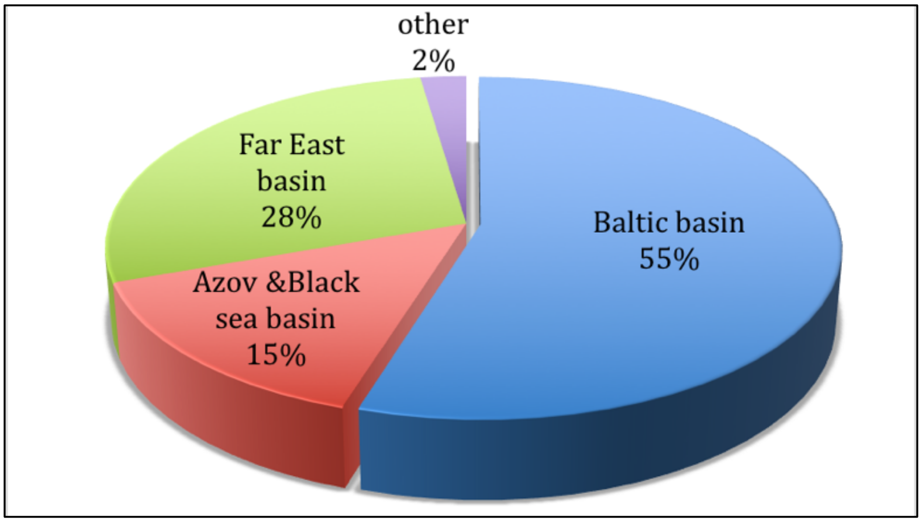


[Figure 11] Container Throughput of Russian Ports by Year, 2010-2014, million TEU.

Ports of the Baltic Sea basin handled approximately 55% of Russian container traffic [Figure 12].

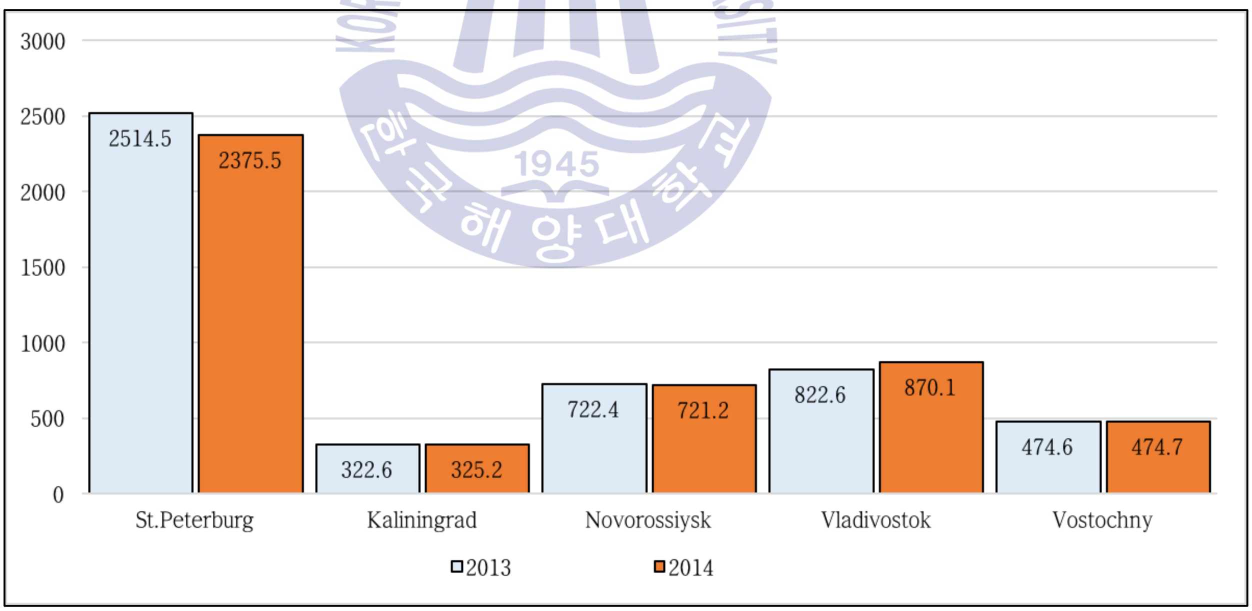
This is more than two times higher than the Far East Basin throughput and almost four times higher than the Black Sea Basin throughput.

10 Industry overview, sourced from the Drewry Reports, for Global Ports (container terminals operator)



[Figure 12] Share of basin in Container Throughput of Russian Ports in 2014.

The growth of container traffic in Russia is accompanied by the development of container terminals - the modernization and increase the capacity of existing terminals and construction of new ones. Throughput of container in some Russian cities in 2013-2014 is presented in [Figure 13].



[Figure 13] Throughput of containers in Russian cities in 2013-2014, ‘000 TEU.

The Big Port of St. Petersburg includes five basins[11] as well as Vasileostrovskiy cargo port, new port in Bronka, berths in Kronstadt and berths in Lomonosov. The port is opened for navigation the whole year. In winter, under ice conditions, navigation is performed by icebreakers.

- First Container Terminal (FCT)

FCT is the largest container terminal in Russia by gross throughput, based in Coal harbor of the Big Port of St Petersburg. The terminal is located at four operational berths with a total area of terminal about 890 000 m^2 and a length of the quay wall of 780m, depth alongside is 11.5 meters. FCT is engaged in handling of all type containers. The terminal has good railway and road connections. The customer base of FCT includes key global carriers and a number of feeder lines.

[Figure 14] Layout of container terminal in St. Petersburg.

[11] Eastern, Baroque, Passenger, Forest Mol roadstead, Coal harbor.

- Petrolesport (PLP)

PLP is the second largest container terminal in Russia by gross throughput, based in Eastern and Baroque basin of the Big Port of St Petersburg. The container terminal is located at 13 berths with a total area of about 1 230 000 m² and a length of the quay wall of 2 201 m, depth alongside is 11 m. PLP is engaged in handling of containers, and also ro-ro, general cargo and metal scrap.

- Container Terminal St. Petersburg (CTSP)

The new complex in Coal harbor of the Big Port of St Petersburg built instead of outdated general cargo handling facilities, in January 2011 terminal started operations on a regular basis. CTSP specializes in handling all types of containerized cargo and ro-ro cargo. The new container-processing scheme simplifies the border control procedures. The container terminal is located at two berths (of 6) with total area of about 320 000 m² and length of the quay wall of 479 m, depth at the water wall is 11,4 m.

- Moby Dik

Moby Dik is located near the St. Petersburg ring-road, approximately 30 kilometers from St. Petersburg. Located at the entry point of the St. Petersburg channel, Moby Dik is the only container terminal in Kronstadt[12]. All necessary border control functions including an official check point at the state border at "Base Litke, island Kotlin" and Baltic customs "Kronshtadt" operate on the terminal site. The terminal is located at two berths with a total area of about 151 000 m² and a length of the quay wall of 321 m, depth at the water wall is 8.9 m. Quays are able to handle container vessels and Ro-Ro vessels. In St. Petersburg, First Container Terminal represents 43,1% of all container traffic, Petrolesport represents 28.3 %, Container Terminal St. Petersburg - 15.8%, Moby Dik - 8.7%.

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[12] Kronstadt is a town of the federal city of St. Petersburg, Russia, located on Kotlin Island, 30 kilometers west of St. Petersburg proper near the head of the Gulf of Finland.

Kaliningrad is located more than one thousand kilometers away from St. Petersburg, fully separated from the main territory of Russia by land frontier of foreign countries (Poland and Lithuania) as well as international seawaters. Berths of Kaliningrad seaport are located on the north side of Kaliningrad sea canal and in remote harbors, including the town of Baltiysk. Kaliningrad Sea port is the only ice-free Russian port in the Baltic region. Two container terminals are located in Kaliningrad:

- Kaliningrad Sea Commercial Port (KSCP)

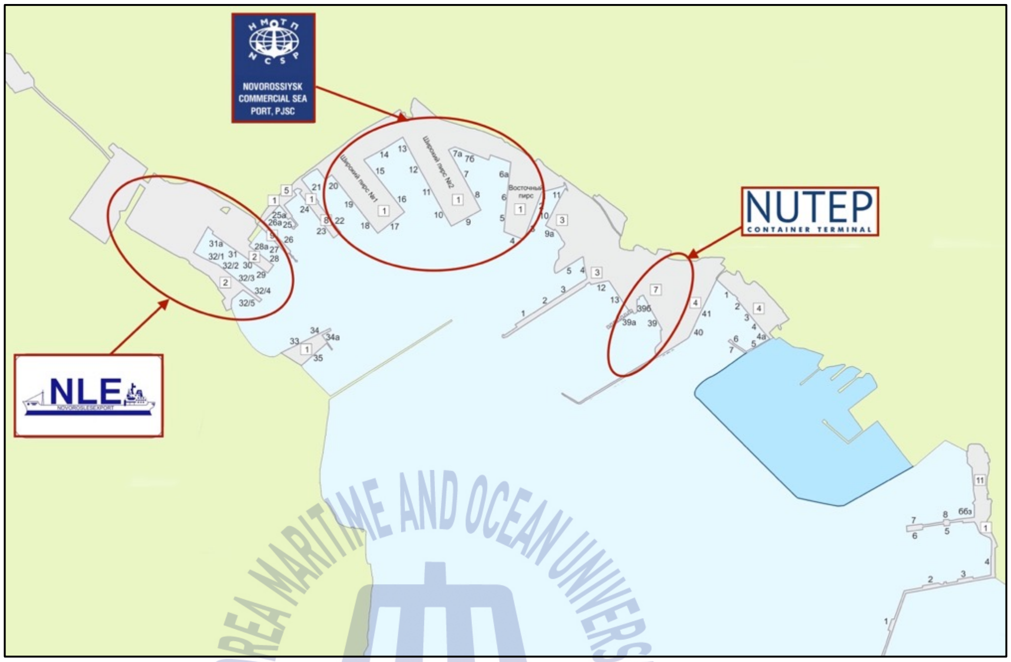
Container Terminal at KSCP is located on the territory between harbors at two berths with a total area of about 250 000 m^2 and length of the quay wall of 420 m, depth at the water wall is 9.5 m. The terminal carries out full range of services connected with handling, storage and transportation of containers. Railway tracks and motorways connect the terminal with transport networks of Russia and European countries.

[Figure 15] Layout of container terminals in Kaliningrad.

- Baltic Stevedore Company (BSC)

The BSC container terminal is located in the Strait of Baltiysk, connecting the Gulf of Kaliningrad (Vislin) with the Baltic Sea, at the entrance to the Kaliningrad Sea Canal. Container Terminal is located at two berths with a total area of about 115 000 m^2 and length of the quay wall of 460 m, depth at the water wall is 9.5 m.

Novorossiysk Sea Port is the largest port in Russia, located on the Black Sea on the north-east coast of the ice-free Tsemes Bay. The port is opened for navigation all year round. Three container terminals are located in the port.



[Figure 16] Layout of container terminal in Novorossiysk.

- Novoroslesexport

The container terminal of Novoroslesexport provides almost full scope of services on handling of all types of containers. Four piers are used for loading/discharge of container vessels, the length of the quay wall is 566.8 m, depth at the water wall is 10-14 m. Total area of terminal is about 167 700 m^2 .

- Novorossiysk Commercial Sea Port (NCSP)

Novorossiysk Commercial Sea Port offers a full range of services, including transshipment of containers, oil products, bulk and general cargo. Container Terminal of NCSP operates on the central 14th pier. One pier is used for loading/discharge of container vessels, length of the quay is 167.9 m, depth at the water wall is 8.3 m. Total area of port is about 959 000 m^2 .

- NUTEP Container Terminal (NUTEP)

NUTEP is a modern container terminal, which handles all type of containers. It has its own railway and a ferry auto complex. Terminal is located at four berths with a terminal total area of about 295 000 m^2 and a length of the quay wall of 875 m, depth alongside is 9-12 m.

[Figure 17] Layout of container terminals in Vladivostok.

- Vladivostok Container Terminal (VCT)

VCT is based in Commercial Port of Vladivostok on north-west of the ice-free Golden Horn Bay, in the downtown of Vladivostok city. The terminal is located at 14-16th berths with a total area of about 120 000 m^2 and a length of the quay wall of 361 m, depth at a water wall is 12.5 m. The terminal can handle all kinds of containers. Developed transport (rail and automobile) infrastructure creates additional competitive advantages for the terminal.

- Vladivostok Sea Container Terminal (VSCT)

VSCT is based in Vladivostok Sea Fishing Port on the southern coast of the Golden Horn Bay. The terminal is located at 50-53th berths with a total area of over 50 000 m^2 and a length of the quay wall of 600 m, depth at a water wall is 9.5 m. The terminal specializes in the transshipment of containers and general cargo of coasting and export-import lines. They are adjacent to the railway station Cape Tchurkin of Vladivostok branch of the Far-Eastern railway.

[Figure 18] Layout of container terminal in Vostochny.

- Vostochnaya Stevedoring Company (VSC)

VSC is the largest container terminal in the Far East Region of Russia and it operates on the territory of Vostochny Port. The terminal is located at four berths with a total area of 720 000 m^2 and a length of the quay wall of 1284 m, depth at a water wall is 13.5 m. Most of VSC import volumes are headed to Central and Western regions of Russia, including Moscow and St. Petersburg, and to the countries of Central Asia, via Trans-Siberian Railway[13].

[13] Trans-Siberian Railway is a network of railways connecting Moscow with the Russian Far East and the Sea of Japan.

3.2. Features of the port and container terminals in South Korea.

3.2.1. Infrastructure of Seaports.

In South Korea 30 seaports are located on the shores of two seas and Korea Strait [Figure 19]. Eight of them handled approximately 87% of total Korean cargo throughput: Busan, Gwangyang, Incheon, Pyeongtaek-Dangjin, Ulsan, Daesan, Pohang, Donghae-Mukho.

The main share of throughput [Figure 20] 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%[14].

[Figure 19] Geography of seaports in South Korea.

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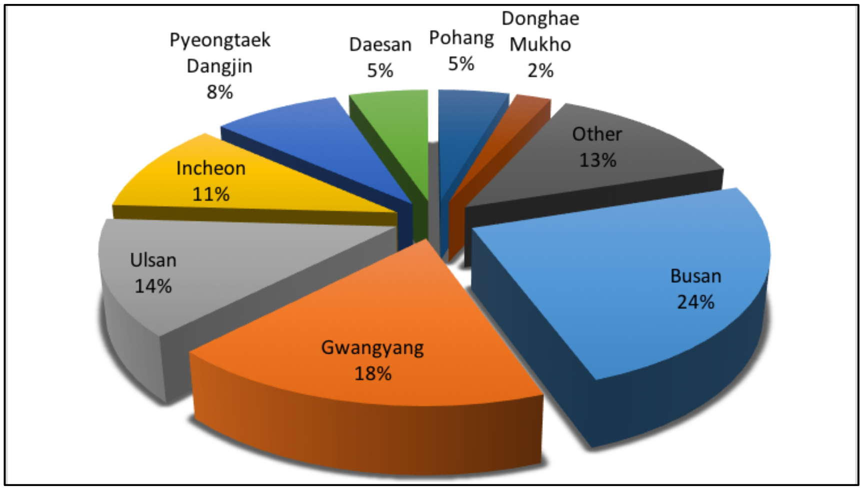
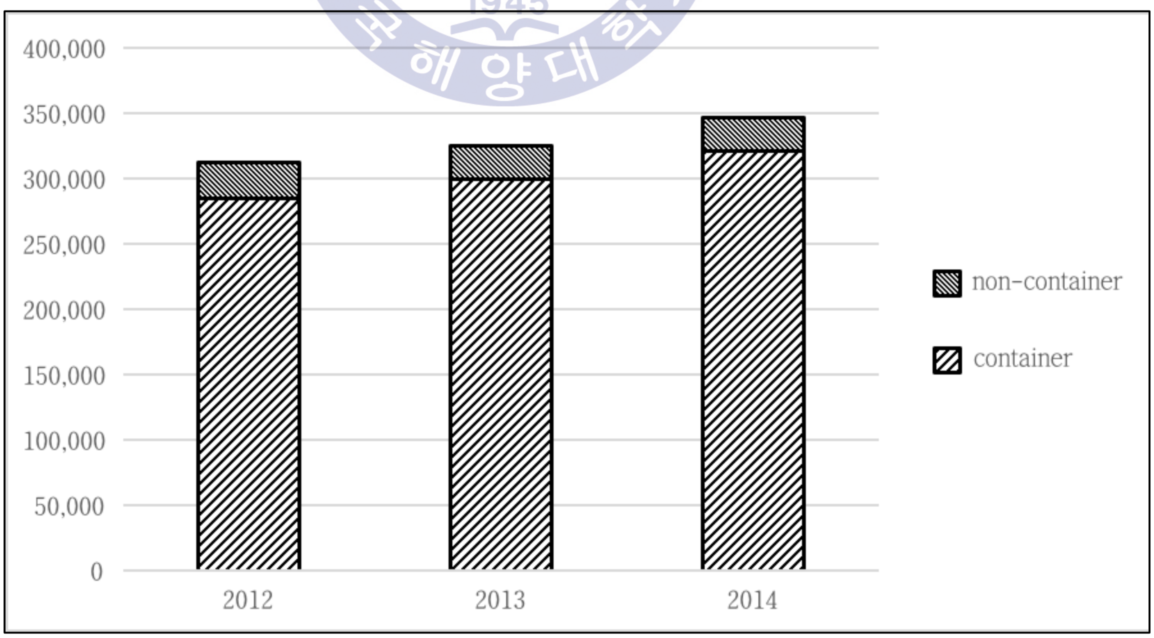
[14] Busan Port Container Statistics



[Figure 20] Share of cargo throughput by ports in South Korea.

Busan port is the largest port in South Korea by total cargo turnover. It is located at the Southeastern edge of the Korean Peninsula. It is the fifth busiest container port in the world. In addition, with the geographical advantage of its location, which connects Asia and North and South America, the port of Busan plays a vital role as the hub of seaborne transportation throughout the Northeast Asia region. In Busan port's turnover structure 92.7% accounts for container and 7.3% for non-container cargo.



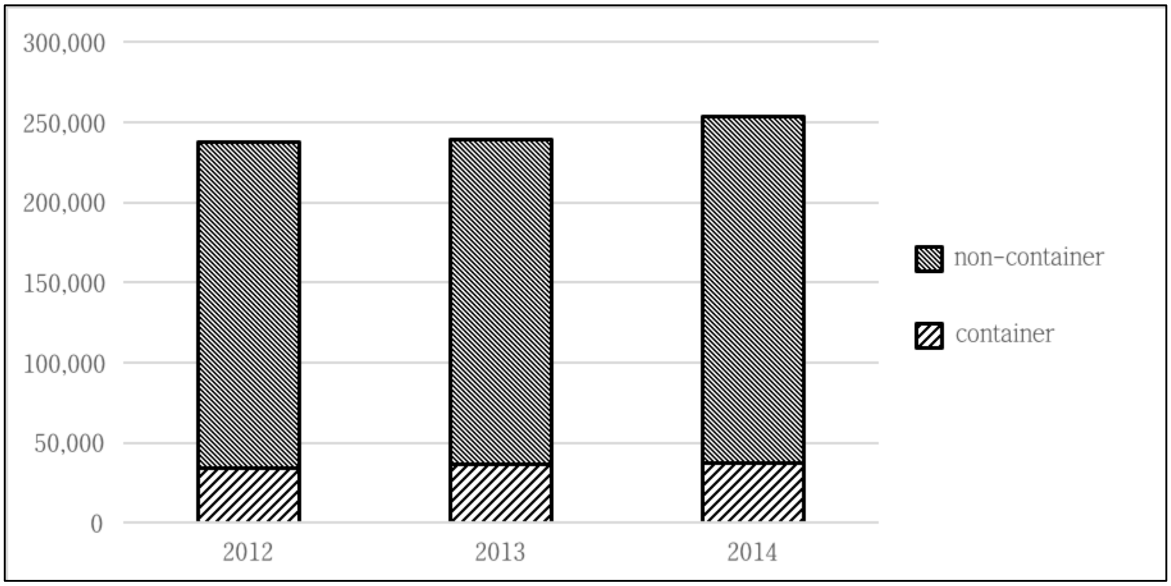
[Figure 21] Throughput of Busan port in 2012-2014, '000 Ton.

There are four fully equipped modern ports - Busan North Port, Busan Port's general pier (South Port, Gamcheon Port, Dadaepo Port), New Port and International Passenger Terminal.

[Figure 22] Layout of seaports in Busan.

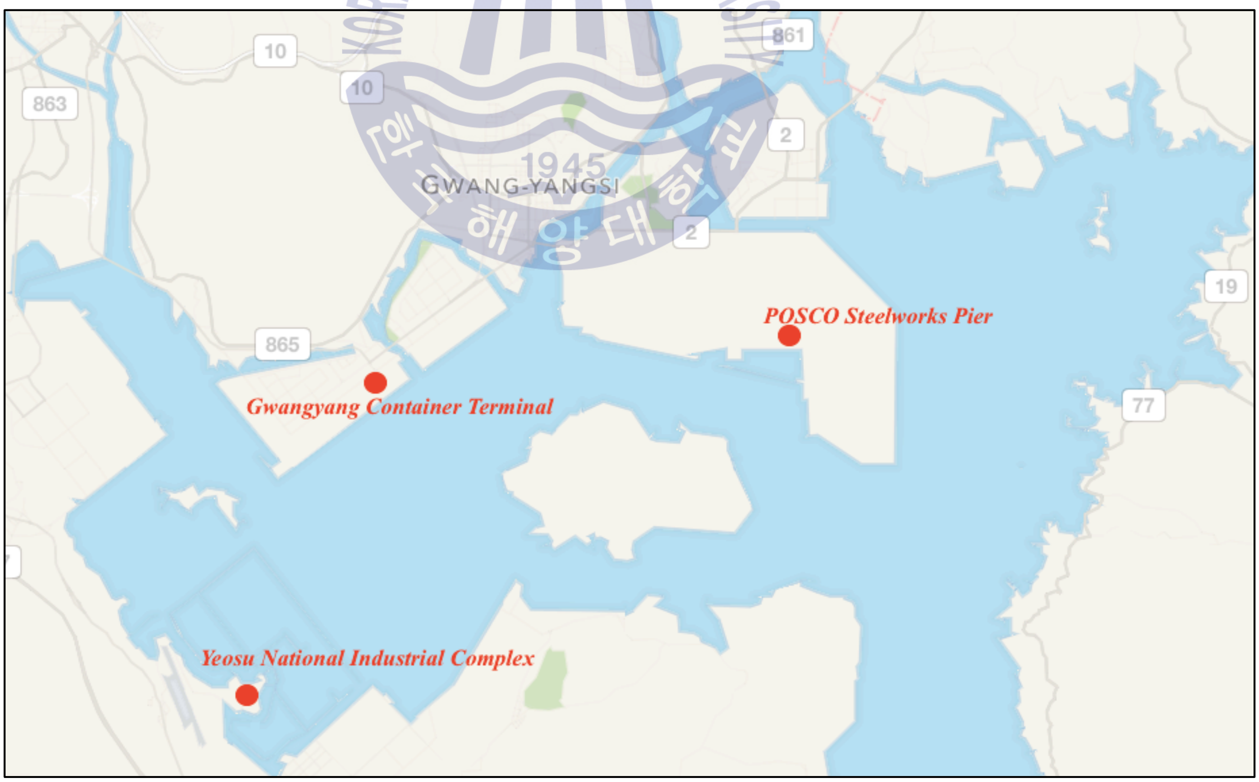
The port is facilitated by 30.7 km of quay wall, allowing it to berth 146 vessels simultaneously and handle cargo of 91 million tons per annum. Busan North Port is the main hub for the nation's international trade. It provides container, cargo and passenger handling facilities. With alongside depths ranging to 8.6m, the terminal's quay can berth 10,000 t vessels. Busan New Port (opened in 2006) has water depth of over 17m and up-to-date facilities, capable of accommodating vessels up to 19,000TEU.

Gwangyang port is located in South Jeolla Province, within a main route for maritime container transportation that serves as the ideal base for global logistics business in the economic zones of both China and Japan. It is the 18th busiest port in the world and the second largest domestic port. With over 20 m deep-water sea lanes and 17 m of water depth in front of piers, the Gwangyang Port has such a vast area and efficient facilities that the world's largest container ship the "Triple E" can dock at Gwangyang Port. The Gwangyang Free Economic Zone covers a vast area of 85.28 km^2, consisting of the Gwangyang area including Gwangyang Port's container terminal. In the turnover structure of the port 15% accounts for container and 85% for non-container cargo.



[Figure 23] Throughput of Gwangyang port in 2012-2014, ‘000 Ton.

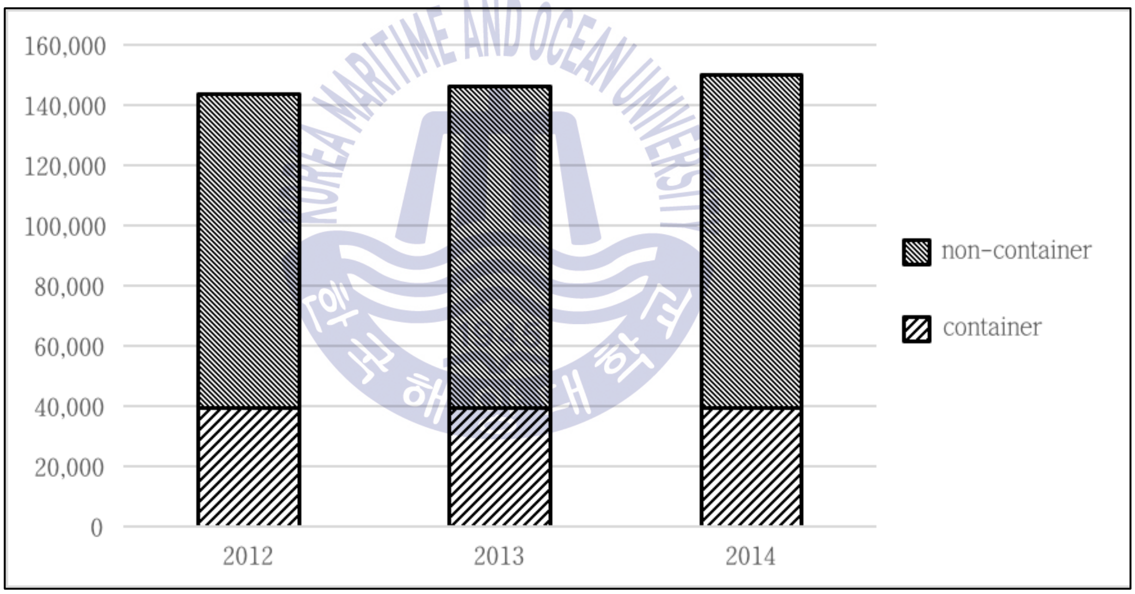
The Port of Gwangyang operates a total of 94 berths, including 14 berths at the container terminal, and is capable of handling 4.6 million TEUs per year.



[Figure 24] Layout of seaports in Gwangyang.

The Gwangyang Port is being promoted as a logistics base, it consist of: Gwangyang Container Terminal, Yeosu National Industrial Complex (petrochemical pier, coal pier, etc.), Gwangyang POSCO Steelworks Pier (steel products pier, general piers, cement pier).

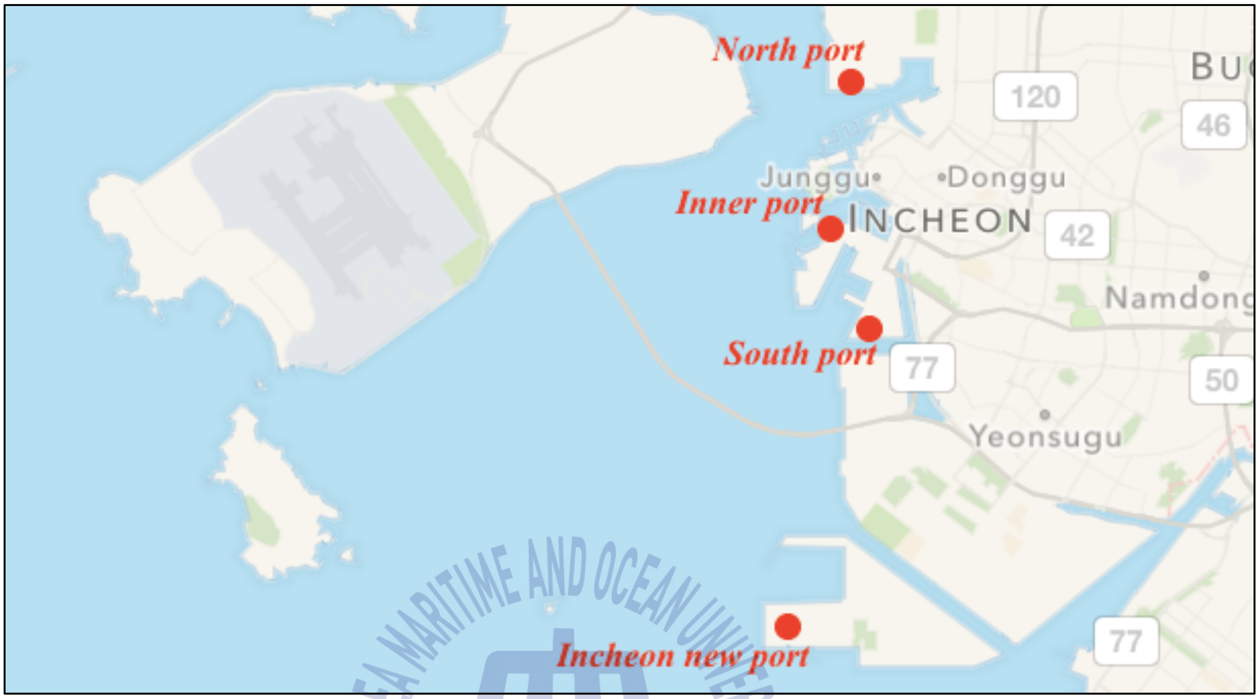
Incheon port is located on the Midwestern coast of the Korean Peninsula, it is an international gateway to Seoul, the capital of South Korea. In the Incheon Port surrounding area, there are seven national and more than 100 regional industrial complexes. Incheon Port, designated as a customs-free zone in appreciation of its strategic geographic location at the heart of Northeast Asia, is quickly rising as a major logistics base. The port has berthing facilities capable of simultaneously accommodating 37 ships inclusive of 50,000 tons class ship. In the turnover structure of the port 26% accounts for container and 74% for non-container cargo.



[Figure 25] Throughput of Incheon port in 2012-2014, '000 Ton.

Incheon Port is divided into inner and outer ports, which are located inside and outside the lock gates respectively. The outer port is divided into South Port, North Port, and New Port.

North Port handles cargo containing industrial materials such as timber, scrap iron, byproducts for nearby factories. Inner Port has the capacity for berthing 48 ships with piers designed for automobiles, grain, general cargo, etc. South Port is equipped with seven berths exclusively for 3,000 TEU container ships. Incheon New Port is designed to operate containers and general cargo berths. The 1st phase (Seongwang New Container Terminal) opened in June 2015.

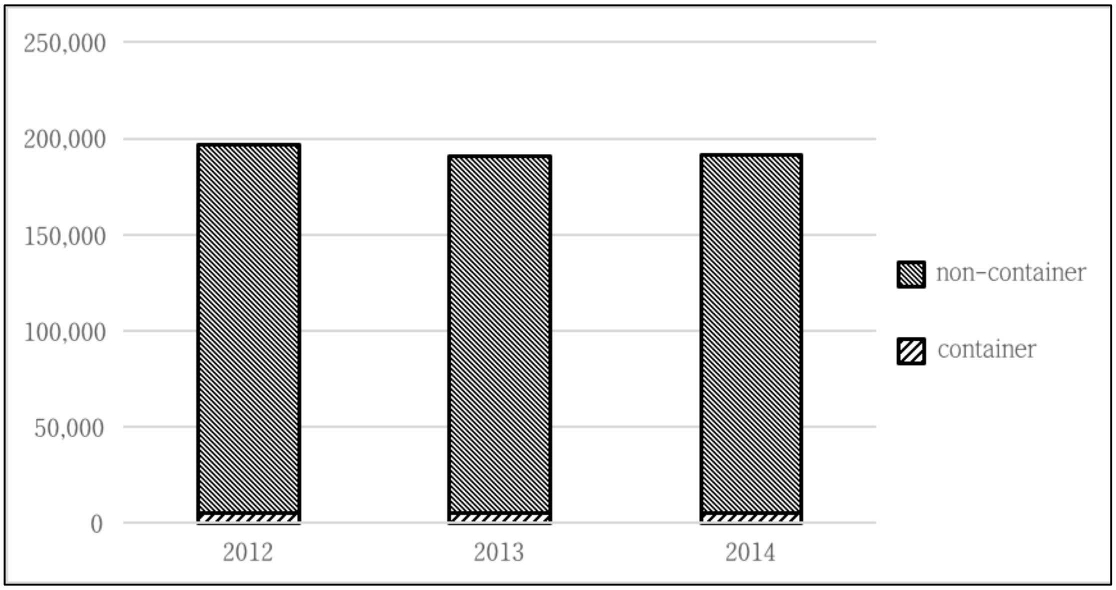


[Figure 26] Layout of seaports in Incheon.

Ulsan port is an industrial port situated in the Southeast of the Korean Peninsula, with the largest national industrial complex in its hinterland. Like other Korean ports, the Port of Ulsan has plenty of advantages such as deep waters and modest tidal differences.

Located along the international arterial route of liquid cargo transportation between the American continents and the Asian region, the port has been intensively fostered as a hub port of liquid cargo transportation in Northeast Asia. In the turnover structure of the port 3% accounts for container and 97% for non-container cargo [Figure 27].

The Port of Ulsan is comprised of Ulsan Main Port (petroleum, coal, automobile and steel), Onsan Port (container, other mineral ores, miscellaneous goods, petroleum and cement), Mipo Port (steel, equipment and materials for ship building) and Ulsan New Port (container, sand, miscellaneous goods, timber, liquid and chemical compounds).

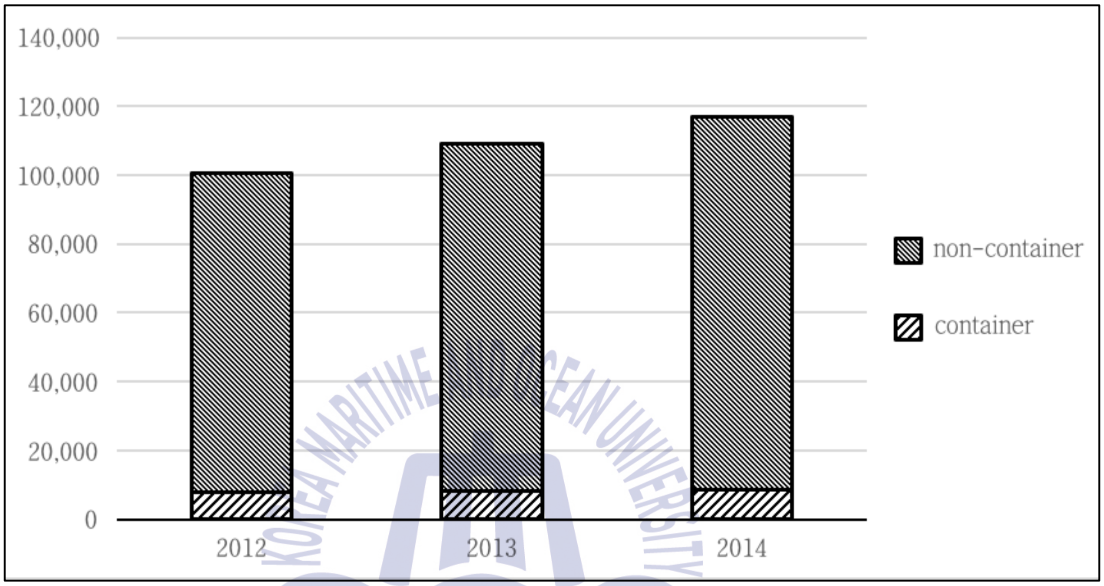


[Figure 27] Throughput of Ulsan port in 2012-2014, ‘000 Ton.

Ulsan Port is a multi-purpose port that is able to handle various cargos, including liquid cargo, bulk cargo, automobile, container etc.

[Figure 28] Layout of seaports in Ulsan.

Pyeongtaek-Dangjin port is located in the Southwestern part of the Gyeonggi province. It is the closest Korean port to Chinese ports. The large industrial complexes lie close to the port, and are supported by well-organized complex transport system in inland areas. Port hinterland (1,429 ㎢) was included in the expansion of a Free Trade Zone. In the turnover structure of the port 7% accounts for container and 93% for non-container cargo.



[Figure 29] Throughput of Pyeongtaek-Dangjin port in 2012-2014, ‘000 Ton.

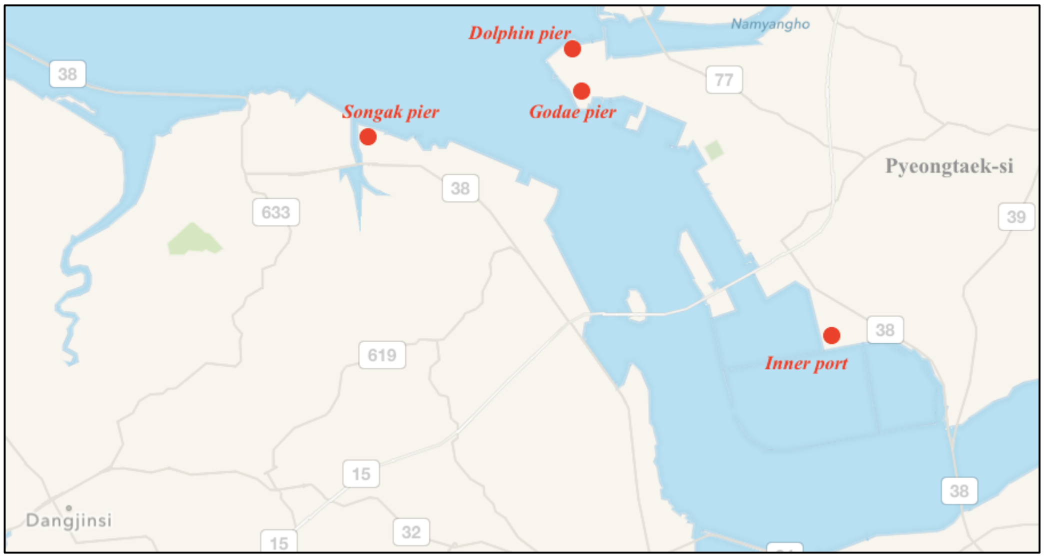
The port features berths designed for loading and unloading of steel, vehicles, cement, crops and liquids and for docking of 60 000-ton vessels and larger. The average water depth is between 11-18m with a difference between flow and ebb of 9-10m. These conditions permit the safe and easy passage of 60,000 ton-class or larger container vessels.

Hyundai Steel pier (Songak pier) – steel, iron ore, coal, tar.

Godae pier – steel, miscellaneous goods.

Dolphin pier - bunker oil, gas.

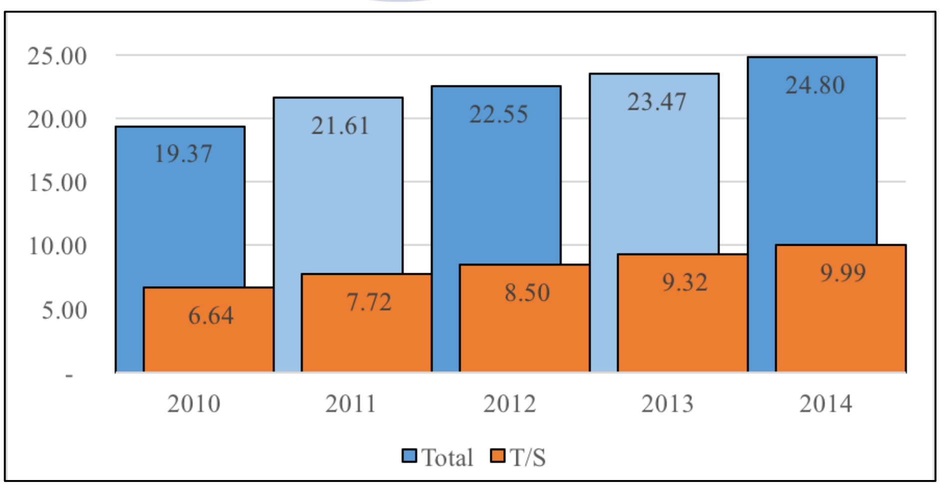
Inner port (East pier, West pier) – automobiles, cement, miscellaneous goods, grain, containers.



[Figure 30] Layout of seaports in Pyeongtaek-Dangjin.

3.2.2. Container Terminals in Korea.

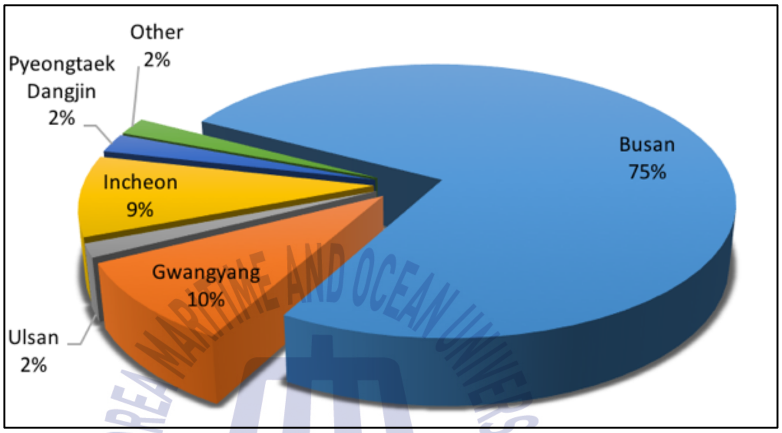
Korea has achieved economic growth over the last decades, largely due to the adoption of export-oriented economic policies. The economic development has resulted in rapid increase in export and import cargoes and, since the foreign trade of Korea is carried predominantly by sea transport, ports play a crucial role in this process. High growth rates in the Southeast Asian economies and, especially, expansion of China' s foreign trade produce demand for Korean ports.



[Figure 31] Container Throughput of Korean Ports by Year, million TEU.

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 container handled in Korea has also risen sharply.

The dramatic growth of China' s economy and increase in trade cargo volumes inbound/outbound of China have also trigged a rise in container throughputs in Korean ports, by boosting the tranship services on those cargoes between China. Korea, neatly positioned between Japan – China and America – Asia, ideal place to tranship the growing volume of container traffic, currently handles cargo moving to and from Japan, Russia, North and South America and Australia.



[Figure 32] Share of ports in Container Throughput in South Korea in 2014

[Figure 31] illustrated growth of container traffic and transshipment volume in Korea since 2010 to 2014. The Korean terminals gained most profit from transshipment cargoes and became a key logistic center in Asia. Along with economic opportunities, Korea has proactively developed their ports and maritime logistic infrastructures in order to play a leading role. Most container traffic has been handled through the port of Busan, the principal port of Korea, the 6th (as of 2014) largest container port after Shanghai, Singapore, Shenzhen, Hong Kong, Ningbo-Zhoushan. As can be seen in [Figure 32] the proportion of Korea' s total container volume handled by Busan 75 % in 2014, in contrast the port of Gwangyang handled 10%, Incheon handled 9%, Ulsan and Pyeongtaek 2%. The Korean terminals are large-scale, advanced, value-added logistics complex areas located in highly urbanized areas and main transport intersection. The Terminals be able to handle any type or size cargo and vessels with a capacity of up 50,000-ton class. [Table 3] shows Korean container terminals' facilities and parameters as of 2014.

[Table 3] Korean container terminal facilities.

Port	Container terminal	Berth	Total area (m2)	Total quay length (m)	Depth alongside (m)
Busan North Port	Jaseongdae Container Terminal	50,000-ton class 4 10,000-ton class 1	624000	1447	15
	Shinseondae Container Terminal	50,000-ton class 5	1170000	1500	16
	Gamman Container Terminal	50,000-ton class 4	727000	1400	15
	Singamman Container Terminal	50,000-ton class 2 10,000-ton class 1	294000	826	15
Busan New Port	Phase 1-1 (New pier 1)	50,000-ton class 3	840000	1200	16
	Phase 1-2 (New pier 2)	50,000-ton class 6	1202000	2000	17
	Phase 2-1 (New pier 3)	50,000-ton class 2 20,000-ton class 2	688000	1100	18
	Phase 2-2 (New pier 4)	50,000-ton class 2 20,000-ton class 2	553000	1150	17
	Phase 2-3 (New pier 5)	50,000-ton class 4	785000	1400	17
Gwang Yang Port	Phase 2-1	50,000-ton class 2 20,000-ton class 2	532813	1150	16
	Phase 2-2	50,000-ton class 2 20,000-ton class 2	620000	1150	16
	Phase 3-1	50,000-ton class 4	840000	1400	16
Incheon Port	ICT	40,000-ton class 2	249000	600	14
	SICT	20,000-ton class 2	75779	407	11
	E1CT	30,000-ton class 1	102309	259	12
	CJKE	5,000-ton class 2	60000	225	8
Pyeongtaek · Dangjin Port	East Pier	30,000-ton class 4 50,000-ton class 2	704000	1760	14
Ulsan Port	Ulsan New Port	20,000-ton class 4	26326	920	14
	JungIl Container Terminal	20,000-ton class 1	7691	220	12

Chapter 4. DEA Empirical Analysis

4.1. The data

In this study, the output-oriented model provides a benchmark for the container industry, because terminal operators can influence the production level, but they cannot so easily influence and change the production inputs.

We therefore consider that the output-oriented model represents the maximum output that can be obtained for a given input level.

In this paper we assume seven inputs and one output.

Output: y1 = container throughput (CT).

Inputs: x1 = terminal area (TA); x2 = quay length (BT); x3 = quay equipment (QE); x4 = yard equipment (YE); x5 = storage capacity (SC); x6 = depth alongside (DA); x7 = handling capacity (HC).

These inputs are key factors of container terminal operation, and are related to container throughput of port. To confirm the correlation between selected inputs and outputs, this paper applies analysis of Pearson correlation coefficients, and find that output variable of container throughput (Y) highly correlates with inputs (X1~X7) of container terminals, as shown in [Table 4].

[Table 4] Pearson Correlation Coefficients of Selected Input/Output Variables.

Output (year)	Input						
	X1	X2	X3	X4	X5	X6	X7
Y (2012)	0,753	0,661	0,857	0,785	0,916	0,660	0,877
Y (2013)	0,760	0,672	0,829	0,810	0,937	0,710	0,898
Y (2014)	0,750	0,664	0,823	0,802	0,941	0,702	0,880

[Table 5] 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

The Pearson correlation coefficients represent a positive relationship between the variables. The p-value is less than 0.00001, which is less than the significance level of 0.05. The p-value indicates that the correlation is significant.

We selected 12 container terminals in Russia and 19 container terminals in South Korea [Table 5]. Numbers of DMUs are in compliance with the rough rule of thumb of DEA[15].

All the data were collected from annual reports for the year 2012-2014, Port-MIS (Port Management Information System) and from port authorities and terminals official sites. Summary information about input and output variables is shown in [Table 6].

[Table 6] Summary statistics for variables in DEA estimation.

Variable	Description	Unit	Average	Min	Max	SD
Y1	Annual container throughput	TEU	840 902	136 138	3 895 202	812 334
X1	Total terminal area	m^2	445 268	7 691	1 202 000	343 068
X2	Total quay length	m	911	168	2 000	494
X3	Quay equipment	unit	7	1	17	4
X4	Yard equipment	unit	28	8	74	18
X5	Storage capacity	TEU	28 762	2 200	112 319	24 166
X6	Depth alongside	m	13	7	18	3
X7	Handling capacity	TEU	899 892	100 000	2 730 000	1. 5

In the current research, we used DEAP version 2.1 software by Tim Coelli to measure DEA efficiency[16].

[15] Previously discussed in part 2.2.2

[16] This software can be downloaded from: http://uq.edu.au/economics/cepa/deap.php

4.2. DEA – CRS and DEA – VRS results.

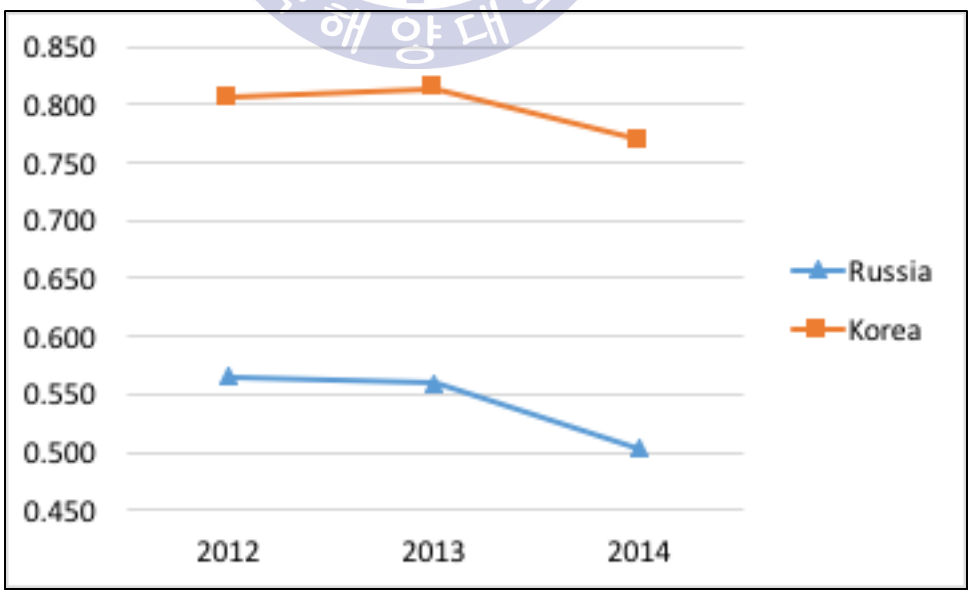
In the first step output-oriented CRS and VRS models have been applied to 31 terminals. [Table 7] and [Figure 33], [Figure 34] shows the efficiency levels of two countries' container terminals.

The DMU with CRS efficiency score equal to 1 is considered to be most efficient amongst the DMUs included in the analysis. The DMU with CRS efficiency less than 1 is deemed to be relatively inefficient. Set of efficient DMUs used as reference set (benchmarks) for each inefficient DMU.

[Table 7] Russian and South Korean container terminals' efficiency

Year	CRSTE		VRSTE		SE	
	Russia	Korea	Russia	Korea	Russia	Korea
2012	0.565	0.806	0.8177	0.8721	0.687	0.904
2013	0.560	0.814	0.8094	0.8571	0.695	0.936
2014	0.503	0.769	0.8142	0.8404	0.623	0.907

The results show that container terminals in Korea have relatively higher CRSTE than in Russia, VRSTE is a little higher in Korea and Scale Efficiency of Korean container terminals is higher than that of Russian container terminals.



[Figure 33] DEA-CRS Efficiency level trends of two countries.

Korean container terminals are close to the efficiency frontier by ranking efficiency scores (CRS) of about 0.8 and mark a shortage of only 2% to reach its potential output.

Russia container terminals with an efficiency score (CRS) of around 0.5 indicating a shortage of about half of their respective potential throughputs.

[Table 8] shows the efficiency level of each DMU, which is measured from the assumptions of CRS and VRS.

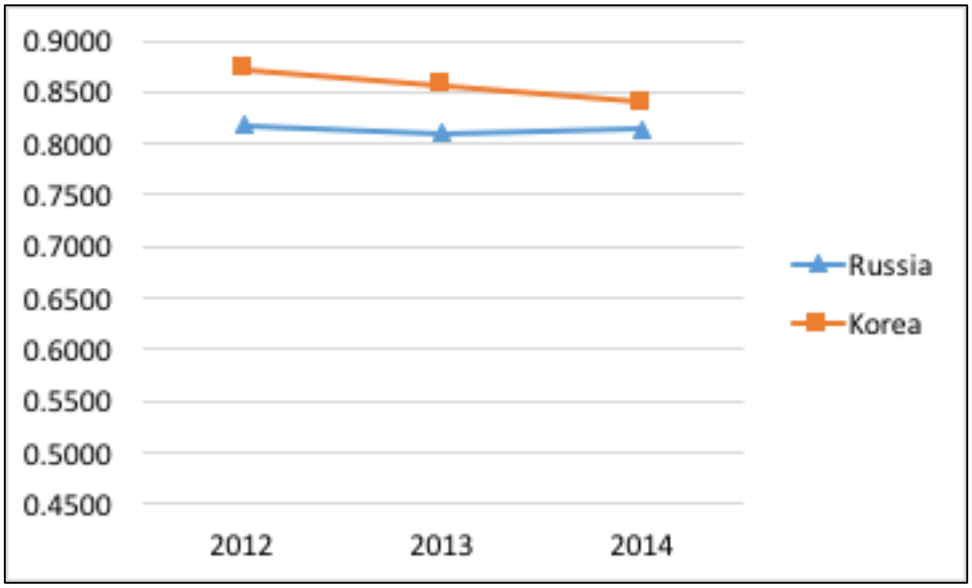
[Table 8] The efficiency levels of DEA-CRS and DEA-VRS models.

		2012	2013	2014	Mean
DMU 1	CRS	0.799	0.687	0.560	0.682
	VRS	0.883	0.833	0.755	0.824
DMU 2	CRS	0.722	0.551	0.479	0.584
	VRS	0.861	0.778	0.737	0.792
DMU 3	CRS	0.381	0.406	0.374	0.387
	VRS	0.698	0.693	0.690	0.694
DMU 4	CRS	0.476	0.435	0.413	0.441
	VRS	0.863	0.863	0.865	0.864
DMU 5	CRS	0.477	0.384	0.312	0.391
	VRS	0.845	0.845	0.901	0.864
DMU 6	CRS	0.321	0.382	0.369	0.357
	VRS	0.787	0.787	0.820	0.798
DMU 7	CRS	0.588	0.663	0.571	0.607
	VRS	1.000	1.000	1.000	1.000
DMU 8	CRS	1.000	1.000	1.000	1.000
	VRS	1.000	1.000	1.000	1.000
DMU 9	CRS	0.407	0.503	0.429	0.446
	VRS	0.652	0.683	0.713	0.683
DMU 10	CRS	0.515	0.560	0.538	0.538
	VRS	0.657	0.631	0.656	0.648
DMU 11	CRS	0.625	0.596	0.496	0.572
	VRS	0.975	0.975	1.000	0.983
DMU 12	CRS	0.467	0.550	0.492	0.503
	VRS	0.591	0.625	0.633	0.616
DMU 13	CRS	0.718	0.675	0.684	0.692
	VRS	0.777	0.764	0.747	0.763
DMU 14	CRS	1.000	0.702	0.796	0.833
	VRS	1.000	0.774	0.833	0.869
DMU 15	CRS	1.000	0.851	0.621	0.824
	VRS	1.000	0.853	0.673	0.842
DMU 16	CRS	1.000	0.980	1.000	0.993

	VRS	1.000	1.000	1.000	1.000
DMU 17	CRS	0.702	0.945	0.867	0.838
	VRS	0.785	0.958	0.889	0.877
DMU 18	CRS	1.000	1.000	1.000	1.000
	VRS	1.000	1.000	1.000	1.000
DMU 19	CRS	1.000	1.000	1.000	1.000
	VRS	1.000	1.000	1.000	1.000
DMU 20	CRS	0.986	1.000	1.000	0.995
	VRS	0.994	1.000	1.000	0.998
DMU 21	CRS	0.290	0.589	0.659	0.513
	VRS	0.456	0.629	0.672	0.586
DMU 22	CRS	0.579	0.531	0.483	0.531
	VRS	0.691	0.655	0.624	0.657
DMU 23	CRS	0.579	0.598	0.574	0.584
	VRS	0.711	0.704	0.676	0.697
DMU 24	CRS	0.576	0.615	0.605	0.599
	VRS	0.693	0.709	0.697	0.700
DMU 25	CRS	0.958	0.923	0.845	0.909
	VRS	0.969	0.926	0.846	0.914
DMU 26	CRS	1.000	1.000	1.000	1.000
	VRS	1.000	1.000	1.000	1.000
DMU 27	CRS	0.669	1.000	1.000	0.890
	VRS	0.957	1.000	1.000	0.986
DMU 28	CRS	1.000	0.962	0.408	0.790
	VRS	1.000	1.000	1.000	1.000
DMU 29	CRS	0.355	0.357	0.347	0.353
	VRS	0.560	0.550	0.549	0.553
DMU 30	CRS	0.897	0.730	0.724	0.784
	VRS	0.976	0.763	0.762	0.834
DMU 31	CRS	1.000	1.000	1.000	1.000
	VRS	1.000	1.000	1.000	1.000
MEAN		0.782	0.777	0.748	

Among Russian DMUs (DMU 1 ~ DMU 12), the average efficiency score of DMU 8 is the highest (equal to 1) in both CRS and VRS models. The average efficiency score of DMU 6 is the lowest in CRS and DMU 12 has the lowest score in VRS model.

For DMU 5 and DMU 6 the difference between CRS and VRS model is relatively large. DMU 13 shows relatively similar results in CRS and VRS models.



[Figure 34] DEA-VRS Efficiency level trends of two countries

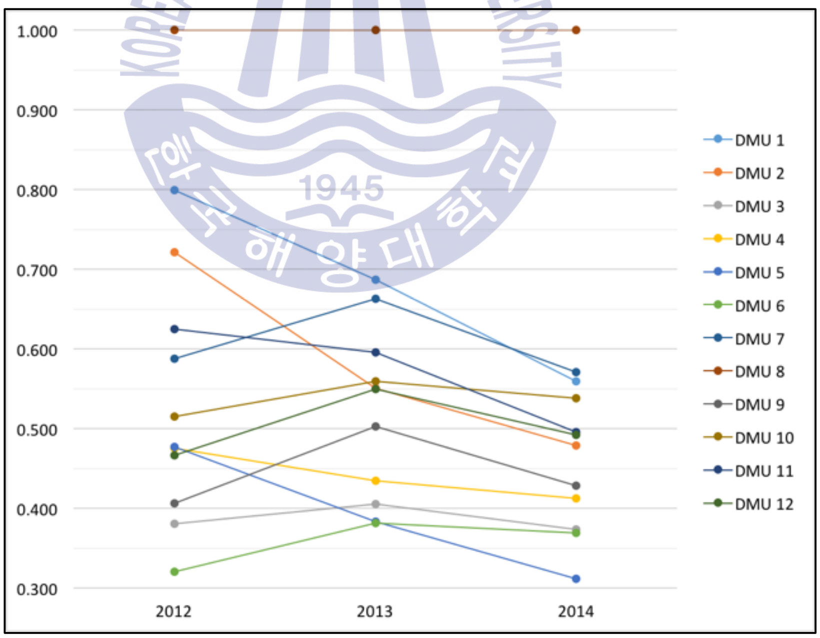
For Korean data (DMU 13 ~ DMU 31) the average efficiency scores of DMU 18, DMU 19, DMU 26 and DMU 31 are the highest (equal to 1) in both CRS and VRS models. The average efficiency score of DMU 29 is the lowest in both CRS and VRS models. In DMU 28 and DMU 29 difference between CRS and VRS models is relatively large. DMU 16, DMU 20 and DMU 25 show relatively similar results in CRS and VRS models.

Of the 31 container terminals, five container terminals were found to be technically efficient. These container terminals together define the best practice frontier; the input utilization process in these container terminals is functioning well. It means that production process of these container terminals is organized without any waste of inputs.

The remaining 26 DMUs have CRS efficiency score less than 1, which means that they are relatively technically inefficient. The results, thus, indicate a presence of marked deviations of the container terminals from the best practice frontier. In this set of inefficient DMU there are range of scores [Table 9]. Nine container terminals in Korea are close to the efficiency frontier by ranking average scores between 0.784 and 0.995. Among Russian DMUs not a single terminal has shown such results in the current research. Eleven terminals showed the average score of around 0.5 (0.503 – 0.692) – six terminals in Russia, five terminals in Korea. That may indicate a shortage of about half of their respective potential throughputs. Six terminals are highly inefficient with their average scores ranging between 0.353 and 0.446 - five terminals in Russia, one terminal in Korea. That may indicate a significant amount of throughput shortages.

These results indicate that some DMUs in the current research (mostly Russian) have to make a substantial improvement in productivity to become efficient. These inefficient DMUs can improve their efficiency by increasing the outputs.

The average CRS efficiency scores among the inefficient banks range from 0.353 for DMU 29 to 0.995 for DMU 20. This finding implies that DMU 29 and DMU 20 can potentially increasing their current output levels by 64.7 percent and 0.5 percent[17], respectively while leaving their input levels unchanged. This interpretation of CRS efficiency scores can be extended for other inefficient DMUs in the sample.



[Figure 35] The efficiency level trends of DEA-CRS models for Russian terminals.

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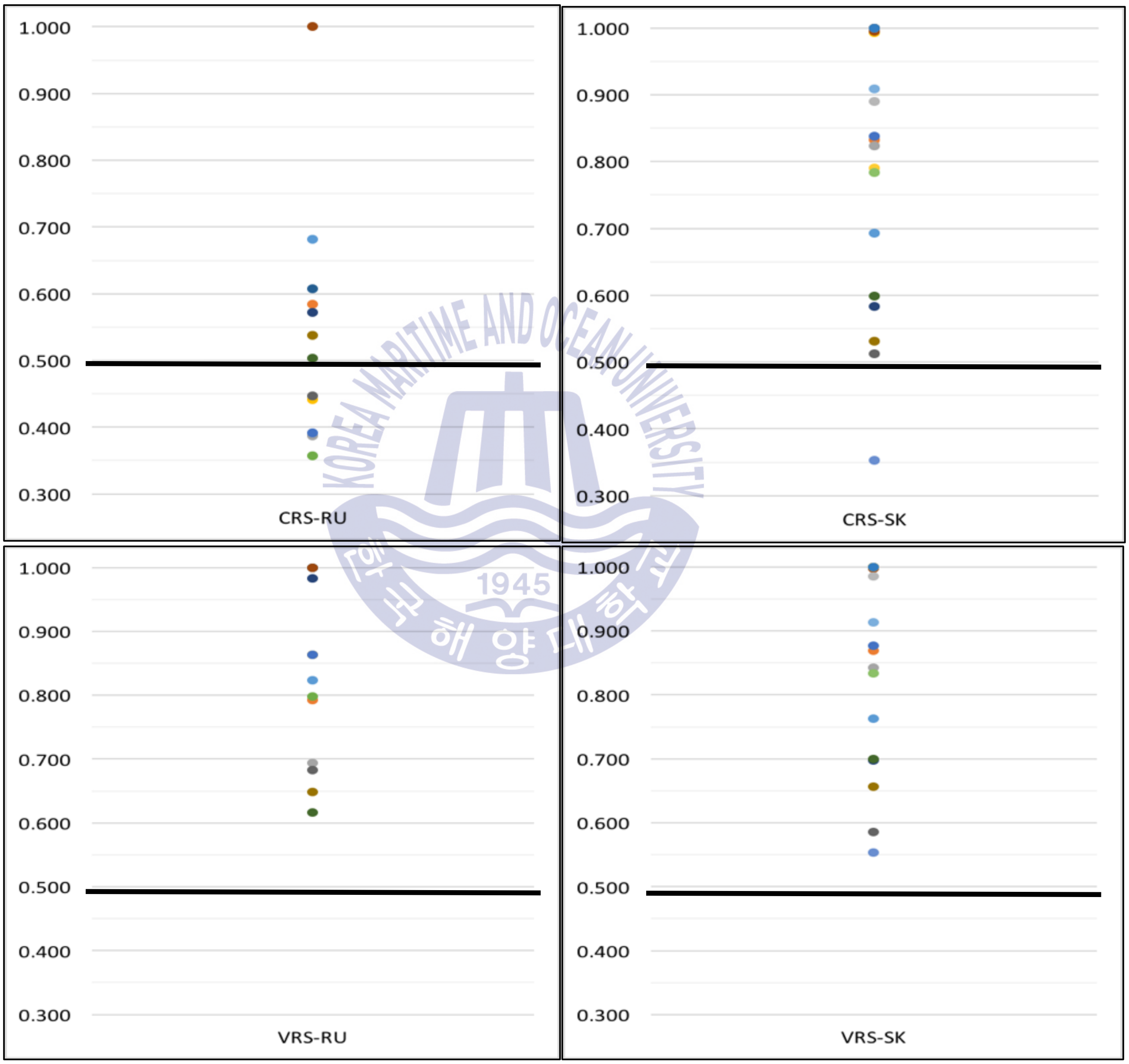
[17] Can be calculated as (1- CRS efficiency)×100

[Figure 35] shows that some of DMUs' efficiency displays tendency to decrease in late period, which can be effect of change in output due to economic slowdown, sanctions on a series of imported goods from Europe and policy of import substitution.

The efficiency measures of VRS [Figure 36] are higher than those of CRS, which can be evident from the definition of VRS.



[Figure 36] Average efficiency level of DEA CRS and DEA VRS models for Russian and Korean container terminals.

It should be noted that DEA model with an assumption of CRS provides information on pure technical (VRS) and scale efficiency (SE) taken together, while a DEA model with the assumption of VRS identifies technical efficiency alone.

The VRS efficiency scores provide that all the inefficiencies directly result from managerial underperformance (i.e., managerial inefficiency) in organizing the container terminals' inputs.

For these DMU that became efficient /more efficient under VRS assumption but have been found to be inefficient under CRS case, we can infer that the CRS inefficiency in these container terminals is not caused by poor input utilization (i.e., managerial inefficiency) rather caused by the operations of the container terminals with inappropriate scale size.

[Table 9] shows CRS and VRS models' efficiency distribution.

[Table 9] Distribution of efficiency level of DEA methods

All DMU presented in 2012, 2013, 2014								
Efficiency	Russia				Korea			
	DEA-CRS		DEA-VRS		DEA-CRS		DEA-VRS	
0.0 - 0.49	18	50%	0	0%	6	11%	1	2%
0.5 - 0.69	13	36%	10	28%	14	25%	11	19%
0.7 - 0.99	2	6%	19	53%	16	28%	22	39%
1	3	8%	7	19%	21	37%	24	42%
SUM	36	100%	36	100%	57	100%	58	102%
Mean value of DMU								
Efficiency	Russia				Korea			
	DEA-CRS		DEA-VRS		DEA-CRS		DEA-VRS	
0.0 - 0.49	5	42%	4	33%	1	5%	0	0%
0.5 - 0.69	6	50%	0	0%	5	26%	4	21%
0.7 - 0.99	0	0%	6	50%	9	47%	9	47%
1	1	8%	2	17%	4	21%	6	32%
SUM	12	100%	12	100%	19	100%	19	100%

Among all DMU presented in 2012, 2013, 2014 in CRS model: for Russian data the range 0.0 – 0.49 is highly frequent, the range 0.5 – 0.69 is not as much frequent and the ranges 0.7 – 0.99 and 1 are less frequent; for Korean data the ranges 0.5 – 0.69, 0.7 – 0.99 and 1 are frequent, the range 0.0 – 0.49 is less frequent.

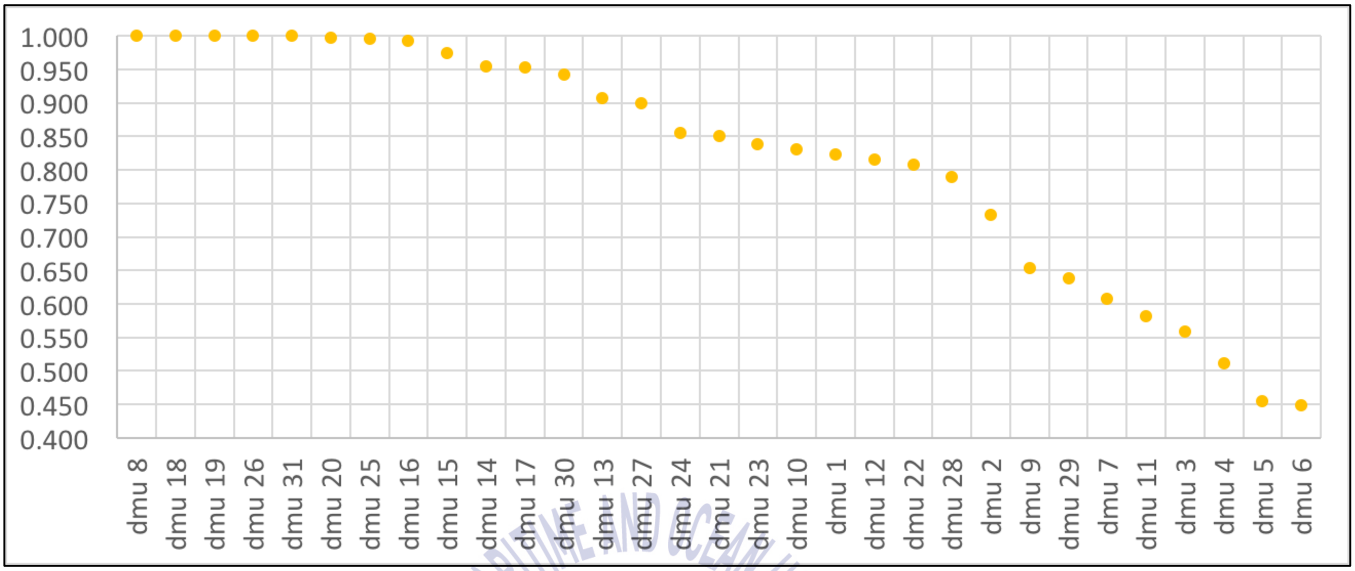
In VRS model for Russian data the range 0.0 – 0.49 has no frequency, the ranges 0.5 – 0.69 and 1 is not as much frequent and the range 0.7 – 0.99 is highly frequent; for Korean data the ranges 0.7 – 0.99 and 1 are frequent, the range 0.5 – 0.69 is not as much frequent and the range 0.0 – 0.49 approximately has no frequency.

4.3. Scale efficiency and Returns to scale.

[Figure 38] shows mean value of scale efficiency by DMU. Compared with Korean container terminals, Russian container terminals' scale efficiency scores are relatively lower. According to [Figure 37] DMU 8, DMU 18, DMU 19, DMU 26, DMU 31 show highest (equal to 1) values of scale efficiency. All of them (except DMU 8) are located in Korea. Next group of 18 DMU (DMU 20 ~ DMU 2 on the [Figure 38]) has relatively high level of scale efficiency: 0.997~0.732. 14 of these DMUs are located in Korea; four DMUs are located in Russia. A group of three DMUs (DMU 11, DMU 3, DMU 4) has level of scale efficiency around 0.5. DMU 5 and DMU 6 showed the lowest values (0.455~0.448). Within the research period, DMU28 Scale Efficiency was rapidly decreasing; DMU21 Scale Efficiency was rapidly increasing. The fact that DMUs have both VRS and SE scores [Table 8, Table 10] less than 1 indicates that CRS inefficiency stems from both VRS and SE inefficiency - technical inefficiency (by poor input utilization) and scale inefficiency (by operations with inappropriate scale size) exit, albeit of different magnitude.

In particular, nine scale inefficient terminals have their average VRS efficiency scores higher than the average SE scores. This implies that the CRS inefficiency is primarily due to the scale inefficiency.

Specifically, three DMUs (DMU 7, DMU 16, DMU 28) have VRS efficiency scores equal to 1, while their SE scores are less than 1. They should adjust their scales of operation to improve their scale efficiencies as well as overall efficiencies.



[Figure 37] – Mean value of scale efficiency by DMU

The fact that DMUs have average VRS inefficiency scores are lower than average SE scores indicated that CRS inefficiency are mainly inefficient due to the VRS inefficiency – technical factors have given more harmful effect on their own whole efficiency rather than scale factors.

These 13 DMU (DMU 10, DMU 12~DMU 15, DMU 17, DMU 21~DMU 25, DMU 29, DMU 30) should improve their productivity and make better use of their resources.

At average Russian container terminals showed VRS efficiency scores higher than average SE scores (7 DMUs) – this implies scale inefficiency.

Korean container terminals showed average VRS inefficiency scores lower than SE scores (12 DMUs) – this implies technical inefficiency.

[Table 11] reports the scale properties of container terminals production yielded by DEA.

When DMU experiences constant returns to scale, it indicates that its current size is optimal. When the current size of DMU is smaller/larger than the optimal size, the DMU experiences increasing/decreasing returns to scale.

[Table 10] Scale efficiency (SE) of DEA Model.

	2012	2013	2014	Sparklines	Mean
dmu 1	0.905	0.825	0.741		0.824
dmu 2	0.839	0.708	0.65		0.732
dmu 3	0.546	0.586	0.542		0.558
dmu 4	0.552	0.504	0.477		0.511
dmu 5	0.564	0.454	0.346		0.455
dmu 6	0.408	0.486	0.45		0.448
dmu 7	0.588	0.663	0.571		0.607
dmu 8	1	1	1		1.000
dmu 9	0.624	0.736	0.601		0.654
dmu 10	0.785	0.887	0.82		0.831
dmu 11	0.64	0.611	0.496		0.582
dmu 12	0.791	0.88	0.776		0.816
dmu 13	0.924	0.883	0.915		0.907
dmu 14	1.000	0.907	0.956		0.954
dmu 15	1.000	0.998	0.923		0.974
dmu 16	1.000	0.980	1.000		0.993
dmu 17	0.895	0.987	0.976		0.953
dmu 18	1.000	1.000	1.000		1.000
dmu 19	1.000	1.000	1.000		1.000
dmu 20	0.992	1.000	1.000		0.997
dmu 21	0.636	0.936	0.981		0.851
dmu 22	0.837	0.811	0.774		0.807
dmu 23	0.814	0.849	0.850		0.838
dmu 24	0.832	0.867	0.868		0.856
dmu 25	0.989	0.997	0.999		0.995
dmu 26	1.000	1.000	1.000		1.000
dmu 27	0.698	1.000	1.000		0.899
dmu 28	1.000	0.962	0.408		0.790
dmu 29	0.634	0.648	0.632		0.638
dmu 30	0.919	0.957	0.949		0.942
dmu 31	1.000	1.000	1.000		1.000

Of the 31 terminals, 20 showed constancy of efficiency scores during the research periods: 10 of them showed increasing returns to scale, five of them showed constant returns to scale, five showed decreasing returns to scale.

Eleven terminals showed fluctuation of scores during the research period, with the tendency of increasing returns to scale at late period.

Russian terminals showed mostly increasing returns to scale, except DMU 10, DMU 12 with decreasing returns to scale and DMU 8 with constant returns to scale.

Korean terminals showed tendency to constant returns to scale (42%) in late periods.

Among the large container terminals[18], constant returns to scale and decreasing returns to scale account for 64% at average.

Among the small container terminals, increasing returns to scale accounts for 52% at average.

The results do suggest a connection between large container terminals and decreasing/constant returns to scale and between small container terminals and increasing returns to scale.

[18] Here for mean throughput more than 1 million TEU, in South Korea there are DMUs 13-20, but in Russia there is DMU 1.

[Table 11] Return to Scale (RTS) of DEA Model

	2012	2013	2014
DMU 1	IRS	IRS	IRS
DMU 2	IRS	IRS	IRS
DMU 3	IRS	IRS	IRS
DMU 4	IRS	IRS	IRS
DMU 5	CRS	IRS	IRS
DMU 6	IRS	IRS	IRS
DMU 7	IRS	IRS	IRS
DMU 8	CRS	CRS	CRS
DMU 9	CRS	IRS	IRS
DMU 10	DRS	DRS	DRS
DMU 11	IRS	IRS	IRS
DMU 12	DRS	DRS	DRS
DMU 13	IRS	IRS	IRS
DMU 14	CRS	IRS	IRS
DMU 15	CRS	DRS	DRS
DMU 16	CRS	DRS	CRS
DMU 17	IRS	IRS	IRS
DMU 18	CRS	CRS	CRS
DMU 19	CRS	CRS	CRS
DMU 20	DRS	CRS	CRS
DMU 21	DRS	DRS	DRS
DMU 22	CRS	IRS	CRS
DMU 23	IRS	IRS	IRS
DMU 24	CRS	IRS	DRS
DMU 25	DRS	DRS	DRS
DMU 26	CRS	CRS	CRS
DMU 27	IRS	CRS	CRS
DMU 28	CRS	IRS	IRS
DMU 29	IRS	CRS	IRS
DMU 30	DRS	DRS	DRS
DMU 31	CRS	CRS	CRS

Chapter 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 firms. However, DEA provides a suitable method for measurement of container terminal operating efficiency.

The research results showed that total average of operating efficiency scores of Korean container terminals is higher in both CCR and BCC models (0.796, 0.857), in comparison with Russian container terminals' efficiency scores (0.542, 0.814). In South Korea the following container terminals demonstrated the best performance in both models: New pier 2 and New pier 3 in Busan New Port, SICT in Incheon Port and JungIl Container Terminal in Ulsan Port. In Russia – Novorossiysk Commercial Sea Port.

While the other container terminals showed variation of performance in different models. The majority of container terminals in Russian dataset are relatively inefficient:

1. 92% of the container terminals have a CRS efficiency lower than 0.70, while in South Korean dataset 31%.
2. 33% of the container terminals have a VRS efficiency lower than 0.70, while in South Korean dataset 21%.
3. 59% of the container terminals have a SE efficiency lower than 0.70, while in South Korean dataset 5%.

In general, Russian terminals showed relatively low Scale Efficiency scores and relatively high VRS efficiency scores that may indicate that resource utilization is efficient, but the operational size of the terminals is not chosen correctly.

Korean container terminals showed relatively high Scale Efficiency scores and relatively low VRS efficiency scores that may indicate that input level (the size of the terminals) is chosen correctly, but container terminals are not using their resources efficiently. Most Russian container terminals showed increasing returns to scale, whereas Korean terminals showed tendency for constant returns to scale.

These findings may be explained by nature of container terminals. Korean container terminals have evolved because of their successful strategies aimed at attaining container hub status. This would inevitably mean that these terminals have, over the years, invested heavily in expensive and evermore advanced equipment in order to attract new container shipping services to the terminal and to enhance the efficiency of their operations. Having achieved a certain level of operational scale, large container terminals have eventually faced the potential limits to their further growth.

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 (for example, "China- Europe" and "China-CIS Countries" routes[19]). They establish large new terminals or improve available terminals by investing in quay length and depth alongside, information systems and modern communication technologies, in order to handle the huge amount of cargo moved by large-sized vessels. This is particularly the case given the level of competition in the market.

In conducting this research, we had several limitations:

1. This study included only terminals from Russian Federation and South Korea, therefore, the DEA model does not give results that reflect the actual position of the DMUs under study in global industry and economic environment.
2. 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 the physical location were not taken into consideration in this research.

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[19] For the empirical research about Asia-Europe routes see Mikulko,J. (2013)

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