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Original scientific paper

Determination of the technical efficiency of the UIRR terminals using Data Envelopment Analysis method (DEA) from CCR model

Milan Milosavljević[1] and Zoran Bundalo[2]

Abstract – **The presented paper measured the efficiency of terminals for combined transport from ten European countries members of UIRR, using DEA method. The results can be used for improving terminals operations and making key management decisions. Also, results indicate that the variable selection has a great influence on the resulting estimates of technical efficiency.**

Keywords – **Efficiency, UIRR terminal operators, DEA**

I. INTRODUCTION

In recent years, there has been a noticeable increase in the volume of transported goods by combined transport in Europe. Nowadays, transporting cargo using intermodal transport units are a key indicator for every shipment. International Union of Combined Road-Rail Transport (UIRR) is the industry association for the sector of combined transport which includes companies and terminals in twelve European countries. Each of these terminals has a railway connection with some of the main European Rail Freight Corridor and because of that can significantly increase the share and competitiveness of railway transport in combined transport in Europe.

Assessing the efficiency of these terminals is a very complex task that consists of determining the relationship between the results achieved on the one hand and the resources involved on the other. One of the most used methods for solving this kind of problem is Data Envelopment Analysis (DEA).

There are a large number of papers which used different DEA method for determining the efficiency of port or container terminals. A study on the efficiency of container terminals in Korea and China based on CCR and BCC DEA models are presented in [1]. Authors [2] measured the relative efficiency of five major commercial ports in West Africa, using CCR, BCC, and Windows I-C DEA methods. In paper [3] authors evaluate the efficiency of the container terminals of North Adriatic ports using DEA CCR, BCC and SBM method.

In most of these papers, authors combine several input factors such as number of cranes, number or berths, terminal area, number of employees, berth length, with mostly one same output variable - container throughput (TEU).

In this paper, we use the CCR DEA method for determining the technical efficiency of UIRR terminals based on three input variables and one output variable.

[1]High Railway School of Vocational Studies, Zdravka Čelara 14, Belgrade, Serbia, mimilan89@gmail.com.

[2]High Railway School of Vocational Studies, Zdravka Čelara 14, Belgrade, Serbia, cheminot2@gmail.com.

II. METHODOLOGY

A. Data Envelopment Analysis

DEA is a non-parametric method for measuring the relative efficiency of decision-making units (DMUs) that have multiple input and output [4], which in this paper are UIRR terminals. A linear programming model developed by [4] is considered as the beginning of the DEA There are two basic models that are most commonly used to measure the efficiency of decision-making units: the CCR model used in this paper [4] and the BCC model with variable yield on volume [5].

Linear DEA models can be input or output-oriented. This is due to the fact that linearization can also be done by equating the numerator in the function of the target with 1, thus minimizing the denominator. Input oriented models give us information on how to reduce input variables in order decision making units to become efficient at a given output level. On the other hand, output-oriented models reach DMU efficiency by increasing the output variable. The objective function in the input-oriented CCR-DEA model is presented as the weighted sum of the output variables that should be maximized as shown in Eq. 1 [6]:

$$(Max)h_k = \sum_{r=1}^{s} u_r y_{rk} \quad (1)$$

Constrains (Eq. 2 - Eq.4):

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \quad (2)$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ik} \leq 0\,, j = 1, \dots, n \quad (3)$$

$$u_r \geq 0, v_i \geq 0, r = 1, \dots, s; i = 1, \dots, m \quad (4)$$

B. Application of DEA method

There are four main phases in the application of DEA method [7]:

I. Defining and selecting decision units whose relative efficiency is to be determined.
II. Determination of input and output variables that are relevant and suitable for evaluating the relative efficiency of the selected decision-making units. At this stage, consultation with experts from the field is necessary. Typical inputs are the resources the unit uses, while results represent outputs. A series of regression analyses can identify the relationships between variables, inputs, or outputs. A weak

relationship of some variables with everything else may mean that you need to check whether the variable is eliminated. Also, strong links may indicate that the information presented in a variable is already contained in other variables and again, elimination should be considered.

III. Choosing an adequate DEA model.
IV. Solving DEA model.

III. MODEL FORMULATION

The selection of variables is the primary step in any efficiency analysis because it weighs on the accuracy of the analysis. In this paper, we considered transshipment terminals managed by UIRR member companies from ten European countries, although there are twelve countries in total in 2019. Slovakia and the Czech Republic are not used in the model because these two countries are new and there is no data for them in recent years. Total number of terminals in the model is twenty, and these terminals represent DMU for the selected problem.

There are several factors that we considered in the selection of some terminal. First, the terminal should have been operated for at least five years and it must have a total turnover of more than 50000 units per year. These terminals have three types of connection with European corridors: unaccompanied combined transport, inland waterways transport (IWW) and intermodal technology A - Rollende Landstrasse (RoLa). In this paper, we do not consider terminals that have only RoLa or IWW type of connection. Data about terminals characteristics are collected by annual statistics of UIRR and from terminal websites [8]. The selected terminals are given in Table 1.

TABLE I
UIRR TERMINALS FOR COMBINED TRANSPORT BY COUNTRY

Country	Terminal	Total
Austria	CTE, CTS, Wels Vbf CCT/RoLa, Wien Sud CCT, Wolfrut CCT	5
Belgium	Combinant, CTE, Main Hub (Zomerweg)	3
Germany	KTL, TSG	2
France	Avignon, Hourcade, Marseille, Venissieux	4
Hungary	Rail Cargo Terminal - BILK	1
Italy	EMT	1
Poland	Railhub Terminal Gadki	1
Romania	Railroad Arad	1
Great Britain	Daventry	1
Switzerland	Aaray	1
Total		**20**

For analyzing the effectiveness of the proposed decision-making units, the CCR model was used. In the DEA method, it is important that the number of decision-making units must be greater than twice the sum of input and output variables, which is satisfied [9].

Three input variables are considered in the DEA model: total surface (m^2), number of cranes (gantry and mobile) and number of railway tracks. Our research shows us that in literature there is an insignificant number of authors which include the number of railway tracks as input variables when solving the terminal efficiency problem. On the other hand, we consider that this input variable can be an important parameter that directly affects terminal efficiency and from whom depends on total turnover.

The output variable is the total turnover, which can be expressed as the total number of intermodal transport units (containers, swap bodies, and semi-trailers) loaded and unloaded, arrived and departed from terminal. The cargo turnover is unquestionably the most important and widely accepted indicator of terminal output. Many authors use container throughput (TEU) as the most important indicator and output variable for measuring the technical efficiency of container ports or terminals [10]. Input and output variables are given in Table 2.

TABLE II
INPUT AND OUTPUT VARIABLES

DMU	Total surface	Num. of cranes	Num. of tracks	Total turnover
CTE	175000	3	8	375000
CTS	120000	2	10	245000
Wels	120000	6	9	202833
Wien CCT	250000	4	4	161673
Wolfurt CCT	106000	6	4	114138
Combinant	99000	4	5	138500
HTA	53000	3	5	87922
Main Hub	202497	6	8	106176
KTL	305000	8	13	354414
TSG	63000	3	4	76808
Avignon	85296	6	10	83769
Hourcade	48755	5	7	87050
Marseille	41363	6	6	68661
Vénissieux	46100	9	4	98332
RCT BILK	223000	7	7	104335
EMT	80000	4	4	61000
RT Gadki	320000	6	4	101535
Railport Arad	8000	5	7	69830
Daventry	12000	2	2	52240
Aarau	27000	3	5	59240

IV. RESULTS AND DISCUSSION

The input-oriented DEA-CCR model is applied for the evaluation of twenty DMUs in 2018. The observed problem is solved by the DEA excel solver. The goal of the CCR model is to find the maximum of the objective function taking into account defined constraints. If we divide this task into twenty linear programming tasks for each of the twenty decision-making units, then in each task we search for the values of the variables v_1, v_2, v_3, and u_1 so that the objective function reaches a maximum under the defined constraints. The efficiency of terminals is shown in Table 3, where an efficiency score of 1 signifies efficient terminals and scores less than 1 indicate inefficient terminals.

TABLE III
EFFICIENCY RESULTS OF DEA CCR MODEL

DMU	Efficiency	Sum of lambdas	Return to Scale
CTE	1.00000	1.000	Constant
CTS	0.98000	0.653	Increasing
Wels	0.64303	1.757	Decreasing
Wien CCT	0.86226	0.431	Increasing
Wolfurt CCT	0.60874	0.304	Increasing
Combinant	0.62723	0.546	Increasing
HTA	0.60850	0.845	Increasing
Main Hub	0.28314	0.283	Increasing
KTL	0.58160	0.945	Increasing
TSG	0.49404	0.533	Increasing
Avignon	0.33526	0.953	Increasing
Hourcade	0.52428	1.279	Decreasing
Marseille	0.41935	1.205	Decreasing
Vénissieux	0.73727	1.090	Decreasing
RCT BILK	0.31797	0.278	Increasing
EMT	0.34329	0.232	Increasing
RT Gadki	0.54152	0.271	Increasing
Railport Arad	1.00000	1.000	Constant
Daventry	1.00000	1.000	Constant
Aarau	0.62119	0.914	Increasing

Based on the CCR efficiency level of each terminal, the analysis shows that only three terminals were efficient with a score of 1: CTE, Railport Arad, and Daventry. The remaining terminals (85%) are inefficient, with scores less than 1. Four inefficient units have decreasing returns to scale, and the other 13 have increasing returns to scale. The average efficiency is 0.6264 and the lowest efficiency is for terminal Main Hub from Belgium (0.2831). This indicates the need to reduce the value of the input variables or input and output combined in order to become efficient for the given output.

A. Sensitivity analysis

Sensitivity analysis consists of determining reference units for inefficient units, based on best practice. In addition to providing efficiency measures, DEA also provides other information relevant to inefficient terminals. For each inefficient DMU, we can define a reference set of efficient DMUs for benchmarking.

Slack variable analysis provides a reference set of specific recommendations to help each inefficient terminal become efficient, by minimizing the input resources to produce a given output efficiently. It should be noted that this information is described only for the inefficient terminals, and the efficient terminals tend not to provide any slack [11]. The sensitivity analysis and slack variable analysis are given in Table 4.

TABLE IV
SENSITIVITY ANALYSIS FOR INEFFICIENT TERMINALS

DMU	Total surface	Num. of cranes	Num. of tracks	Total turnover	Effic iency
CTS	114333.33	1.96	5.23	245000	1.00
Wels	77163.93	3.86	5.58	202833	1.00
Wien CCT	75447.40	1.29	3.45	161673	1.00
Wolfurt	53264.40	0.91	2.43	114138	1.00
Combinant	62096.17	1.43	3.14	138500	1.00
HTA	32250.45	1.83	2.50	87922	1.00
Main Hub	49548.80	0.85	2.27	106176	1.00
KTL	165393.20	2.84	7.56	354414	1.00
TSG	31124.63	1.22	1.98	76808	1.00
Avignon	28596.52	2.01	2.54	83769	1.00
Hourcade	25561.43	2.62	2.93	87050	1.00
Marseille	17345.61	2.43	2.52	68661	1.00
Vénissieux	33988.03	2.31	2.95	98332	1.00
RCT BILK	48689.67	0.83	2.23	104335	1.00
EMT	27462.87	0.62	1.37	61000	1.00
RT Gadki	47383.00	0.81	2.17	101535	1.00
Aarau	16772.22	1.86	2.04	375000	1.00

As we can see from table 4 efficiency of terminals will be 1.00 when input variables are not an integer. In that case, we can round these numbers to be an integer for input variables such as a number of tracks or cranes. It will not change the result of efficiency which average value is 0.99.

For the input-oriented method, input variables must decrease to DMU to become technically efficient. For example, the inefficient terminal KTL has efficiency 0.5816, and it must adjust all of the input variables by 42% to become technically efficient. KTL must decrease the input variables total surface (-139606.80), number of cranes (-5) and number of tracks (-5) to become efficient and satisfy achieved turnover. Based on this example all inefficient DMUs can adjust their input variables to become technically efficient with a score of 1. The reduction of input variables is given in Fig. 1.

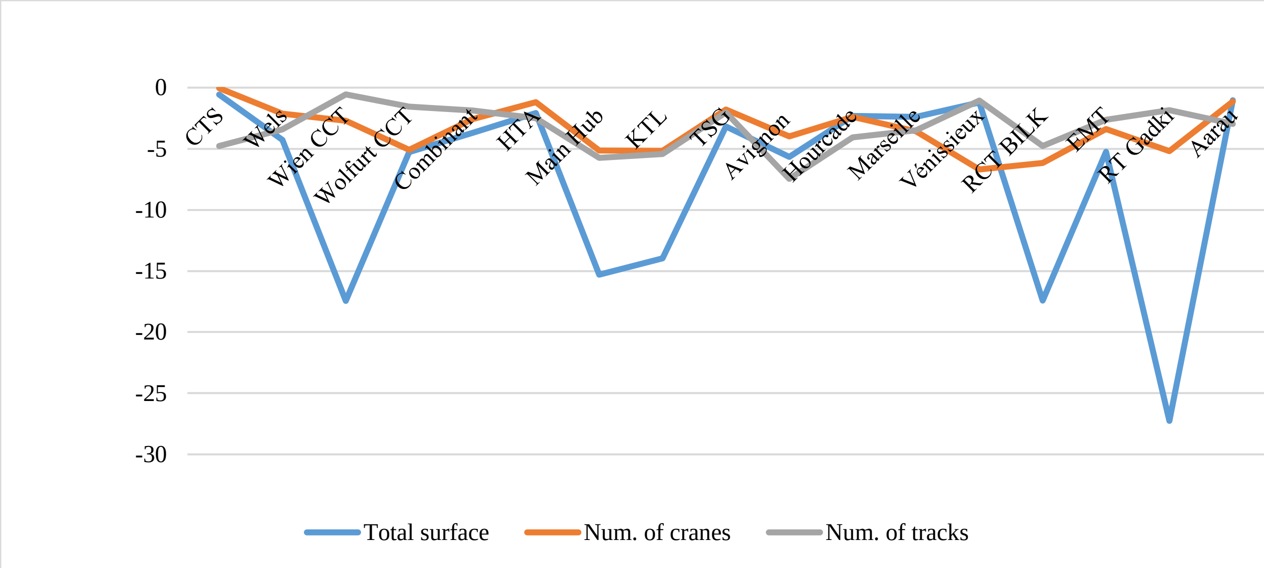

Fig. 1. Efficient input target

As we can see from figure 1, for almost every inefficient terminal number of cranes and the number of tracks is decreased in the range from 0.5 to 7.46. The input variable total surface has the biggest oscillations from 5667 m^2 (5%) for CTE to 272617 m^2 (85%) for RT Gadki. Average decrease of these input variable is 51% for all 17 terminals.

V. Conclusion

This paper demonstrated how CCR DEA method can be applied to measure the efficiency of terminals for combined transport in Europe. The sensitivity analysis of the obtained solution can identify the sources of inefficiency of individual decision-making units. Only three terminals are efficient and the other 17 are inefficient. Sensitivity analysis shows us that inefficient DMU may be efficient if some input parameters are increased.

According to the results, the terminal that is most frequently used as a benchmark by inefficient terminals is the CTE, which is used by 17 inefficient terminals. Railport Arad and Daventry are benchmark terminals in only one case. This means that inefficient terminals can follow their reference benchmark terminal to improve themselves and become efficient.

One of the main indicators shows us that the relationship between efficiency and terminal size suggested that the large terminals are not necessarily more efficient than smaller ones.

The future research can be based on the usage of some of the other DEA models such as BSS or SBM, and taking more input variables into consideration.

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