Ekonomika i Organizacja Logistyki
4 (3), 2019, 77–85

DOI: 10.22630/EIOL.2019.4.3.25

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Efficiency of Polish seaports against the background of the largest ports in Europe

Efektywność polskich portów morskich na tle największych portów Europy

Abstract. Seaport efficiency are the critical factors for handling of goods in the international supply chains and plays an important role in trade exchange with other countries. It is important to evaluate efficiency of seaports to reflect their status and reveal their position in competitive environment. The main purpose of this article is to use Data Envelopment Analysis to measure the technical efficiency of main seaports in Poland and main seaports in Europe. Data Envelopment Analysis enables one to assess how efficiently a Polish seaports uses the available inputs to generate a set of outputs relative to other units in the data set. The analysis gives a possibility to create an efficiency ranking of seaports.

Key words: seaports, efficiency, Data Envelopment Analysis

Synopsis. Efektywność portów morskich jest kluczowym czynnikiem w obsłudze towarów w międzynarodowych łańcuchach dostaw, a tym samym odgrywa ważną rolę w wymianie handlowej z innymi krajami. Ocena efektywności portów morskich umożliwia zidentyfikowanie ich pozycji w konkurencyjnym środowisku. Głównym celem tego artykułu jest wykorzystanie metody Data Envelopment Analysis do pomiaru efektywności technicznej głównych portów morskich w Polsce i głównych portów morskich w Europie. Analiza DEA pozwala ocenić, jak skutecznie polskie porty morskie wykorzystują dostępne nakłady do generowania wyników (efektów) względem głównych portów morskich w Europie. Przeprowadzenie analizy umożliwi stworzenie rankingu efektywności badanych portów morskich.

Słowa kluczowe: porty morskie, efektywność, Data Envelopment Analysis

Introduction

Recent trends in international trade in an era characterised by the globalisation of production and consumption patterns have led to the increasing importance of container transportation. This is largely because of the numerous technical and economic advantages it possesses over traditional methods of transportation. Standing at the interface of sea and inland transportation, container ports play a pivotal role in the container transportation process. The above-mentioned two characteristics of the contemporary container port industry are particularly true for the container ports in Europe. The paramount importance of the container port industry as the basis for the economic development of the EU and the fierce competition between/among ports have been variously discussed [Notteboom 1997, Wang and Cullinane 2004, Winkelmans 2004].

There have been hardly papers interested comparing the biggest world container ports. The issue of seaports efficiency is usually considered in literature from a one-dimensional perspective, using conventional economic indicators, such as: labour productivity or asset productivity. One the other hand the use of non-parametric methods for the assessment of the efficiency of seaport is also a very popular direction of research.

The purpose of this article is to use the Data Envelopment Analysis to compare the technical efficiency of seaports in Poland, Germany, Belgium and the Netherlands.

Methods

Data Envelopment Analysis (DEA) is a non-parametric mathematical programming approach for measuring relative efficiencies of comparable decision making units (DMUs) with respect to multiple inputs and outputs [Charnes et al. 1978]. The efficiency score in the presence of multiple input and output factors is presented mathematically in the following manner [Charnes et al. 1978]:

$$\max \frac{\sum_{k=1}^{s} u_k y_{kp}}{\sum_{j=1}^{m} v_j x_{jp}}$$

$$\frac{\sum_{k=1}^{s} u_k y_{ki}}{\sum_{j=1}^{m} v_j x_{ji}} \leq 1$$

$$u_k, v_j \geq 0 \quad \forall k$$

s – quantity of outputs;
m – quantity of inputs;
u_k – weights denoting the significance of respective outputs;
v_j – weights denoting the significance of respective inputs;
y_{ki} – amount of output of k-th type in i-th object;
x_{ji} – amount of input of j-th type in i-th object.

Each DMU selects input and output weights that maximize its efficiency score. In general, a DMU is considered to be efficient if it obtains a score of 1 while a score of less than 1 implies that it is inefficient.

The DEA models may be categorised based on two criteria: model orientation and type of returns to scale. Depending on the model orientation a calculation is made of technical efficiency focused on the input minimization or of technical efficiency focused on the output maximisation. But taking into account the type of returns to scale the following models are distinguished: the Charnes–Coopers–Rhodes (CCR) model providing for constant returns to scale [Charnes et al. 1978] and the BCC model providing for changing return to scale [Banker et al. 1984]. The CCR model is built on the assumption of constant returns to scale: this means that inputs and output are linked in a strictly proportional manner. The CCR efficiency scores measure the overall technical efficiency. The Banker–Charnes–Cooper (BCC) model is an extension of the CCR model and allows for the fact that the productivity at the most productive scale size may not be attainable for other scale sizes at which a given DMU is operating. Therefore, the BCC model estimates the pure technical efficiency of a DMU at a given scale of operation. The only difference between the CCR and BCC models is the convexity condition of the BCC model, which means that the frontiers of the BCC model have piecewise linear and concave characteristics, which lead to variable returns-to-scale.

Literature review

Meyrick and associates and Tasman Asia Pacific report, there are two partial productivity measures have been used in port productivity studies [ATC et al. 1998]. First is annually lifts per employee (labour productivity), and it is defined as the number of container movements (container lifts) per terminal employee. The other is net crane rate (capital productivity), and it is defined as the number of container movements (container lifts) per net crane hour. This is the key word of an efficient container terminal to show to the stakeholders for high productivity [Mokhtar and Shah 2013].

On the other hand full efficiency is attained by any port container if and only if none of its inputs or outputs can be improved without worsening some of its other inputs or outputs. Many researchers have used various approaches to evaluate seaport efficiency. There are numerous studies on port performance with Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). For example, Roll and Hayuth [1993] apply a DEA model to measure the efficiency of twenty seaports. Tongzon [2001] investigates the efficiency of sixteen international seaports. Bonilla et al. [2002] employ DEA in order to measure the commodities traffic efficiency of the seaports in Spain. Barros [2003] utilizes DEA in Portuguese seaports and finds that the reform made by the authorities does not fulfil the targets. Similarly, Barros and Athanassiou [2004] compared the efficiency of seaports in Portugal and Greece and provided benchmarks. Cullinane et al. [2004] used a DEA window analysis in order to achieve more robust results. Estache et al. [2004] applied the Malmquist Productivity Index (MPI) to examine if seaport liberalisation was a success in Mexico. Park and De [2004] used a four-stage DEA to investigate the efficiency of the North American seaport infrastructure productivity from 1984 to 1997. Pang [2006] analysed and evaluated 50 major ports in China by using DEA and dynamically evaluated their efficiency based on three years of consecutive data. Min and Park [2008] proposed a hybrid DEA-simulation model to evaluate the relative efficiency of major container terminals in South Korea. Wu and Lin [2008] performed an international comparison of logistic port operations with a focus on India. Ablanedo Rosas and Ruiz-Torres [2009] used DEA to evaluate the efficiency of cargo and cruise operations in major Mexican ports. Ablanedo-Rosas et al. [2010] used a financial ratio-based data envelopment analysis to examine the relative efficiency of 11 major Chinese ports.

Results

The port market in Poland records annual increase in transshipments. The cargo turnover of Polish ports in 2018 reached a record result of over 100 million t. The position of the leader is invariably the Port of Gdansk, where transhipments increased by over 8 million t. The Port of Gdynia and the Port of Szczecin-Świnoujście also recorded higher results (Table 1). The increase in trans-shipments at the Port of Gdansk by 20.7% is the highest dynamics of growth on the Polish coast.

Table 1. Turnover in the biggest Polish seaports in years 2012–2018
Tabela 1. Obrót towarowy w największych polskich portach morskich w latach 2012–2018

Seaport	2012	2013	2014	2015	2016	2017	2018	Change 2018/2017
	thous. t							%
Gdańsk	15 809	17 659	19 405	18 198	19 536	21 225	23 492	10.7
Gdynia	21 267	22 750	23 401	23 174	24 113	25 424	28 614	12.6
Szczecin--Świnoujście	26 897	30 259	32 278	35 914	37 289	40 614	49 032	20.7
Total	63 973	70 668	75 084	77 286	80 938	87 263	101 138	15.9

Source: [Polish ports in 2018. ActiaForum Port Monitor February/March 2019].

The results of Polish seaports are very favourable compared to the Baltic ports. In total, Baltic ports have transshipped over 482.8 million t of cargo. High dynamics and a significant increase in cargo turnover influenced the promotion of the Port of Gdansk to the 4th position in the ranking (Fig. 1). The biggest port in the Baltic Sea is Ust Luga with transhipments at the level of 98.7 million t. The port, which occupies the second position in the ranking is Port St. Petersburg. On the third position was located Port Primorsk (Fig. 1).

The dominant group in the transshipments in Polish seaports was general cargo, which share in total cargo turnover in Polish ports is 48%. The large share of general cargo is due to increased container handling in the Port of Gdansk. The Port of Gdańsk has the largest share in container handling in Polish ports. Through Port of Gdańsk passes 69% of all containers handled by Polish seaports. In 2018 Port of Gdańsk recorded increase in container turnover by over 23% (+368,466 TEU). Container handling in Port of Gdynia increased by 13.1% (+93 173 TEU). However, Port of Szczecin-Świnoujście recorded drop by 13% (–12,128 TEU) – Table 2.

The sample comprises the 6th container ports ranked in 2016. Based on data availability, the ports are listed below according to the country where they are located:

- Germany: Hamburg;
- Belgium: Antwerp;

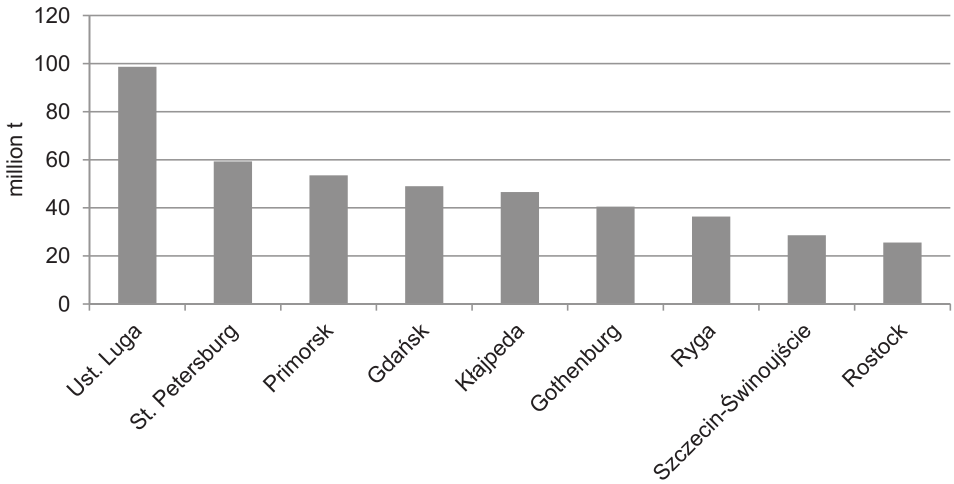

Figure 1. The busiest Baltic seaports in 2018
Rysunek 1. Najbardziej aktywne porty bałtyckie w 2018 roku
Source: [Polish ports in 2018. ActiaForum Port Monitor February/March 2019].

Table 2. Container handling in the biggest Polish seaports in years 2012–2018
Tabela 2. Obsługa kontenerów w największych polskich portach morskich w latach 2012–2018

Seaport	2012	2013	2014	2015	2016	2017	2018	Change 2018/2017
	TEU							%
Gdańsk	928 399	1 177 626	1 212 054	1 091 202	1 299 373	1 580 508	1 948 974	23.3
Gdynia	676 349	729 518	684 796	642 195	642 195	710 698	803 871	13.1
Szczecin--Świnoujście	52 179	62 307	87 784	90 869	90 869	93 579	81 451	–13.0
Total	1 656 927	1 969 451	1 863 782	2 032 437	2 032 437	2 384 785	2 834 296	18.85

Source: [Polish ports in 2018. ActiaForum Port Monitor February/March 2019].

- Netherlands: Rotterdam;
- Poland: Gdańsk, Gdynia, Szczecin-Świnoujście.

Since the main activity of container ports is handling containers only one output will be identified in this study and four variable input factors:

- input x_1 – number of berths (total number of berths of all terminals);
- input x_2 – terminal area (total terminal area in m^2);
- input x_3 – employees (total number of employees);
- input x_4 – quay length (total quay length in m);
- output y_1 – annual throughput (annual port throughput in TEU).

Data Envelopment Analysis models can be distinguished according to whether they are input- or output-oriented. The former is closely related to operational and managerial issues, whilst the latter is more related to planning and macroeconomic strategies. Both orientations have their usefulness in the container port industry context. 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 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 maximised given the input. From this point of view, the output-oriented model provides a benchmark for the container industry. Finally, it has been decided that output-oriented models should be chosen as the basis for the analysis undertaken herein.

Table 3 indicates the BCC model which are used to evaluate container ports. In 2016, the average technical efficiency (BCC model) score is 0.772. Two out of the six container ports included in the analysis are identified as efficient. The highest average indices of technical efficiency were recorded in the Rotterdam and Antwerp. In turn, the lowest annual average indices of efficiency were observed in the Szczecin seaport (Table 1). The ports located in Rotterdam and Antwerp have high technical efficiency scores, which implies that they can well exploit their facilities and serve a large amount of containers (TEUs). The Szczecin-Świnoujście has relatively low technical efficiency. Those ports accommodate a large number of containers with limited performance, as they do not efficiently manage their resources.

With the information about the returns to scale properties of the individual terminal production yielded by DE–BCC model, in 2016, five out of the six samples exhibits decreasing returns to scale, only 1 seaport in Szczecin showed constant returns to scale (Table 3).

Table 3. The technical efficiency and returns to scale of seaports in 2016
Tabela 3. Efektywność techniczna i korzyści skali w portach morskich w 2016 roku

DMU	DEA, BCC model Technical efficiency	RTS Return to Scale
Rotterdam seaport	1	decreasing
Antwerp seaport	1	decreasing
Hamburg seaport	0.97	decreasing
Gdańsk seaport	0.95	decreasing
Gdynia seaport	0.63	decreasing
Szczecin-Świnoujście seaport	0.09	constant
Average	0.77	

Source: own calculations.

Table 4 contains the improvements required in order to make inefficient seaport efficient. Projections suggest that the total number of TEUs handled should increase as follows: Hamburg by about 10%, Gdańsk 17%, Gdynia 154%, Szczecin-Świnoujście 2,174%.

Table 4. Projections values of output
Tabela 4. Prognozowana poprawa wyników

DMU	Projections improvement (TEUs handled) (%)
Hamburg seaport	10
Gdańsk seaport	17
Gdynia seaport	154
Szczecin-Świnoujście seaport	2 174

Source: own calculations.

Conclusions

In this paper, DEA analysis has been applied to determine the relative efficiency of Polish main seaport and Europe's leading container terminals. From the practical point of view the results of this analysis can be summarized as follows:

- The average efficiency of container terminals under study amounts 0.77.
- Rotterdam and Antwerp were the leaders in technical efficiency. They have the highest position in the ranking.
- Parameters of transportation activity in efficient seaports may constitute a benchmark for other (inefficient) evaluated entities.
- It was found that, while one seaport (Szczecin-Świnoujście) container terminals are scale-efficient, in general, rest of the container ports under study exhibit decreasing returns to scale. However, most of the container terminals that are large in production scale are more likely already to be associated with higher efficiency scores. These findings are particularly informative for policy-makers and corporate decision-makers. For example, these findings provide some theoretical support for the increasing tendency towards the construction of large-scale container ports (mega-ports) that is progressing world-wide, These findings, however, also suggest that not every individual container terminal (even ones that are currently small) follows the law of increasing returns to scale. Decision-makers, both commercial and political, will need to study carefully, therefore, their own particular set of circumstances and general situation.

From the methodological point of view the proposed approach for ranking and benchmarking of transportation sectors has a universal character and can be applied in a variety of industries. It is composed of the following stages: 1 – recognition of the DMU; 2 – definition of the variables based on the literature review; 3 – definition of DEA model (model orientation and type of returns to scale); 4 – computational experiments leading to the final ranking.

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