Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-44322
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 21, No.4, 2023
Review Paper
Paper number: 21(2023)4, 1150, 1098-1107

DEFINING TERMINALS` EFFICIENCY IN A SEAPORT USING DATA ENVELOPMENT ANALYSIS

Deda Đelović

Adriatic University, Maritime faculty Bar, Port of Bar, Bar, Montenegro
** deda.djelovic@lukabar.me*

Efficiency is the capability of a port or terminal to fit the optimum number of inputs to a given output level. In principle, there are three required elements for measuring efficiency: decision making unit (DMU), output variables, and input variables. The measurement of efficiency in production units and the identification of sources of their inefficiency is a precondition to improve performance of any production unit in a competitive environment. Many research studies have been conducted around the world for efficiency assessment in the maritime sector, including ports/terminals utilizing different methods, but in the significant percentage of those studies have been used Data Envelopment Analysis (DEA) and DEA-based approaches. After some general theoretical considerations on port/terminal efficiency and standard approaches for its measuring, elements related to a research of seaport terminals overall efficiency, using DEA-CCR input oriented method is shown. Four port terminals are taken into consideration and their efficiency scores are calculated using appropriate software, based on established data series - values of input/output variables - related to the cargo handling system in the Port of Bar (Montenegro).

Key words: efficiency, data envelopment analysis, terminals

1 INTRODUCTION

Maritime transport can be considered as the backbone of the world globalization and trade because over 75% of the volume of international trade in goods is carried by sea, thus supporting significantly the ongoing and complex processes of global supply chains [1, 2, 3].

The port industry is, in general, an indispensable factor of development in a globalized economy [3]. At the same time, seaports play an integral role of utmost importance and act as an incentive to the development of the marine economy and national economy in general [2, 4, 5, 6]. Numerous changes in world economy in the previous periods (globalization of production, distribution and consumption, changes within ports, port-hinterland relationships and logistics) have strengthened the role of ports as nodes in the global transport system [7]. The level of port capability has a very strong influence on the country's productivity and competitiveness [4].

Evaluating port efficiency is of crucial importance to port authorities, port operators, investors, governments, and users as it helps to identify the critical factors which support improvements in port efficiency and trade competitiveness [8]. Port efficiency is the capability of a port or terminal to fit the optimum number of inputs to a given output level [4].

Speaking in general terms, productivity in the port sector can be improved in different ways. One from the group of basic ways is introducing technical progress - through new cargo handling equipment with better performances. The characteristic next way is achieving a greater degree of efficiency: improving the qualification of the workers in order to train them for using port machinery more efficiently, etc. [6, 9]. Technological improvements occurring in the port industry and changes in port management models, have led to a modification in the field of port operations, causing increased level of specialization. These factors have had a great impact on the productivity and efficiency of port operations [10].

In the reference [6] are elaborated manners how a port terminal efficiency can be defined. It is stated, that could be done along: i) an efficient production frontier, which maximizes terminal output for different input levels; ii) a benchmark of best practices; iii) observable gaps between what terminals currently produce and what they would optimally produce.

Between different approaches possible, in the reference [1] are pointed out two solutions for resolving sources of inefficiencies in seaports: firstly, inefficient seaports are advised to increase the quantity of the cargoes handled by attracting more port customers. Secondly, these ports should rent their unused resources to other interested companies in order to reduce the use of inputs (stevedoring equipment, number of employees, size of storage area, etc.) in proportion to the achieved output (throughput).

When efficiency is considered, it is important to have in mind that economic efficiency is a broader term than technical efficiency. It is related to the optimal selection of inputs and outputs based on reactions to market. Being economically efficient considers selecting a certain volume and structure of inputs and outputs in order to minimize cost/maximize profit. Economic efficiency requires both technical efficiency and efficient allocation. While technical efficiency only requires input and output data, economic efficiency requires price data, too [1, 11].

A firm k is said to be technically efficient if its input-output combination (X_k,Y_k) is characterized by following: it is not possible to reduce the use of any inputs without decreasing one of the outputs or increasing the use of another input, or it is not possible to increase the amount of any output without decreasing the amount of another output or increasing the input usage [12]. In principle, there are three required elements for measuring efficiency: decision making unit (DMU), output variables, and input variables [4]. The measurement of efficiency of a DMU and the identification of sources of its inefficiency is one of initial preconditions to improve Its performances [11]. Methods for measuring efficiency emerged in 1960s [13]. The literature on efficiency in the port industry is relatively new (the first studies appeared in the mid-90s) [14].

There are numerous studies on efficiency evaluation in various industries [2]. Detailed port efficiency literature overviews are given in references [1, 4].

Based on the available literature, it can be said that many researchers have used parametric and non-parametric methods to measure ports' capacity and efficiency. These techniques include original least squares (OLS), corrected original least squares (COLS), data envelopment analysis (DEA), and stochastic frontier analysis (SFA) [5].

DEA, originally proposed by Charnes et al., utilizes multiple inputs to produce multiple outputs without parametric assumptions. The past 40 years have witnessed the appearance of a great number of studies on DEA theory and its application [10]. It is said e.g., that in some papers were listed more than 3000 references about DEA from 1978 to 2001 [10]. As well, summary of different studies where DEA was implemented is given in many references [e.g., 6, 15, 17].

DEA is frequently applied in many areas of applied economic sciences, including agricultural economics, development economics, financial economics, public economics, and macroeconomic policy [12]. DEA approach has been applied, as well, across different research domains such as environmental management, banking and finance, health sector, educational sector, transport, airline, tourism, and many more because it is popular and robust [5, 13, 14, 15, 16]. The DEA has been extensively used in evaluating efficiency for various industries and institutions such as airports, ferry services, agriculture, hotels, hospitals, schools, etc., too [17].

Many research studies have been conducted around the world utilizing DEA and DEA-based modeling approaches in the maritime sector, including terminals in the ports [2, 4, 6, 7, 8, 9, 10, 12, 18, 20].

2 SUBJECT OF THE RESEARCH

In the available references is suggested, based on the results of the literature review, that it is not the best approach to study ports in general; instead, it is a better approach to take into consideration limited number of ports/terminals, a specific type of cargo, a concrete activity, etc.

Implementation of DEA has been done commonly in container operations [17] and the number of papers related to dry bulk and liquid bulk cargo terminals is significantly smaller [6, 17]. Although in the reference [17] is stated that DEA is a linear programming method computes the efficiency level within the numbers of organization or within the same organization, studies on efficiency of different terminals within the same port are not in the front plan. In addition, in the available literature cannot be found any paper related to efficiency of the Montenegrin seaports.

Respecting all previously mentioned, especially following facts: there is a lack, in the available literature, of researches related to comparison of terminals within the same port and there is no paper (taking into account available literature) related to measuring efficiency of the Montenegrin seaports, as an object of research are selected following four terminals in the Port of Bar (Montenegro): Terminal, T1 – VOL; Terminal, T2 – SOB; Terminal, T3 – ROR; Terminal, T4 – PTE. Summary of the general characteristics of the Port of Bar as well as some specific features of mentioned terminals are systematized in the further text [21].

The Port of Bar is a multipurose port, managed according to the landlord port management model (having as the legal base Montenegrin Law on ports). Port infrastructure is owned by the State of Montenegro. Two main Port Terminal Operators have rigths (granted by the Goverment of Montenegro, based on long term concession agreements) to use defined parts of the port area, exploit belonging port infrastructure and carry out port actvitities: Port of Bar JSC, where major shareholder is The State of Montenegro, owning 78.15% of shares, and the Port of Adria JSC, where majority of shares – 62% are owned by the Turkish Company Global Ports Holding. Main cargo groups which are handled in the Port of Bar are: liquid bulk cargoes; dry bulk cargoes; general cargoes; containers; Ro-Ro cargoes. In the throughput structure appear passengers, too.

An automatized integral information system, which covers all business activities, is in use. As well PCS (Port Community System) is implemented. ISPS Code is in force since July 1st, 2004. National and international regulation on safety and health on work, environmental protection and protection against different hazards is fully implemented, as well.

Terminal, T1 – VOL – a multipurpose port terminal. Cargo groups handled within this terminal are: liquid bulk cargoes; dry bulk cargoes; general cargoes; containers; Ro-Ro cargoes. Total length of the operational quay at the terminal is 556 m. Water depth is up to 14 m, and maximal allowed vessel draught is 12.80m. Following shore port machinery is used in handling operation to vessel and from vessel: gantry cranes (3 peaces), rail mounted, with SWL 12 t, as well as Mobile Harbor Crane LHM550, on rubber tires, with SWL 144 t and Mobile Harbor Crane LHM420, on rubber tires, with SWL 124 t. Terminal has its own railway network which is a part of the integral port railway network, directly connected with the railway Bar – Belgrade.

Terminal, T2 – SOB – a multipurpose port terminal. Cargo groups handled within the terminal are: liquid bulk cargoes; dry bulk cargoes; Total length of the operational quay at the terminal is 346 m. Water depth is up to 13.5 m, and maximal allowed vessel draught is 12.50m. Terminal is partially covered by the railway network (two out of four berths are approached by the railway).

Terminal, T3 – ROR – a multipurpose port terminal. Cargo groups handled at the terminal are: dry bulk cargoes; general cargoes; Ro-Ro cargoes. Total length of the operational quay at the terminal is 374 m. Water depth is up to 10.5 m, and maximal allowed vessel draught is 8.5 m. Terminal is partially covered by the railway network (one out of two berths is approached by the railway).

Terminal, T4 – PTE – a multipurpose port terminal. Cargo groups handled are: General cargoes and passengers. Total length of the operational quay at the terminal is 245 m. Water depth is up to 6 m, and maximal allowed vessel draught is 5.2 m.

3 OBJECTIVES OF THE RESEARCH

General objective of the research is to define overall efficiencies of four terminals in the Port of Bar (DMUs): T1-VOl, T2-SOB, T3-ROR, T4-PTE - using DEA CCR input oriented method – to compare their inputs/output ratios and determine that one unit is more or less efficient than another in order to establish bases for identifying reasons for difference in efficiency. More exactly, objective of the research is to create bases to answer on following initial questions (modified questions from reference [20]): 1) which port terminal is the most efficient among four analyzed? 2) which group of reasons has the biggest influence on inefficiency of the other terminal(s)? 3) what are the main directions for resolving inefficiency problems?

4 METHODOLOGY

Data Envelopment Analysis (DEA), developed by Charnes et al. in 1978, is a linear programming-based method for evaluating performance of organizational units called decision-making units (DMUs) [2, 6, 10, 12, 22, 23]. The aim of the DEA approach is to select a set of efficient and inefficient units [2]. The DEA methodology gives a tool to estimate "relative" efficiency of a chosen entity in a given group of units and criteria [11]. DMUs relate to a collection of seaports, terminal operators, warehouses, shipping companies, etc. [2]. The DEA technique is useful in resolving the measurement of port efficiency because the calculations are non-parametric and do not require specification or knowledge of a priori weights for the inputs or outputs [24].

The main advantages and information provided from DEA are [13]: (1) the comparison of all units allows identifying the most efficient ones; (2) DEA can handle multiple inputs and outputs calculating the amount and type of cost and resources savings that can be achieved by making the inefficient ones as efficient as the most efficient units. (3) as inputs and outputs can have different units, DEA identifies the specific changes in the inefficient units that can be implemented to achieve defined targets.

Standard DEA tends to be sensitive to the number of variables of a chosen sample [8]. It is important to point out that DEA will not erroneously locate an efficient unit as inefficient [22]. As it was already mentioned, DEA is good at estimating "relative" efficiency of a DMU but it converges very slowly to "absolute" efficiency. In other words, it can provide information on how well a DMU is doing compared to its peers but not compared to the optimal efficiency level [6].

Basic DEA models, DEA-CCR (Charnes–Cooper–Rhodes) and DEA-BCC (Banker–Charnes–Cooper), have been considered in various studies on the maritime sector [2]. The concept of the DEA-CCR model (most basic DEA model) is to identify the overall (in)efficiency [2]. For realization of the research whose results are presented in this paper is used DEA-CCR model and it will be elaborated with more details.

There are two versions of DEA-CCR model: the first - input-oriented and the second - output-oriented. The objective of the first is to minimize inputs satisfying outputs, while the second attempts to maximize outputs [5, 13]. The original DEA-CCR model problem formulation for assessing efficiency was constructed as a task of fractional programming (FP), while the solution procedure consists of linear programming (LP) usage for each of the units under assessment [13]. The DEA-CCR model has following structure for the chosen entity "o" [13, 23].

$$(FP)\ max\theta = \frac{\sum_{r=1}^{p} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1}$$

Subject to

$$\frac{\sum_{r=1}^{p} u_r y_j}{\sum_{i=1}^{m} v_i x_j} \leq 1, \forall j = 1, 2, \ldots, jo, \ldots, n \tag{2}$$

$$u_r \geq 0, r = 1, 2, \ldots, p \tag{3}$$

$$v_i \geq 0, i = 1, 2, \ldots, m \tag{4}$$

As for the relative efficiency θ of one DMU "o", the maximum of function (1) is desired and assuming the condition (2), the conclusion that $0 \leq \theta \leq 1$ for each DMU_o is clear. Additionally, the weight values may vary from one DMU to another and the calculation of weights (v_i) and (u_r) maximizing the ratio of DMU_o is the objective of each evaluated DMU. On the other hand, if relation (2) is true for every DMU, each of them belongs to the efficiency frontier beyond it. When max $\theta = \theta^* = 1$, that indicates the achievement of efficiency and means that DMU_o is efficient. The case when $\theta^* < 1$ means that DMU_o is inefficient [13]. The fractional problem (FP) is non-convex, nonlinear, has linear and fractional objective function and constraints and is replaced by the following linear programming problem (LP_o). These two problems are equivalent, thus the DEA-CCR basic model can be defined as follows [13, 23]:

$$(LP)\ max\theta = \sum_{r=1}^{p} u_r\, y_{r0} \tag{5}$$

Subject to

$$\sum_{i=1}^{m} v_i\, x_{i0} = 1 \tag{6}$$

$$\sum_{r=1}^{p} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \le 0, (\forall j = 1, 2, \dots, n) \tag{7}$$

$$u_r \ \ge 0, r = 1, 2, \dots, p \tag{8}$$

$$v_i \ \ge 0, i = 1, 2, \dots, m \tag{9}$$

Besides mentioned DEA models, DEA-CCR and DEA-BCC, in the available literature can be found examples of implementation of some more DEA variants: DEA-Additive models have been applied to examine the technical efficiency of ports [1]; inverse data envelopment analysis (IDEA) [10]; bootstrapped DEA [8]; DEA window analysis [25]; etc.;

In the context of DEA window analysis, it is important to add that there is no theory for the definition of window length [25]. As well, an essential advantage of window analysis is that it increases the number of units for evaluation, which in turn increases the discriminatory power of the method [20].

The efficiency scores raised by the application of the DEA models in available references were calculated using different software: DEAP 2.1 program [1]; DEA Excel Solver [4, 12, 20, 23]; algorithms for solving linear programming problems as part of optimizing software (e.g., GAMS, GAUSS) [12]; standard linear program package [22], etc.

5 SELECTION OF INPUT AND OUTPUT VARIABLES

The assessment of port efficiency using DEA begins with the appropriate choice of input and output variables [3]. It has been known that DEA results depend heavily on the selection of these variables [10]. A detailed overview on different inputs/outputs combinations are given in the reference [4]. The most frequent inputs are resources such as land, human resources, and equipment's. Outputs on the other hand are categorized into more tangible products like goods and also intangible products like services [6]. The measurement of the *inputs* is considered by the indicators [1, 3, 5, 8, 14, 25]: *number of stevedoring equipment*: e.g. total number of reach stackers, number of straddle carriers, number of quayside cranes, number of harbor mobile cranes, etc; *number of employees*; *storing area (m²); the total quay length (m); Net Berth Productivity (t/h); investment value; operation costs; towed ships; the size of the port; the extent of the private sector participation in the port; salaries paid; uniformity of facilities; depreciation charges; the number of tugs; book value of assets; maximal allowed ship draft (m);*

The measurement of the *output* is indicated as follow [1, 3, 5, 8,25]: *throughput (t); terminal capacity (t); number of ships; number of passengers; number of containers; the number of ship calls; customer satisfaction; revenue from the port facilities; berth occupancy; vessel turnaround time;*

Obviously, there is a variety of approaches to selection of input/output variables in the available literature and there is no consensus in the selection of input and output variables [3, 19].

In the available literature is treated relation between number of input and output variables and number of analyzed Decision Making Units (DMUs), too. Very different approaches were used in that context, so, it is very difficult to make any definitive conclusion. Some authors (e.g., references [6, 10, 26]) recommend: the total number of DMUs should be either equal to or more than three times the sum of input and output variables. But, on the other hand, mentioned “rule” is not implemented by some other authors: e.g., in the reference [1] sum of input and output variables is eight and the number of DMUs is eleven. As well, in the reference [25] were used in total four input and output variables for measuring efficiency of five DMUs.

Considering all previously mentioned, for this research are used following variables: *input - number of workers engaged in the cargo handling process and quay length (m); output – annual cargo throughput (t);* Reasons for selecting these input and output variables were directly found in the reference [8], where is stated, based on the detailed literature review, that various inputs and outputs have been used in previous studies to analyze the efficiency of seaports. Among these, the more frequently used variables are cargo throughput as the output variable and berth length, terminal areas, warehouse capacity, and cargo handling equipment as the input variables. As well number of workers engaged in the cargo handling process was frequently used as an input variable in the process of measuring seaports/terminals efficiency. Some authors have pointed out correlation between the number of engaged workers and number of used cranes/cargo handling equipment [6, 8], thus explaining reasons for choosing number of cranes/cargo handling equipment as an input variable instead of number of workers. Finally, in the Table 1 are presented data series for selected DMUs (terminals: T1-VOL; T2 – SOB; T3 – ROR; T4 – PTE), input variables (number of workers engaged in the cargo handling process and quay length (m) and output variable (annual cargo throughput (t)) for the period from the year 2018 to the year 2022. Sources of data were official reports from the Port of Bar Information System [27].

Table 1 Input/output variables

Terminal	Year	Output	Inputs	
		Annual throughput (t) (x 10^3)	Number of workers (x 10^3)	Quay length (m) (x 10^3)
T1-VOL	2018	662.20	2.10	0.40
	2019	931.40	2.90	0.40
	2020	1,147.70	3.60	0.40
	2021	866.70	3.80	0.40
	2022	1,910.80	8.90	0.50
T2 - SOB	2018	602.70	0.30	0.34
	2019	453.30	0.20	0.34
	2020	367.40	0.20	0.34
	2021	389.50	0.20	0.34
	2022	386.30	0.20	0.34
T3-ROR	2018	51.10	1.60	0.37
	2019	51.00	2.10	0.37
	2020	27.70	1.20	0.37
	2021	33.60	1.80	0.37
	2022	86.10	4.00	0.37
T4-PTE	2018	16.20	0.40	0.24
	2019	14.40	0.40	0.24
	2020	2.70	0.10	0.24
	2021	13.10	0.40	0.24
	2022	8.10	0.30	0.24

6 RESULTS OF THE RESEARCH

Based on values of input and output variables given in the Table 1, efficiency scores of analyzed terminals, per years of the period from the year 2018 to the year 2022 are calculated through appropriate software [28] (based on DEA CCR input oriented model). Efficiency scores per analyzed terminals and related years are systematized in the Table 2.

Table 2 Efficiency scores

Terminals	2018		2019		2020		2021		2022	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
T1 – VOL	0.8240	2	1	1	1	1	1	1	1	1
T2 – SOB	1	1	1	1	1	1	1	1	1	1
T3 – ROR	0.0635	3	0.0612	3	0.0410	3	0.0501	3	0.0806	3
T4 – PTE	0.0403	4	0.0429	4	0.0146	4	0.0458	4	0.0287	4

Average efficiency scores and ranks for the complete analyzed period (from the year 2018 to the year 2022) are shown with the Table 3.

Table 3 Average efficiency scores

Terminals	Average values	
	Score	Rank
T1 – VOL	0.9648	1.2
T2 – SOB	1	1
T3 – ROR	0.0593	3
T4 – PTE	0.0345	4

7 DISCUSSION OF RESULTS

Results given with tables 2 and 3, clearly show that terminal T2 – SOB was the most efficient, it had rank “1” for each year from the analyzed period and the same average rank for the whole period. The conclusion is that, through the whole period, terminal T2 – SOB was efficient.

Terminal T1 – VOL took the second place from the efficiency level point of view. It had rank “2” for the year 2018 and in the remaining years its rank was “1”. Its efficiency scores range from 0.8240 in the year 2018 to 1 in remaining years from the analyzed period. In average, its rank for the complete period was 1.2 and efficiency score was 0.9648. In the first year from the period, terminal T1 – VOL was inefficient, then in all remaining years efficient.

Research results show that terminal T3 – ROR in all years from the analyzed period had rank “3”. Its efficiency scores range from 0.0410 (in the year 2020) to 0.0806 (in the year 2022). In average, for the whole period this terminal had rank “3” with efficiency score of 0.0593. In the time window 2018 – 2020, level of its efficiency declined from 0.0635 (in the year 2018) to 0.0410 (in the year 2020). Through the time window 2020 – 2022, efficiency of this terminal than was increasing, from 0.0410 (in the year 2020) to 0.0806 (in the year 2022). Through the whole period terminal T3 – ROR was inefficient.

As for the terminal T4 – PTE, it took rank “4” for all years from the analyzed period. Its efficiency scores range from 0.0146 (in the year 2020) to 0.0458 (in the year 2021). Average rank of the terminal for the whole period was “4” and its average efficiency score was 0.0345. Values of efficiency score “oscillated”: looking at trends for any two years time windows from the period (2018 – 2019, 2019 – 2020, 2020 – 2021, 2021 – 2022), efficiency level firstly was increasing than decreasing, after that again increasing and finally decreasing. Per all years of the period, terminal T4 – PTE was inefficient.

It is important to discuss what is level of coordination between calculated efficiency scores and values of output and input variables and how variations of input/output variables are influencing level of efficiency. In that sense, in following tables are shown (per analyzed terminals, DMU_S and each year from period) variations of input and output variables (based on Table 1) and efficiency scores (from Table 2) – through “year over year” (“yoy”) indicators.

Table 4 Analysis of trends related to DMU_1: T1-VOL

terminal/year	2018	2019	2020	2021	2022
DMU_1: T1-VOL					
- throughput (t) (x1000)	662.20	931.40	1147.70	866.70	1910.80
yoy		1.41	1.23	0.76	2.20
- number of workers (x1000)	2.10	2.90	3.60	3.80	8.90
yoy		1.38	1.24	1.06	2.34
- Efficiency	0.8240	1	1	1	1
yoy		1.21	1	1	1
- throughput (t) (x1000)	662.20	931.40	1147.70	866.70	1910.80
yoy		1.41	1.23	0.76	2.20
- quay length (m) (x1000)	0.40	0.40	0.40	0.40	0.50
yoy		1.00	1.00	1.00	1.25
- Efficiency	0.8240	1	1	1	1
yoy		1.21	1	1	1

Increasing of throughput in the year 2019 for 41% (comparing with 2018) was followed by increasing of engaged workers for 38% and increasing of efficiency for 21%. In the year 2020, throughput had further increased for 23% (comparing with the previous year), having at the same time increasing of number of engaged workers for 23% and keeping efficiency level unchanged, “1”. For the year 2021 is characteristic decreasing of throughput for 24% (comparing with the year 2020), but the number of engaged workers was increasing for 6% and the terminal kept its efficiency level. Finally, in the year 2022 throughput increased for 120% (looking at the 2021 as a base) and number of workers increased for 134%. Efficiency score of the terminal continued to be “1”. Results of analysis showed that trends of throughput and number of engaged workers were not in line for the time window 2020-2021, it is necessary to identify reasons for appeared situation – if the only reason is inflexible employment strategy or there are additional factors of influence. It is important, as well, to find out why the increasing rate of engaged workers in the year 2022 (comparing with 2021) was bigger (134%) than increasing of throughput (120%) if the available cargo handling technologies remain unchanged (if that was connected with variations in throughput structure, or ...).

Due to different reasons (maintenance works on the quay construction, operational reasons, ...), in the period from 2018 to 2021, 400 m out of 556 m of the operational quay at the Terminal T1-VOL was available and in the year 2022 the length of the available part of the quay was increased from 400 m to 500 m. Values of efficiency scores indicate that changes in the length of the available part of the quay were not followed with changes in the terminal efficiency level.

Table 5 Analysis of trends related to DMU_2: T2-SOB

terminal/year	2018	2019	2020	2021	2022
DMU_2: T2-SOB					
- throughput (t) (x1000)	602.70	453.30	367.40	389.50	386.30
Yoy		0.75	0.81	1.06	0.99
- number of workers (x1000)	0.30	0.20	0.20	0.20	0.20
Yoy		0.67	1.00	1.00	1.00
- Efficiency	1	1	1	1	1
Yoy		1	1	1	1
- throughput (t) (x1000)	602.70	453.30	367.40	389.50	386.30
Yoy		0.75	0.81	1.06	0.99
- quay length (m) (x1000)	0.34	0.34	0.34	0.34	0.34
Yoy		1	1	1	1
- Efficiency	1	1	1	1	1
Yoy		1	1	1	1

Overall efficiency level of the Terminal T2-SOB through the whole analyzed period was “1”: terminal was efficient from the aspect of achieved throughput and related inputs - number of engaged workers and length of used operational quay. It is important to define factor which caused situation to have constant number of engaged workers per years in the period from 2019 to 2022 although variations in the annual throughput existed (if the dominant factors of influence are of organizational nature or depends on used cargo handling technology, etc.).

Table 6 Analysis of trends related to DMU_3: T3-ROR

terminal/year	2018	2019	2020	2021	2022
DMU_3: T3-ROR					
- throughput (t) (x1000)	51.10	51.00	27.70	33.60	86.10
Yoy		1.00	0.54	1.21	2.56
- number of workers (x1000)	1.60	2.10	1.20	1.80	4.00
yoy		1.31	0.57	1.50	2.22
- Efficiency	0.0635	0.0612	0.0410	0.0501	0.0806
yoy		0.96	0.67	1.22	1.61
- throughput (t) (x1000)	51.10	51.00	27.70	33.60	86.10
yoy		1	0.54	1.21	2.56
- quay length (m) (x1000)	0.37	0.37	0.37	0.37	0.37
yoy		1	1	1	1
- Efficiency	0.0635	0.0612	0.0410	0.0501	0.0806
yoy		0.96	0.67	1.22	1.61

Table 6 - contianution

In the year 2019, comparing with 2018, annual throughput remained unchanged, although number of engaged workers increased for 31% and it was followed by decreasing of efficiency level for 4%. Throughput in the year 2021, comparing with the previous year, increased for 21%, what is in line with the increasing rate of efficiency (22%), but the increasing of number of engaged workers was much bigger: 50%. It is important to define reasons which caused mentioned trends (throughput structure, work organization, implemented cargo handling technology, ...). From the managerial point of view, situation got better in the year 2022 (in comparison with previous year): increasing of throughput was 156% and the increasing of engaged workers was smaller 122% what resulted in increasing efficiency level for 61%.

Used quay length over the whole period was the same, 370 m, so no simple explicit correlation between values of this input parameter and level of terminal efficiency cannot be identified.

Table 7 Analysis of trends related to DMU_4: T4-PTE

terminal/year	2018	2019	2020	2021	2022
DMU_4: T4-PTE					
- throughput (t) (x1000)	16.20	14.40	2.70	13.10	8.10
yoy		0.89	0.19	4.85	0.62
- number of workers (x1000)	0.40	0.40	0.10	0.40	0.30
yoy		1	0.25	4.00	0.75
- Efficiency	0.0403	0.0429	0.0146	0.0458	0.0287
yoy		1.06	0.34	3.14	0.63
- throughput (t) (x1000)	16.20	14.40	2.70	13.10	8.10
yoy		0.89	0.19	4.85	0.62
- quay length (m) (x1000)	0.24	0.24	0.24	0.24	0.24
yoy		1	1	1	1
- Efficiency	0.0403	0.0429	0.0146	0.0458	0.0287
yoy		1.06	0.34	3.14	0.63

Although annual throughput for the year 2019, comparing to 2018, decreasing for 11%, number of engaged workers remained unchanged in that year and it was followed by increasing in efficiency for 6%.

Trends of annual throughput and number of engaged workers were in line in other time windows (looking from the aspect of indicator “yoy”), but it is worthy to mention that decreasing in throughput (81%) was bigger than decreasing number of engaged workers (75%) in the time window 2019-2020, having reduced efficiency score for 66%. Increasing of throughput in the year 2021, comparing with the previous year, was 385%, while the number of engaged workers was increasing for 300% and efficiency has raised for 214%. In the year 2022, comparing with 2021, decreasing rate of throughput was bigger (38%), than decreasing rate of number of engaged workers (25%) and efficiency level was decreasing for 37%. Mentioned situation has to initiate thorough examination of reasons for registered differences in trends (throughput structure, implemented cargo handling technology, employment strategy, ...).

Length of used quay was the same over the complete period and variations in efficiency level cannot be explicitly correlated with this input parameter.

In general, the changes in efficiency (its increasing) can be due to the evolution of staff and/or operational policy or as a result of seasonal factors that are in different units dependent in various ways [3]. Difference in efficiency level will be due to the cargo handling technology used, throughput structure at the terminal (DMU_i), how well the working process is managed, etc. (some elements given in reference [22] are used).

DEA identifies the amount of inefficiency factors that is required to be reduced or increased from inputs and outputs to become efficient. In fact, the dataset required does not have to be necessarily huge or voluminous as this prompts the DEA to be easily applicable and become a comparable toolkit [17].

8 CONCLUSION

Through the research shown in this paper is confirmed that DEA CCR model can be used for measuring efficiency of different terminals within the same seaport. Efficiency level of terminals within the Port of Bar (Montenegro) was defined for the period from the year 2018 to the year 2022. In the year 2018, only terminal T2-SOB was found efficient and in the remaining years of the analyzed period terminals T1-VOL and T2-SOB were efficient (had efficiency score 1), while remaining two terminals had efficiency score smaller than 1 and were found inefficient. It is important to point out that with the results of research is defined overall efficiency of port terminals and in that manner are established bases both for necessary improvements in order to increase level of terminals` efficiency and for further research. Although in the paper are taken into consideration relations between levels of efficiency and variations of input and output variables in the further researches author plans to model intensity of influence of input and output variables on efficiency scores. As well, it would be interesting to compare level of efficiency of port terminals within different ports in Adriatic and Ionian seas or for wider area using DEA model on bigger number of DMUs, with increasing number of input and output variables thus compensating lack of such studies in the available literature.

9 REFERENCES

[1] Kammoun, R., The Technical Efficiency of Tunisian Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis Scores, from https://sciendo.com/pdf/10.2478/jlst-2018-0011, accessed on 2023-03-07.

[2] Wang, C. N., et.al. (2021), Efficiency Assessment of Seaport Terminal Operators Using DEA Malmquist and Epsilon-Based Measure Models, from https://doi.org/10.3390/axioms 10020048, accessed on 2023-03-10.

[3] Dewarlo, O. (2019), DEA Window Analysis for Measuring Port Performances Efficiency of Four Islands Countries Located in West Indian Ocean Countries, American Journal of Industrial and Business Management, no. 9, 2098-2111, from https://www.scirp.org/journal/ajibm, accessed on 2023-03-17.

[4] Weerawat, W., Evaluation Efficiency of Indonesian Seaports: Data Envelopment Analysis, from https://www.eg.mahidol.ac.th, accessed on 2023-03-11..

[5] Boakye, G., Li Y, Asare, E. (2021) Determination of the Efficiency of Port Performance and Productivity Based on Data Envelopment Analysis in the West Africa Sub-region. Indian Journal of Science and Technology, vol.14, no.46, 3396-3406, from https://doi.org/ 10.17485/IJST/v14i46.1755, accessed on 2023-03-12.

[6] Madeueke, U. A., Measuring and Benchmarking Efficiency and Productivity Levels of Liquid Bulk Terminal Operations Using a DEA AND OEE Approach Considering Nigeria's Atlas Cove Jetty and Depot Facility, from https://thesis.eur/nl, accessed on 2023-01-31.

[7] Park, R.-K., De, P., An Alternative Approach to Efficiency Measurement of Seaports, from https://link.springer.com, accessed on 2023-02-10.

[8] Nguyen, H.-O., et.al. (2015), Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports, from http://dx.doi.org/10.1080/03088839.2015.1107922, accessed on 2023-01-22..

[9] Kaiser, E., et.al. (2017), Developing Measures of Us Ports Productivity and Performance: Using DEA and FDH Approaches, from https://agris.fao.org, accessed on 2023-01-27..

[10] Lin, Y., et.al. (2019), Performance Evaluation and Investment Analysis for Container Port Sustainable Development in China: An Inverse DEA Approach. Journal Sustainability, no.11, 4617, from www.mdpi.com/journal/sustainability, accessed on 2023-01-11.

[11] Vincová, K., Using DEA models to Measure Efficiency, from https://nbs.sk/_img/documents/biatec/bia08_05/24_28.pdf, accessed on 2023-01-17.

[12] Kuosmanen, T., Kortelainen, M., Data Envelopment Analysis in Environmental Valuation: Environmental Performance, Eco-efficiency and Cost-benefit Analysis, from https://econwpa.ub.uni-muenchen.de, accessed on 2023-02-07.

[13] Ewertowska, A., Systematic Tools Based on Data Envelopment Analysis for the Life Cycle Sustainbility Evaluation of Technologies, from https://www.txd.cat, accessed on 2023-02-02.

[14] Taboada, G. L., et.al. (2020), Exploratory Data Analysis and Data Envelopment Analysis of Construction and Demolition Waste Management in the European Economic Area, from https://www.mdpi.com/2071-1050/12/12/4995, accessed on 2023-01-01.

[15] Tsaples, G., Papathanasiou, J. (2021), Data envelopment analysis and the concept of sustainability: A review and analysis of the literature. Journal Renewable and Sustainable Energy Review, Vol. 138, from https://www.sciencedirect.com/science/article, accessed on 2023-02-11.

[16] Zamora-Antuñano, M. A., et.al., Statistical Analysis and Data Envelopment Analysis to Improve the Efficiency of Manufacturing Process of Electrical Conductors, from https://www.mdpi.com, accessed on 2023-01-22.

[17] [17]Suliman, K. R, et al (2019), Measuring technical efficiency of dry bulk terminal performance using the frontier application of data envelopment analysis: A proposed framework, from https://iopscience.iop.org/article/10.1088/1742-6596/1366/1/012100/pdf, accessed on 2023-02-27.

[18] González, M. M., Trujillo, L (2009)., Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence. Journal of Transport Economics and Policy, vol. 43, no.2, 157-192, from https://www.jstor.org, accessed on 2023-01-12.

[19] Barros, C.P. (2006), A Benchmark Analysis of Italian Seaports Using Data Envelopment Analysis. Journal Maritime Economics & Logistics, no.8, 347-365, from https://link.springer.com/article, accessed on 2023-02-03.

[20] Nwanosike, F. (2013), Benchmarking the operational efficiency of Nigeria seaport terminals using Data Envelopment Analysis (DEA), from http://isl21.org/wp-content, accessed on 2023-03-01.

[21] Port of Bar (2022), Documentation of the Development Department, Bar.

[22] Sherman H., D., and Zhu, J. (2006), Data Envelopment Analysis Explained. In: Service Productivity Management. Springer, Boston, MA, from https://doi.org/10.1007/0-387-33231-6_2, accessed on 2023-02-18.

[23] Jablonský, J., A Spreadsheet Based System for DEA models, from https://mcdm.ue.katowice.pl, accessed on 2023-02-05.

[24] Poitras, G., et.al. (1996), Measuring Port Efficiency: An Application of Data Envelopment Analysis, from https://mpra.ub.uni-muenchen.de, accessed on 2023-02-19.

[25] Pjevcevic, D., et.al. (2012), DEA Window Analysis for Measuring Port Efficiencies in Serbia, from https://hrcak.srce.hr/file/122164, accessed on 2023-02-10.

[26] Ilic, I., Petrevska, I. (2918), Using DEA method for determining tourism efficiency of Serbia and the surrounding countries, Journal Hotel and Tourism Management, vol. 6, no. 1, 73-80, from https://scindeks-clanci.ceon.rs/data/pdf, accessed on 2023-02-11.

[27] Port of Bar (2022), Information System, Bar.

[28] https://cbom.atozmath.com/CBOM/DEA.aspx, accessed on 2023-03-17

Paper submitted: 03.05.2023.

Paper accepted: 26.10.2023.