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ANALYSIS OF THE EFFICIENCY OF PORT CONTAINER TERMINALS WITH THE USE OF THE DATA ENVELOPMENT ANALYSIS METHOD OF RELATIVE PRODUCTIVITY EVALUATION

Bogusz WIŚNICKI, Leszek CHYBOWSKI, Maksymilian CZARNECKI
Maritime University of Szczecin

Abstract:
The article presents a method for evaluating the efficiency of port container terminals. The research was conducted for nine European terminals which use different handling technologies. The terminals have been divided due to the level of automation of transport processes. In the efficiency research DEA (Data Envelopment Analysis) method is applied, that was previously used in studies of the relative productivity in the industry. This method allows you to multicriteria process analysis based on the properly selected production system model processing input parameters on output. Conclusions from analysis can be a ground for making a decision on organizational or investment issues.

Key words: *container terminals, transport efficiency, transport system modelling*

INTRODUCTION

Nowadays there is a container terminal in every large seaport. A characteristic feature of port container terminals is that everyone is unique in their own way despite offering the same port-handling services. The differences arise from the adopted concept of spatial and technological solutions. External factors that determine the most important technical and technological parameters of container terminals include: the water and land access, the available development area, the maximum ships' size, the throughput measured in trains and trucks, financial limits of an investment [15]. Given the above considerations, local terminals are tailored to local needs and at the same time meet the standards of global or regional container shipping line networks.

There is a need to evaluate the effectiveness of an individual container terminal operating on the competitive port market. Hence, it must be the comparative assessment. However, comparison of the first choice technical and operational parameters of the selected terminals can lead to erroneous conclusions. Hence, the properly matched technological, economic and social parameters of given container terminals can bring the desired results in the comparative analysis. This type of advanced analysis requires the use of dedicated tools.

The conclusions of the terminal efficiency analysis are very important and make it possible to take a rational decision regarding the modernisation of the existing port infrastructure or building a new one [3]. Taking this into account, the authors propose the use of the method proven in studies of the relative productivity of the industrial units called the DEA (Data Envelopment Analysis). This method allows for the evaluation of the effectiveness of different technological entities subject to the adoption of comparable input and output parameters. The purpose of further research is to check the effectiveness of the DEA method regarding the production processes of port container terminals.

HANDLING TECHNOLOGY OF PORT CONTAINER TERMINALS

Port container terminal is a node transport system strongly associated with two external systems, i.e. water transport system and land-based transport system. Both systems can be considered as the input and the output for the container terminal node system. In practice, we do not treat a container terminal as a transport system but as a transhipment hub offering water-side and land-side transhipment of containers. The space between the ships transhipment interface and trucks and trains transhipment interfaces creates an integral part of the terminal that has a specialised infrastructure and technical equipment. The basic transport processes of the container terminal include: handling, internal carriage and storage of loading units.

In the typical port container terminal we can identify five functional areas:

1. Quay equipped with ship-to-shore (STS) transhipment facilities,
2. Waterfront area dedicated for movement of terminal transport vehicles,
3. Container yards equipped with transhipment and storage facilities,
4. Trucks loading area with transhipment facilities,
5. Intermodal yard with transhipment facilities,
6. Gates equipped with inspection and monitoring facilities.

Transport technology differs between enumerated functional areas above. The biggest differences arise from the degree of automation of terminal equipment (Table 1).

Table 1
Transport equipment used in port container terminals

Terminal area	Equipment
quay	Ship-to-Shore Gantry Crane (STS) Automatic Ship-to-Shore Gantry Crane (ASTS)
waterfront area	Terminal Tractor Unit (TTU) Automated Guided Vehicle (AGV) Self-loading Automated Guided Vehicle (Lift-AGV)
container yards and trucks loading area	Rubber Tyred Gantry Crane (RTG) Rail Mounted Gantry Crane (RMG) Automated Stacking Crane (ASC) Straddle Carrier (SC) Automated Lifting Vehicles (ALV) Reach Stacker (RS)
intermodal yard	Rubber Tyred Gantry Crane (RTG) Reach Stacker (RS)

Source: [9, 12].

Terminals with all facilities operated manually can be defined as a conventional terminals. Semi-automatic terminals use at least one transhipment facility controlled automatically or remote-controlled. At the automatic terminals all or almost all transport operations are performed automatically. The most difficult process to automate is container handling at intermodal yard, i.e. loading operations of railway wagons, so in most cases this process is largely controlled manually.

The selection of the terminal equipment is of great importance and affects the productivity of the whole terminal. Equipment operating at the different terminal functional areas should fit together to form the ship-to-truck or the ship-to-train transhipment processes. In addition, in case of hub terminals the ship-to-ship transhipment process is carried out [18]. Organizational and technical integration of each of the processes and interrelationships and synergies between processes impact on the operation efficiency of the terminal. Customers of the terminal, which are the shippers, carriers and transport operators expect reliability, high performance, and flexibility of services offered [4, 5]. All these expectations are difficult to meet, but the continuous improvement of the terminal transport system by choosing better technological solutions and better processes management methods is critical in a competitive market.

One can observe the growing number of new terminals equipped with automatic handling equipment. Their owners expect their costly terminals will have higher performance, greater reliability, and lower unit costs. At the same time, the owners of the existing non-automatic terminals make significant investments upgrading the terminal devices and management systems in order to achieve the same objectives. In practice, the actual operating parameters of existing and newly constructed terminals are difficult to verify, especially in a situation of strong market competition and, lasting for a few years lower than expected demand for terminal services.

In order to compare the productivity of terminals that use different transport technology one must specify differences in handling equipment. Assuming three technology types of container terminals: conventional, semi-automatic and automatic, standard handling equipment enabling transhipment processes is shown in Table 2.

Each of presented transhipment processes precedes the phase, during which the containers are transhipped from the ship moored to the quay, i.e. the ship-side operations. These handling operations are carried out with the use of ship-to-shore gantry cranes (STS) or automatic ship-to-shore gantry cranes (ASTS), the first are used in conventional terminals and the second in semi-automatic or automatic terminals.

At conventional terminals many variants of handling equipment exist, of which the following four are the most common:

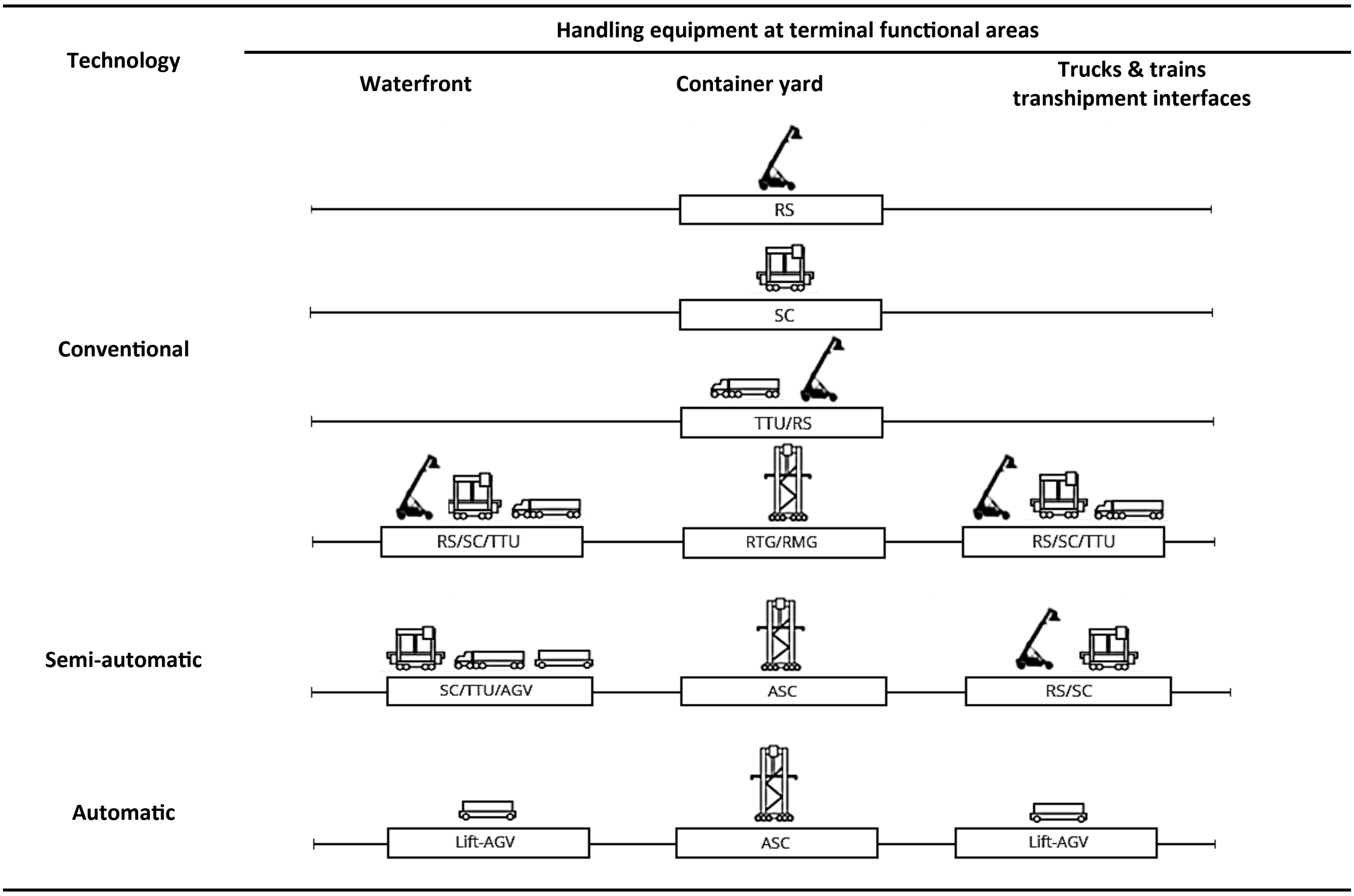
1. All terminal handling operations are performed by reach stackers (RS),
2. All terminal handling operations are performed by straddle carriers (SC),
3. Terminal tractors (TTU) are used for internal carriage and all loading operations are performed by reach stackers (RS),
4. Internal carriage and trucks and trains loading operations are performed by using terminal tractors (RS), straddle carriers (SC) or terminal tractors (TTU) and container yard handling operations are performed by gantry cranes (RTG or RMG).

At semi-automatic terminals most common variant of the handling equipment include the use of terminal tractors (TTU), straddle carriers (SC) or automated guided vehicles (AGV) for internal carriage, and the use of automated stacking cranes (ASC) container yard handling operations. Trucks and trains loading operations are performed by reach stackers (RS) or straddle carriers (SC).

Fully automatic port container terminals are equipped with self-loading automated guided vehicles (Lift-AGV), which perform internal carriage. Container yard handling operations are performed by automatic stacking cranes (ASC). Lift-AGV unlike AGV have option to load or unload autonomously, so the vehicles don't need to wait for the gantries at land-side and water-side container yard interfaces.

The above characteristics of the three types of port container terminals take into account only the equipment differences excluding the equally important issues as terminal infrastructure parameters or terminal management systems. It is obvious that parameters such as the quay length, the container yard area and the maximum height of the storage must be matched to the handling technology requirements. The level of automation of transhipment processes forces also the use of the appropriate terminal identification, monitoring and control subsystem. As a rule, these subsystems are an integral part of the main Terminal Operational System (TOS) [16].

Table 2
Handling technology in port container terminals



Source: [7, 12, 17].

METHODS OF ASSESSING THE EFFICIENCY OF CONTAINER TERMINALS

The efficiency of port container terminals is difficult to assess due to the very large number of parameters affecting its performance. The terminal is a complex system, where the interaction between the terminal equipment, containers, and infrastructure is accompanied by uncertainty about the future container market. There are a lot of decision-making issues related to strategic and operational planning as well as real time planning [9].

Efficiency is the ratio between the effects (output parameters) and the used resources (input parameters). It may be presented in the many aspects: economic, technical or allocative one. There are many ways to measure the terminal effectiveness, and the choice depends on what kind of performance one is going to evaluate. In the following research analysis the technical efficiency of the port container terminals will be evaluated [10].

In order to analyse transport efficiency one can use efficiency analysis methods used to measure productivity and efficiency of enterprises. The existing models can be divided into parametric and non-parametric methods [14]:
Parametric methods include:
1. Least Squares (LS) method, which assumes that all observed units are equally efficient,
2. Deterministic Frontier (DF) method, for which an example might be Corrected Ordinary Least Squares (COLS) models allowing for inefficiency between the observed units,
3. Stochastic Frontier (SF) method, these are models which assume both inefficiency and random noise method for the analysed units.

Non-parametric methods can be subdivided into:
1. Total Factor Productivity (TFP) method, used to calculate the ratio of outputs to inputs with the use of appropriate set of weights,
2. Data Envelopment Analysis (DEA) method, which utilizes mathematical programming to determine the efficient frontier and distance of the analysed parameter from that frontier. It is thus possible to calculate the relative efficiency for all analysed cases.

Of the aforementioned methods: DEA, DF and SF allow to evaluate the technical efficiency of the transport system. Other models are designed for other purposes [19]. To carry out further research in this study the DEA method was selected. This method allows to apply a variety of input and output parameters, the values of the parameters may have different units, and this method does not require the use of a large number of comparable systems.

Data Envelopment Analysis (DEA) is a nonparametric method developed by Charnes, Cooper and Rhodes in 1978 [1]. Their research work led to conceiving a model known as CCR, whose name was derived from the first letters of the authors' surnames. In Poland DEA method was adopted in 1998 but is still little known. This method is very popular in the United States and in countries of Western Europe [7, 13].

The authors of the DEA method which defines efficiency as a ratio of a single output to a single input, employed this method in a multi-dimensional situation, in which there is more than one input and more than one output. In the case of best practice frontiers, their efficiency ratio is one, which is when units are effective. In the case of units situated below the boundary of the production possibility set, the ratio is below one and indicates their level of inefficiency (Figure 1).

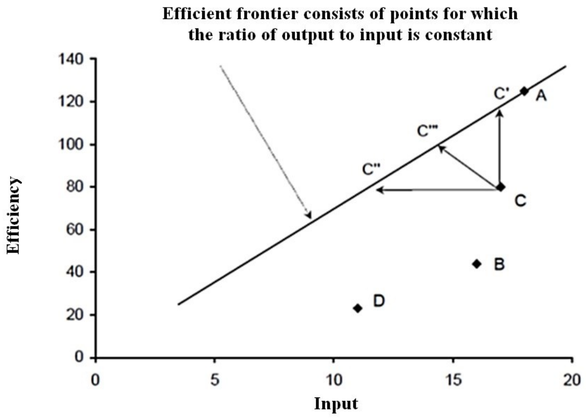


Fig. 1 Efficiency of decision units and efficient frontier
Source: [7].

Efficiency in the DEA method is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs. The efficiency is relative because it is constructed in relation to the whole analysed group of units. In the approach applied in constructing DEA models a user is not required to attribute weights to each kind of input and output themselves, as is necessary in the case of traditional index methods. This approach does not require designation of a function of a given phenomenon, which is usually essential when using statistical and econometric regression functions. The DEA method uses mathematical linear programming, which can cope with a considerable number of variables and relations among them. Another advantage of the suggested method is the possibility of analysing inputs and outputs expressed in any units [8].

Basic model in the DEA method is a CCR model. Other models, i.e. Additive Model (ADD) or Slack-Based Measure (SBM), are modifications of the basic model [6]. The CCR model were used to calculate the efficiency of the chosen port container terminals as presented below.

RESEARCH RESULTS

In order to measure the efficiency of container terminals using the DEA method nine European port container terminals were selected: three conventional terminals, five semi-automatic terminals and one fully-automatic terminal (Table 3). Selected terminals, as to the quantity and size, can be considered as representative for Europe. These terminals, with the exception of the TTI Algericas, are located in the Northern Europe ports and having the common hinterland, compete with each other. In accordance with the DEA model requirements, five input parameters (the length of the quay, the maximum allowable ship's draught, the number of ship-to-shore gantry cranes, the number of container yard gantry cranes, the container yard capacity) and one output parameter (the annual throughput of the terminal) were selected. Choice of parameters depended on their reliability and availability.

All terminals use the STS cranes for the ship-side transhipment operations. The APM Terminal Maasvlakte II in Rotterdam as the only one is equipped with the automated STS cranes. At conventional terminals the RTG cranes are used, and the semi-automatic and automatic terminals use rail mounted ASC cranes. Additionally, at the CTB Terminal in Hamburg part of container yard operations is handled by SC cranes. Table 4 shows the values of the input and output parameters for the selected port container terminals.

The completed analysis with the help of DEA model software available on-line (www.deaos.com) allowed the result shown in Figure 2. The analysis used CCR model in the input-oriented option, which means that model aims at maximizing the terminal throughput at the upper limit of the input parameters. Efficient container terminals proved to be DCT Gdańsk, CTB Hamburg and APM Maasvlakte II. Each of these terminals represents a different type in terms of technology used, i.e. conventional, semi-automatic and automatic. Inefficient terminals are: DB Port Szczecin, BCT Gdynia, CTA Hamburg, Euromax Rotterdam, DPW Antwerp and TTI Algericas. Also among these terminals one can find all three technology types.

Table 3
The classification of analysed container terminals

Container terminal	Technology	Handling equipment
DB Port Szczecin	Conventional	STS, RTG
BCT Gdynia	Conventional	STS, RTG
DCT Gdańsk	Conventional	STS, RTG
CTA Hamburg	Semi-automatic	STS, ASC, SC
Euromax Rotterdam	Semi-automatic	STS, ASC
DPW Antwerp	Semi-automatic	STS, ASC
TTI Algericas	Semi-automatic	STS, ASC
CTB Hamburg	Semi-automatic	STS, ASC, SC
APM Maasvlakte II	Automatic	ASTS, ASC

Source: [2].

Table 4
The input and output parameters of the DEA method analysis

Container terminal	Input parameters					Input parameter
	Quay length [m]	Ships' draught [m]	Number of STS [units]	Number of RTG/ASC [units]	Yard capacity [TEU]	Throughput [million TEU]
DB Port Szczecin	240	9.15	2	4	3260	0.12
BCT Gdynia	800	12.70	6	18	20000	0.80
DCT Gdańsk	650	16.50	6	20	29000	1.50
CTA Hamburg	1400	16.70	15	52	28860	2.30
Euromax Rotterdam	1500	19.60	16	58	29150	1.80
DPW Antwerp	1860	16.00	9	14	17129	1.00
TTI Algericas	1200	18.00	8	32	21600	1.00
CTB Hamburg	2850	15.20	25	15	25700	2.90
APM Maasvlakte II	1000	19.15	8	54	18000	2.70

Source: [2].

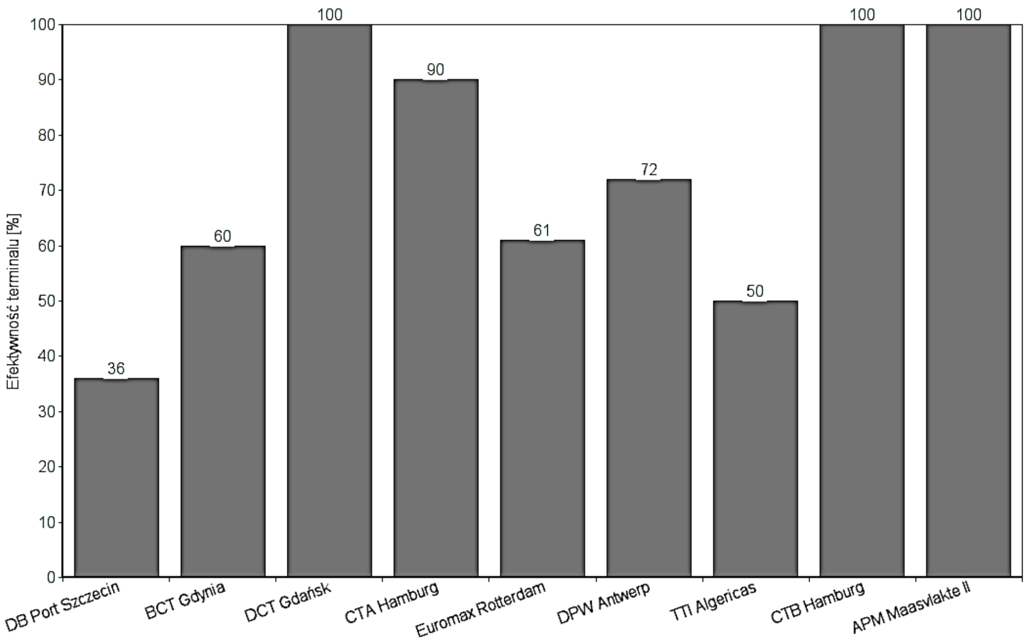


Fig. 2 The results the efficiency analysis

The analysis of the results allows for the identification of the following dependencies between terminal parameters and its throughput:

1. The quay length and maximum ship's draught do not impact directly on the terminal efficiency, although in most cases, the greater length and draught means the greater handling capacity,
2. A large number of STS and container yard cranes does not guarantee the terminal effectiveness; it seems the cranes' productivity is more important, which is an argument in favour of the automated terminals,
3. Capacity of container yard is dependent on the storage technology, in particular the height of container blocks is a key parameter; the results show that a fully automated terminal APM Maasvlakte II reached the best efficiency despite the relatively small container storage capacity.

CCR model used in the analysis focused on results allows not only to designate the efficient and inefficient terminals, but also gives a directions for improving inefficient terminals. Effective throughput is greater and the model assumption for achieving it is the use of technology of effective terminals. The results of the analysis is presented in Table 5.

The shown improvement indicators for inefficient terminals seem to be very telling. If inefficient terminals improve their technology, their throughput should increase from 11% in case of CTA Hamburgand up to 219% in case of BCT Gdynia, in proportion to the status quo. Especially, in case of Polish ports the terminal capacity reserve is significant. The increased efficiency of analysed terminals can be obtained through the technical and operational modernisation.

Table 5
The throughput improvement indicators for inefficient terminals

Container terminal	Throughput [million TEU]		
	Present	**Effective**	**Difference**
DB Port Szczecin	0.12	0.33	175%
BCT Gdynia	0.80	2.55	219%
CTA Hamburg	2.30	2.55	11%
Euromax Rotterdam	1.80	2.94	63%
DPW Antwerp	1.00	1.39	39%
TTI Algericas	1.00	1.98	98%

CONCLUSIONS

The DEA method of relative productivity evaluation has proven to be useful in assessing the technological efficiency of port container terminals. Based on conducted analysis it is possible to formulate the conclusions as follows:

1. Terminal efficiency is not closely related to the level of their automation, therefore conventional terminals can be fully effective,
2. Efficiency of container terminals depends on a great number of input parameters, which should be specific to terminals being compared,
3. There are no perfect values of input parameters of port container terminal to guarantee its effectiveness,
4. Interpretation of results based on a limited number of input parameters is generally not reliable.

To make the DEA method more reliable one should analyse the sufficient number of input parameters. The parameters that have not been included in the above analysis represent two categories: macroeconomic factors (labour costs, economic development of the port hinterland, and the quality of the transport infrastructure connecting the terminal with its hinterland) and social factors (demographic situation, qualifications of employees, environmental awareness). In addition, in the DEA model analysis one should compare large numbers of terminals. One of the conclusions of previous research with DEA models is that the amount of analysed entities should be approximately 3-5 times greater than the total number of input and output parameters [11]. Taking into account these recommendations the authors wish to conduct further research using alternative DEA models and matching sets of parameters to evaluate effectiveness of transport processes.

REFERENCES

[1] A. Charnes, W.W. Cooper and E.L. Rhodes. "Measuring the efficiency of decision making units", *European Journal of Operational Research*, vol. 2(6), 1978, pp. 429-444.

[2] *Container Terminal Automation* (2014), City of Los Angeles, Harbor Department, Planning and Economic Development Division [Online]. Available:https://www.portoflosangeles.org

[3] L. Chybowski. "A New Aproach To Reliability Importance Analysis of Complex Technical Systems", *Journal of Polish CIMAC*, vol. 6(2), 2011, pp. 65-72.

[4] L. Chybowski and K. Gawdzińska. „On the Possibilities of Applying the AHP Method to a Multi-criteria Component Importance Analysis of Complex Technical Objects", in Advances in Intelligent Systems and Computing Janusz Kacprzyk Ed., vol. 445, Springer International Publishing, 2016, pp. 701-710.

[5] L. Chybowski and K. Gawdzińska. „On the Present State-of-the-Art of a Component Importance Analysis for Complex Technical Systems", in *Advances in Intelligent Systems and Computing*Janusz Kacprzyk Ed., vol. 445, Springer International Publishing, 2016, pp. 691-700.

[6] A. Ćwiąkała-Małys and W. Nowak. „Sposoby klasyfikacji modeli DEA", Badania Operacyjne i Decyzje, no. 3, 2009, pp. 5-18.

[7] A. Domagała. „Metoda Data Envelopment Analysis jako narzędzie badania względnej efektywności technicznej", *Badania Operacyjne i Decyzje*, no. 3-4, 2007, pp. 21-34.

[8] H.K. Hwan Kim and L. Hoon. "Container Terminal Operation: Current Trends and Future Challenges", in *Handbook of Ocean Container Transport Logistics* Chung-Yee Lee and Qiang Meng Ed., Springer, Hong Kong 2015, pp. 43-74.

[9] K.H. Kim and H.O. Günther. *Container Terminals and Cargo Systems*, Berlin: Springer-Verlag, 2007.

[10] J. Kozłowska. „Zastosowanie metody DEA w analizie efektywności działania przedsiębiorstw usługowych", *Zeszyty Naukowe Politechniki Śląskiej*, z. 73, 2014, pp. 305-317.

[11] A. Masternak-Janus and M. Rybaczewska-Błażejowska. „Analiza efektywności innowacyjnej przedsiębiorstw przemysłowych w Polsce z wykorzystaniem metody DEA", in *Innowacje w Zarządzaniu i Inżynierii Produkcji* Ryszard Knosala Ed., Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole 2016.

[12] F. Meisel. *Seaside Operations Planning in Container Terminals*, Berlin: Physica-Verlag, 2009.

[13] P. Pachura and T. Nitkiewicz, „Ocena efektywności wybranych komponentów kapitału intelektualnego regionów przy zastosowaniu metody Data Envelopment Analysis", *Organizacja i Zarządzanie*, no. 1, 2008, pp. 21-38.

[14] A. Smith, P. Wheat and M. Wolanski. Public transport operations costs, in *Handbook of Research Methods and Applications in Transport Economics and Policy*, Edited by Chris Nash, Edgar Edward Publishing, USA, 2015, pp. 38-70.

[15] B. Wiśnicki. „Mierniki jakości terminali kontenerowych", in *Koniunktura w gospodarce światowej a rynki żeglugowe i portowe*, H. Salmonowicz, Ed., Szczecin: Wydawnictwo Kreos, 2009, pp. 279-290.

[16] B. Wiśnicki, L. Chybowski and B. Pietrzyk. „Systemy informatyczne wspomagające pracę potowych terminali kontenerowych", in *Systemy Wspomagania w Inżynierii Produkcji – Inżynieria Systemów Technicznych*, vol. 11, no. 2, 2015, pp. 227-239.
[17] B. Wiśnicki and M. Czarnecki. „Procesy logistyczne portowego terminalu kontenerowego", in *Systemy zarządzania logistycznego w transporcie morskim*, H. Salmonowicz, Ed., Szczecin: Wydawnictwo Zapol, 2013, pp. 233-240.
[18] B. Wiśnicki and M. Klabacha. „Analiza porównawcza koncepcji rozwoju terminalu kontenerowego w Porcie Szczecin", in *Porty i żegluga morska na rynku transportowym Unii Europejskiej – Funkcjonowanie. Rozwój. Ekologia*, H. Salmonowicz, Ed., Szczecin: Wydawnictwo Zapol, 2011, pp. 237-247.
[19] B. Wiśnicki and A. Kujawski. "Conditions for the development of port city transport infrastructure illustrated with the example of Szczecin agglomeration", in *2nd International Conference "Green Cities – Green Logistics for Greener Cities"*, Szczecin, Poland, to be published in December 2016.

dr inż. Bogusz Wiśnicki
Maritime University of Szczecin
Faculty of Transport Engineering and Economics
ul. Henryka Pobożnego 11, 70-507 Szczecin, POLAND
e-mail: b.wisnicki@am.szczecin.pl
dr hab. inż. Leszek Chybowski
Maritime University of Szczecin
Faculty of Marine Engineering
ul. Wały Chrobrego 1-2, 70-500 Szczecin, POLAND
e-mail: l.chybowski@am.szczecin.pl
mgr inż. Maksymilian Czarnecki
Maritime University of Szczecin
Faculty of Transport Engineering and Economics
ul. Henryka Pobożnego 11, 70-507 Szczecin, POLAND
e-mail: m4ks@o2.pl