Assessment of Efficiency of the North Adriatic Container Terminals

Procjena učinkovitosti kontejnerskih terminala u lukama sjevernog jadranskog mora

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Summary

This paper evaluates the efficiency of the container terminals of north Adriatic ports Rijeka, Koper and Trieste. The methodology is based on Data Envelopment Analysis. The ports' container throughput data for the last 12 years have been taken into consideration. Possible changes in the terminals' operational efficiency were observed. The study furthermore assesses organisational inefficiencies; on that basis, possible solutions for improving the terminals' operational efficiency were discussed. Based on input and output data, analysis results signal early warning regarding the terminals' inefficiency. The results can be used for improving ports' operations and making key management decisions. They also indicate potential procedures aimed at maintaining a competitive market position in the observed region.

KEY WORDS
container port
DEA
north Adriatic ports
efficiency
competitiveness
containers' transhipment

Sažetak

Ovaj rad ocjenjuje učinkovitost kontejnerskih terminala luka sjevernog Jadrana, Rijeke, Kopra i Trsta. Metodologija se temelji na analizi omeđivanja podataka. U obzir uzimaju se podaci o prekrcaju kontejnera za posljednjih 12 godina. Promatraju se moguće promjene u operativnoj učinkovitosti terminala. Studija nadalje procjenjuje organizacijske neučinkovitosti te se na toj osnovi raspravlja o mogućim rješenjima za poboljšanje operativne učinkovitosti terminala. Na temelju ulaznih i izlaznih podataka rezultati analize signaliziraju rano upozorenje o neučinkovitosti terminala. Rezultati se mogu koristiti za poboljšanje rada luka i donošenje ključnih upravljačkih odluka. Također ukazuju na potencijalne postupke usmjerene na održavanje konkurentne tržišne pozicije u promatranoj regiji.

KLJUČNE RIJEČI
kontejnerska luka
DEA
sjeverne jadranske luke
učinkovitost
konkurentnost
prekrcaj kontejnera

1. INTRODUCTION / *Uvod*

Positioned relatively close to each other, in the north Adriatic, ports of Rijeka, Koper and Trieste are all equipped to handle containerised cargo. Although they are all members of NAPA Association, being the ports in different countries, each of them has its own operational practise, investment policies and development strategies. Usually, considering worldwide, ports situated in the same area, sharing the same or similar hinterland, in some way, compete among each other with the clear focus to draw ever more cargo. There is no exception with the subject ports. However, one has to admit that competitiveness between ports is one of the driving factors in their development. Given the trend of the development of sea ports in the last decades, along with constant investment in modernization in order to attract more cargo, a port should stay as efficient as possible to be able to operate in a profitable manner.

Since efficiency is a dynamic category that changes over time, for a high-quality analysis it is important to monitor its development over the observed period. With the aim of avoiding errors in efficiency calculation and interpretation, results of various DEA models are correlated. The technique, by Asmild, Paradi, Aggarwall & Schaffnit [1], is useful for determining performance trends of decision-making units in a time period.

This research focuses on assessment of the operational efficiency of the subject container terminals, considering the generated container traffic volume (2006-2017) and the transhipment equipment that each of them has on its disposal. The procedure is based on CCR, BCC and SBM models of the Data Envelopment Analysis (DEA) method. Since all the ports differ in terms of certain indicators (traffic, port technology, equipment, position, etc.), the paper demonstrates how DEA method can detect which of the indicators affects and can affect the improvement in efficiency of the port's operation. Furthermore, the possibility of increasing the transhipment rate was analysed and the obtained results are presented in the following chapters.

2. LITERATURE REVIEW / *Pregled literature*

Evaluation of the efficiency of various business entities, including seaports, using DEA have been the subject of many researches over the past two decades. As far as ports are concerned, most of the researches have been conducted on the ports of Asia [11], North America, Australia and southwestern Europe. Some of the papers are focused on the USA, Africa [7] and Australia [6]. Martinez-Budria, Diaz-Armas, Navarro-Ibanez and Ravelo-Mesa [12] made research on 26 Spanish ports. The entering variables were depreciation charges, labour expenditures and miscellaneous expenditures. They formed three groups of ports: low, medium and high complexity ports on which they applied different DEA models to examine the efficiency. The results indicated that the medium and low complexity ports have notably, lower efficiency than the high complexity ports.

The efficiency of 31 European and North American seaports was analysed by Valentine and Gray [19]. The container berth length and the total length of berth were input variables. The number of containers and overall throughput are used by the authors to make conclusion that the DEA method can lead to optimal results in seaport analysis. The main objective of the research by Barros [3] was to access the productivity of five Portugal's seaports from 1999 to 2000. The paper proposes an operation policy revision instead of the incentive regulations' application to increase efficiency. Inputs were number of employees and the value of assets. The resulting values were market share, liquid bulk, containers, movement of freight, gross tonnage, etc. Cullinane, Song and Wang [5] compared the world's major container seaports and made evaluation of their efficiency using DEA window analysis. The method showed the performance of the ports over time and performance comparison between ports.

Taking the size of storage, number of cranes, total quay length and the longshoreman as inputs, Min and Park [13] evaluated by DEA window analysis efficiency of eleven container terminals observing four years time span. The result was represented by cargo throughput over time. The analysis of productivity of various ports, employing DEA method, in which the efficiency is weighted relatively to each other was done by Kaisar, Pathomsiri and Haghani [10]. The objective to achieve was to maximise the output, container turnover along with the minimum of input variables, cranes, quay length, etc. The comparison of relative efficiency of six west African ports was studied by van Dyck [7]. The DEA method was selected to assess the container throughput values, which eventually showed high efficiency of four out of six ports, scoring to more than 70% in the observed period.

Several studies on cargo throughput of north Adriatic ports have been carried out in recent years. Over the years, DEA turned out to be one of the main operative tools for the efficiency analysis in the private and public sectors. DEA is nowadays used for efficiency and performance analysis in a variety of analyses of productivity and efficiency by comparing companies, organisations, regions and countries (Nijkamp & Suzuki [14]; Škuflić, Rabar & Šokčević [16]), according to a systematised bibliography (Emrouznejad, Parker & Travers [8]). In assessing operational efficiency using the DEA method, several models have been developed, which differ depending on the type of returns to scale (constant or variable returns), scope of action, orientation of the model on inputs and outputs, etc., Rabar & Blažević [15].

This research is focused on measurement of the efficiency of the north Adriatic ports Rijeka, Koper and Trieste by comparing both the generated traffic volume and their equipment. The study is based on actual data and applies DEA methods as described in the following chapters.

3. RESEARCH METHODOLOGY / *Metodologija istraživanja*

For measuring technical efficiency, Farell [9] took several inputs that participate in creating one output and he also defined the efficient frontier taking into account best practices from the set of analysed units. For the purpose of defining an overall synthetic indicator that will take into consideration all significant multiple results and all the resources used for generating them, a measure of efficiency was defined:

$$\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of intputs}} = \frac{\sum_{r=1}^{s} u_r y_r}{\sum_{i=1}^{m} v_i x_i} \qquad (1)$$

where:

y_r - amount of output *r*

u_r - weight allocated to output *r*

x_i - amount of input *i*

v_i - weight allocated to input *i.*

Efficiency is calculated as the quotient of virtual output and virtual input, which solves the problem of expressing input and output data that have different values and are compared to one another. The next step is to determine the relative importance of individual inputs and outputs (allocating weighting coefficients or weighting).

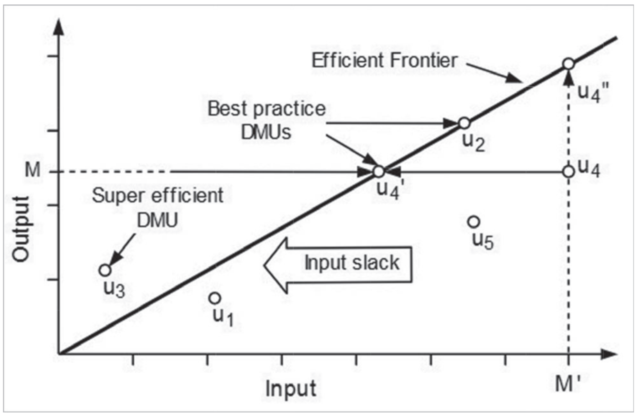
DEA essentially includes different methodologies to evaluate the performance of various business entities. Data from the selected decision-making units (DMUs) are introduced into a programme that characterizes the model of DEA. In that way, the efficiency of an individual DMU within a set of units is evaluated. The model type is selected in accordance with the type of the return to scale. The method's advantage reflects in its flexibility to management strategies, i.e. by varying the number of inputs and outputs. However, the method is not used as a decision making instrument, but rather as a tool for measuring the decisions' efficiency (for inefficient DMUs – a correction of the decision; for efficient DMUs – the determination of the efficiency areas). There is no need to know exact link between inputs and outputs. In that way, the efficiency of an individual DMU within a set of units is evaluated. The efficiency of an individual DMU is measured in relation to other decision-making units.

Based on the process that is being analysed, a comparison of the applicable DEA models are selected:

- CCR model – input-oriented, constant return to scale;
- BCC model – output-oriented, variable return to scale;
- SBM model – input-oriented, constant return to scale.

In respect of the process that is being analysed, the model can be input-oriented (with the aim of minimising inputs for the given outputs) or output-oriented (with the aim of maximising outputs for the given inputs).

The CCR model is based on the assumption of constant returns to scale. The objective is to obtain the ratio of the weighted output-input weights. Starting from the collected data, appraisal of the efficiency of each DMU is made through n optimizations. Graph 1 depicts the situation geometrically.



Graph 1 Efficient frontier of the CCR input oriented model
Grafikon 1. Učinkovita granica modela CCR usmjerenog na unos

The efficient frontier represented by the solid line passes through u_2, u_4' and u_4'' and no other point. On graph 1, the inefficient DMU, u_4 achieves efficiency through projections onto the efficient frontier. Point u_4' represents a projection according to the input-oriented model and u_4'' according to the output-oriented model.

Assume there are *n* DMUs and they are marked [20] as:

$x_i = (x_{i1}, x_{i2}, \dots, x_{ip})$: the inputs vector of $\mathrm{DMU}_i, i = 1, 2, \dots, n$

$x_0 = (x_{01}, x_{02}, \dots, x_{0p})$: the inputs vector of the target DMU_0

$y_i = (y_{i1}, y_{i2}, \dots, y_{iq})$: the outputs vector of $\mathrm{DMU}_i, i = 1, 2, \dots, n$

$y_0 = (y_{01}, y_{02}, \dots, y_{0q})$: the outputs vector the target DMU_0

Then we start from the following linear program (Wen, [20]) in which the slacks are taken to their maximal values:

$$\max \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \tag{2}$$

subject to:

$$\begin{aligned} &\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta^* x_{i0}, \quad i = 1,2,\dots,p \\ &\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0}, \quad r = 1,2,\dots,q \\ &\lambda_j \geq 0, \quad j = 1,2,\dots,n \\ &s_i^- \geq 0, \quad i = 1,2,\dots,p \\ &s_r^+ \geq 0, \quad r = 1,2,\dots,q \end{aligned} \tag{3}$$

where a nonnegative vector of variables is defined as $\lambda = (\lambda_1, \lambda_2, \dots \lambda_n)$ and a real variable as θ. Furthermore, s_i^- and s_r^+ do not affect the optimal objective value θ^*, set by the model [20]:

$$\theta = \min \theta \tag{4}$$

subject to:

$$\begin{aligned} &\sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{i0}, \quad i = 1,2,\dots,p \\ &\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{r0}, \quad r = 1,2,\dots,q \\ &\lambda_j \geq 0, \quad j = 1,2,\dots,n \end{aligned} \tag{5}$$

This model leads to a solution $\theta^* = 1$, $\lambda_j^* = 0, (j \neq 0)$, meaning, the maximum θ can achieve is 1. The calculation of optimal solution θ^* for each DMU is made to obtain efficiency score. DMU's with $\theta^* < 1$ are inefficient. The final expression for input-oriented model [20] can be written as:

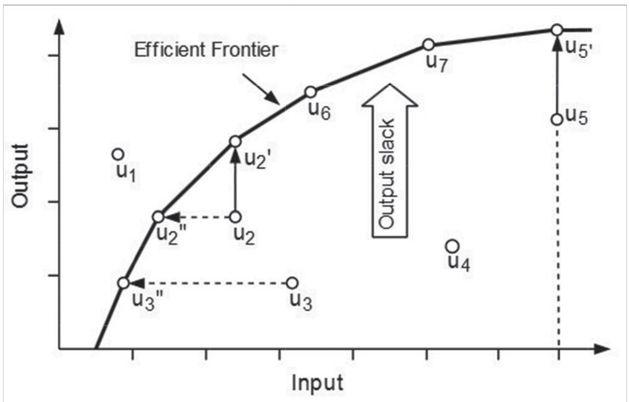
$$\min \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \tag{6}$$

subject to:

$$\begin{aligned} &\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{i0}, \quad i = 1,2,\dots,p \\ &\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0}, \quad r = 1,2,\dots,q \\ &\lambda_j \geq 0, \quad j = 1,2,\dots,n \end{aligned} \tag{7}$$

On the other hand, the BCC model is used in case of increasing or decreasing returns to scale, in which a proportionate increase of input results in more or less than proportionate increase of output.

The BCC model compared to the CCR model of the same orientation, exposes different attributes only because it contains the additional condition $\sum_{j=1}^{n} \lambda_j = 1$. The input-oriented BCC model is proposed by Banker, Charnes and Cooper [2] and evaluates the efficiency of DMU-s. This is similar to the output-oriented BCC model with the added condition $\sum_{j=1}^{n} \mu_j = 1$. The efficient boundaries of the BCC and the CCR models differ substantially due to the additional condition. The example is illustrated in Graph 2.



Graph 2 Representation of the efficient frontier of the BCC model
Grafikon 2. Prikaz učinkovite granice BCC modela

According to the output-oriented model, the entity u_2 (Graph 2) achieves efficiency by means of a projection into the point u_2' and according to the input-oriented model, by means of a projection into the point u_2''. Using a combination of both orientations, the entity u_2 can achieve efficiency through a projection into any point on the part of the frontier between the points u_2' and u_2''. In the output-oriented model, the entity u_5 achieves efficiency through the maximum proportionate increase of output, by shifting into the point u_5', and through the elimination of the input excess without impairing the previously achieved output value, by shifting into the point u_7 [4]. This research focuses on the port analysis with application of the BCC output-oriented model.

For the purpose of further testing the efficiency of the ports taking the measure which is invariant with respect to the unit of measurement used, the SBM model has been selected. The measure stays the same when x_{ij} are replaced by $k_i x_{ij}$ and y_{rj} are replaced by $c_r y_{rj}$, where the k_i and c_r are random positive constants, *i* = 1, 2, …, *p*, *j* = 1, 2, …, *q*. This formulation was named as "dimension free" [17] and was first introduced [18] in the form of a single scalar, Slacks Based Measure. The following formulation [20] has been additionally taken to test the efficiency of the ports:

$$\min q = \frac{1 - \frac{1}{p}\sum_{i=1}^{p}\frac{s_i^-}{x_{0i}}}{1 + \frac{1}{q}\sum_{j=1}^{q}\frac{s_j^+}{y_{0j}}} \tag{8}$$

subject to:

$$\begin{aligned}
&\sum_{k=1}^{n} x_{ki}\lambda_k = x_{0i} - s_i^-, \quad i = 1,2,\ldots,p \\
&\sum_{k=1}^{n} y_{kj}\lambda_k = y_{0j} + s_i^+, \quad j = 1,2,\ldots,q \\
&\lambda_k \geq 0, \quad k = 1,2,\ldots,n \\
&s_i^- \geq 0, \quad i = 1,2,\ldots,p \\
&s_j^+ \geq 0, \quad j = 1,2,\ldots,q
\end{aligned} \tag{9}$$

The assumption is that $x_k \geq 0,\ k = 1, 2, \ldots, n$. If $x_{0i} = 0$, the item $\frac{s_i^-}{x_{0i}}$ in the objective function is deleted. Furthermore, if $y_{0j} \leq 0$, the item is replaced by a very small positive number [20].

4. THE PROBLEM SETUP / *Postavljanje problema*

Applying the previously described DEA methods, the efficiency of the north Adriatic ports Trieste, Koper and Rijeka has been assessed. Focus is on the container traffic because significant portion of ports' capacities is dedicated to the transhipment of that kind of cargo. The ports that are positioned in the vicinity but in different countries, are certainly competing with each other. However, increased transhipment norms, higher productivity, better throughput and a more developed hinterland and foreland are not sufficient for increasing the competitiveness. There is a need to demonstrate their efficiency and performance through a high-quality network of land routes, highly developed port infrastructure, new information technologies of the entire system and modern communications. Modern vessels with increasing capacities are emerging on the maritime market, so it is necessary to adapt container terminals to market requirements and to technical and technological features of modern vessels.

In this paper, we identified three inputs – the warehouse, quay and cranes – and one output – the generated container traffic volume of the ports (TEU). The data are compiled from official published reports regarding the operation of the observed ports and are listed in Table 1.

Table 1 Input and output variables
Tabela 1. Ulazne i izlazne varijable

Year / TEU	Trieste	Koper	Rijeka
2006	220,661	218,970	94,390
2007	267,854	305,648	145,024
2008	338,299	353,880	168,761
2009	277,245	343,165	130,740
2010	281,629	476,731	137,048
2011	393,195	589,314	150,677
2012	411,247	570,744	171,945
2013	458,497	600,441	168,943
2014	476,507	674,033	192,004
2015	443,882	790,736	200,102
2016	449,481	844,776	214,348
2017	546,000	911,528	244,807
Quay length (m)	1,370	596	628
Number of cranes	7	8	4
Total area of stacking yard (m²)	400,000	180,000	126,000

Source: Authors basis data of Ports' Authorities

As previously stated, to measure the efficiency of the ports Trieste, Koper and Rijeka three models were used, CCR, BCC and SBM. Design of the models begins with identification of the input and output results that reflect the desired objectives, as well as the main (output) resources that are thereby used. Input and output variables should appropriately be selected, so that all the resources and relevant outcomes are encompassed for a certain efficiency analysis. To reach the maximal accuracy of the analysis' results, the relation between the number of input and output variables and the number of analysed units should be considered. Also, the number of units should be at least 3-5 times higher than the sum of input and output variables.

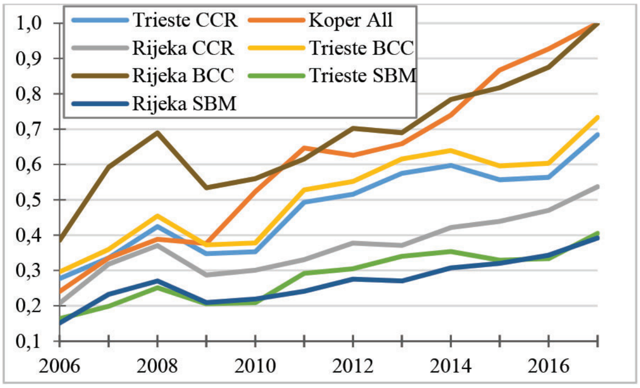
5. THE RESULTS AND DISCUSSION / *Rezultati i rasprava*

Each port is considered to be a separate entity in each of the observed periods; therefore, the analysis comprises a total of 36 (3 x 12) observed entities. If the number of inputs and outputs is significantly higher than the number of analysed units, it is more likely that there is one or several combinations of variables in terms of which the observed unit is the best and will be evaluated as efficient [15]. In the assessment of the operative performance of the north Adriatic ports, data on the generated container traffic volume for the period 2006-2017 were used. The temporal dynamics of the selected ports' performances were determined with the assistance of DEA Solver. Table 2 shows the results of the CCR input-oriented, BCC output-oriented and SBM input-oriented models' analysis.

Table 2 Results of the container ports' efficiency according to the CCR, BCC and SBM models (2006-2017)
Tablica 2. Rezultati učinkovitosti kontejnerskih luka prema CCR, BCC i SBM modelu (2006. – 2017.)

	CCR		All	BCC		SBM	
Year	Trieste	Rijeka	Koper	Trieste	Rijeka	Trieste	Rijeka
2006	0.277	0.207	0.240	0.296	0.386	0.164	0.151
2007	0.336	0.318	0.335	0.360	0.592	0.199	0.232
2008	0.424	0.370	0.388	0.454	0.689	0.251	0.270
2009	0.348	0.287	0.377	0.372	0.534	0.206	0.209
2010	0.353	0.301	0.523	0.378	0.560	0.209	0.219
2011	0.493	0.331	0.647	0.528	0.616	0.292	0.241
2012	0.516	0.377	0.626	0.552	0.702	0.305	0.275
2013	0.575	0.371	0.659	0.616	0.690	0.340	0.270
2014	0.597	0.421	0.740	0.640	0.784	0.353	0.307
2015	0.557	0.439	0.868	0.596	0.817	0.329	0.320
2016	0.564	0.470	0.927	0.604	0.876	0.333	0.343
2017	0.685	0.537	1.000	0.733	1.000	0.405	0.392
Aver.	0.477	0.369	0.611	0.511	0.687	0.282	0.269

The analysis encompasses the period of 12 years, each year being analysed separately. Efficiency is expressed as a value in the range 0-1, 1 being the highest possible efficiency. Results for Koper are the same for all three models. According to the results of the CCR model, in 2006 the port of Rijeka was the least efficient, considering the port's equipment and the generated traffic volume for that year, while the most efficient was the port of Trieste. During the observed period of 12 years, 2017 was, on average, the most efficient year according to the CCR model, while the most efficient port was Koper (1). The results from Table 2 are also demonstrated on the Graph 3.



Graph 3 Comparison of the container ports' efficiency according to the CCR, BCC and SBM models
Grafikon 3. Usporedba učinkovitosti kontejnerskih luka prema CCR, BCC i SBM modelu

In the CCR model the most efficient port is port of Koper (2017). The same is true for the BCC model, however, port of Rijeka has also achieved efficiency value 1. Interestingly, Koper in 2006 was the least efficient (in the previous model it was the port of Rijeka), but with regard to port facilities and achieved container traffic in the time period of 12 years, the efficiency increased year by year. In the year 2006, the port of Rijeka was the most efficient porth among the others.

It is also noted that in period of 12 years, the efficiency of the port of Rijeka increased over the observed period, as is shown in the Graph 3, and the last year Rijeka equalled to Koper. According to the BCC model, the most efficient port was the port of Rijeka in 2017, whose efficiency value was 1. If we observe the annual average, the most efficient year for all the ports, according to both models, was 2017 (CCR – 0.741, BCC – 0.911). In the first case, where the CCR model was used, the most efficient port on average proved to be the port of Koper (0.611), followed by Trieste (0.477) and then Rijeka (0.369). In the second case, the results of the BCC model showed that, on average, the most efficient port was the port of Rijeka (0.687), followed by Koper (0.611) and finally Trieste (0.511).

According to the BCC model, it is interesting that in 2006 the port of Koper was the least efficient one, but 12 years later (in 2016), it was the most efficient one. In the CCR model, the least efficient port in 2006 was the port of Rijeka with the value of 0.207, which is the lowest recorded efficiency value of all the ports in all the years. In the same model, 12 years later, Rijeka remained the least efficient port in comparison to the other two ports (considering the port's equipment and the generated container traffic volume). By contrast, in the BCC model, Rijeka came to the first place in terms of efficiency, ahead of the other two ports.

From the results of the SBM model, contained in the Table 2, it is evident that again Trieste achieved the highest efficiency, taking all the observed years together. The least efficient port is Rijeka, growing steadily from efficiency of 0.151 in 2006 to 0.392 in 2017 (see Graph 3), with overall average efficiency of 0.269. Taking all the three ports together, the best results are achieved in the last observed year (0.599). In the year 2009, the efficiency of all the ports dropped to 0.264 from 0.303 in the previous year. The next year, 2010, the efficiency raised up to 0.317. Such performance of the ports can be explained taking into consideration the global economic hiccup in the 2008/2009.

It is obvious, taking overall results from all three models, that the port of Koper have had the most efficient container terminal among the observed ports in the time period 2006-2017. In the Table 3, a possibility for improving inputs and outputs is demonstrated, i. e. a possibility for improving port efficiency and the way in which that could be done. In the first case, where the CCR model was used, the port of Koper was the most efficient, as it was previously said. However, taking into consideration its resources and container throughput in the overall observed time span, the port is over capacitated for 38.93%. In the same period, port of Rijeka has had more than 63% of resources unused, considering achieved TEU turnover. Trieste is no exemption among the north Adriatic ports, with more than 81% of quay and warehouse space ineffective. Therefore it is obvious that all the ports are in possession of more resources (warehouses, quays, cranes) than what is needed for the given TEU turnover. Possible solution would be in renting or conversion of some capacities for other purposes (activities, cargoes).

Table 3 Input and output improvements (%)
Tabela 3. Ulazna i izlazna poboljšanja (%)

		Warehouse	Quay	Cranes	TEU
CCR	Trieste	-81.22	-81.85	-52.31	0
	Koper	-38.93	-38.93	-38.93	0
	Rijeka	-73.63	-82.48	-63.09	0
BCC	Trieste	-58.38	-55.91	0.00	110.68
	Koper	0	0	0	96.13
	Rijeka	0	0	0	54.41

According to the results of the BCC model, port of Rijeka and port of Koper have a possibility of increasing its turnover volume by 54.41% and 96.13% respectively with the existing inputs. Port of Trieste, according to the same model, can increase its traffic volume by 110.68%, but, in line with the results of the analysis, in order to operate efficiently, it should decrease the inputs by the obtained percentage (convert the use of the warehouse/quay for other forms of cargo/traffic).

5. CONCLUSION / *Zaključak*

Using the data envelopment analysis method (DEA), comparative efficiency of the container terminals of three north Adriatic ports have been evaluated on the basis of three selected input units (the size of the warehouse, the length of the quay, the number of cranes) and one output unit (the generated container traffic volume, TEU). The research is based on the CCR, BCC and SBM models of DEA, relating the ports' generated traffic volume with the corresponding input units.

The data from the selected inputs and outputs for all the decision-making units are introduced into a programme that characterizes the DEA models. The efficiency of an individual DMU within a set of units is evaluated. Also, the efficiency of an individual DMU is measured in relation to other DMUs.

Data for the time period of 12 years, 2006-2017 are compiled from official published reports regarding the operation of the observed container terminals of ports Trieste, Koper and Rijeka. Efficiency is expressed as a value in the range 0-1, where 1 is the highest possible efficiency.

The results of the study show that the overall operation of the north Adriatic ports is becoming more efficient year after year. As per CCR and SBM input-oriented model, port of Koper proved to be the most efficient port, with regards to container throughput. Koper is followed by port of Trieste and port of Rijeka as the least efficient port in the period 2006 to 2017. However, BCC output-oriented model showed that Rijeka has the highest efficiency followed by Koper and then Trieste.

This study and the described approach can provide a strong support to the decision-making units, i.e. the ports' management, in the process of making operational decisions.

With the aim of avoiding possible errors in calculations due to the static components, a possible extension of the study in the future would comprise the DEA window analysis which is expected to possibly hook performance trends of decision-making units over time.

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