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Railway stations in the Republic of Serbia in the function of transportation of goods: efficiency according to the DEA system

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Abstract:

*Introduction/*purpose*: Data Envelopment Analysis (DEA) is commonly used to calculate the efficiency of similar Decision-Making Units (DMUs), which as such are elements of one set. In the article, it is considered that each such element of a set (of similar elements) is at the same time an element of a system (of various elements). An example of DMUs are 27 railway stations in the Republic of Serbia (RS) as an element of a set of railway stations and as an element of the railway transportation system, in the function of transporting goods, after division of the company Serbian Railways in 2015 (into "passengers" and "goods"). For the sake of better service, attraction and retention of clients, in the newly opened, free, transport market, the purpose of this article is to find the efficiency of the RS stations iin the period of 2018-2022.*

Methods: Set-systemic-model comparative DEA analysis of railway stations as a DMUs. A unit is an element of the set, a unit is an element of the system, and a unit is the subject of the mathematical DEA-CCR/BCC/SE model.

Results: The final efficiency, the average of all average values, is 0.7666, as a result of a triple comparative DEA analysis: 27 DMU, three DEA models and five years of functioning.

Conclusion: Stations are functionally different in terms of efficiency and each station functionally differs by years and by model. The final aim is an input-output balance and the 27/27 option which is achieved with corrective actions – reduction/addition, input or output.

Key words: efficiency, DEA-CCR/BCC/SE, railway stations, set-system, transportation of goods.

Introduction

The article is intended to those aiming to achieve as much as possible with as little investment as possible, especially in wider and wider environments.

The environment here refers to the system, the structure of various elements-subsystems and more structures in the supersystem. A concrete element-subsystem is a railway station, as an object of research, in the function of transporting goods.

Efficiency is the issue here. It is a property of someone or something, on the one hand, and a mathematical quantity, on the other. Hence, it is treated here in two levels: (1) practically, shown through the examples of other authors and the example of the RS railway stations, and (2) theoretically, shown by the first DEA mathematical method, the CCR model, named after its authors - Charnes, Cooper and Rhodes (Charnes et al, 1978). Later, the method was innovated over several decades, through numerous mathematical models by other authors.

In terms of such a tendency, a new idea is presented here, which is an upgrade to a known method. The emergence of a new idea – set-system DEA analysis – originates from the reality and that is now open free transport market.

But why railways, why railway stations and why efficiency assessment? The railway, as a complex, profit-making system, is a good sample for this kind of research. Furthermore, railway stations, as a numerous set, are a true example of decision-making units. Furthermore, after more than eight years from the division of the Serbian Railways company (in 2015) and the start of the new business, further system changes follow, according to the guidelines of developed countries, according to the principles of dynamic market economy. On the basis of the guidelines and the transition process there are business indicators as input-output parameters. Hence the topic of efficiency, evaluation of the efficiency of railway stations and measures for better competitiveness in the newly opened, free, transport market. This article deals with a DEA analysis from the time of its creation, the railway stations of the RS from the recent era and the multi-year transition process of the ŽS (Serbian Railways).

Set-systemic DEA analysis

Set-systemic DEA analysis is a combination of the DEA method and system theory, and the important determinants are:

1. Set analysis, where the decision-making unit is an element of the set, and an important step is the correct selection of the set size, i.e., the number of analyzed units.
2. System analysis, where the decision-making unit is an element of the system, which according to system theory has many diverse elements (subsystems) and complex connections between them, and an important step is the correct selection of inputs and outputs.
3. DEA analysis – a mathematical DEA model which solves the problem of linear programming; for a concrete sample from practice and for each decision-making unit, it determines whether a particular is either efficient or inefficient in regard to the remaining units. There are two options for the functioning of decision-making units – they are either followed by other (inefficient) units or they are followers of other (efficient) units. The numerical value of efficiency is from zero to one. Efficient units are best practice units, where Eff=1. The other, opposite, inefficient units, where 0<Eff<1, emulate the efficient units, the best practice units, as their role model. The logic of inefficient units reads: Under the same conditions, here in the same set and with the same input-output variables, inefficient units can be efficient, because the model (best practice) is realistic (already achieved) and relative (valid for a concrete sample, i.e., one and the same set of decision units). One can go further and ask which one is the most exemplary.

Set-systemic DEA analysis is mathematically represented by models where the mathematical model consists of:
1. Set DEA models (a unit is an element of a set of similar elements):
- CCR CRS model is with constant returns to scale (Charnes et al, 1978):

$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1,\ j = 1, \dots, n$$

$$u_r,\ v_i \geq 0;\ r = 1,\dots,s;\ i = 1,\dots,m$$

where:
h_0 – relative efficiency of the 0th DMU;
n – number of DMU; m – number of inputs; s – number of outputs;
u_r – weight coefficient of the rth output;
v_i – weight coefficient of the ith input.

- BCC VRS is a model with variable returns to scale or the extended CCR model (1) for an additional variable u_0, in the numerator of the efficiency formula (Banker et al, 1984):

$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0} - u_0}{\sum_{i=1}^{m} v_i x_{i0}} \qquad (2)$$

where (Banker et al, 1984, p.1087):
- Increasing returns to scale <=> $u_0^* < 0$,
- Constant returns to scale <=> $u_0^* = 0$, and
- Decreasing returns to scale <=> $u_0^* > 0$.

- SE model (Panwar et al, 2022) is:

$$\text{Scale efficiency} = E_{CCR}/E_{BCC}, \qquad (3)$$

where: E_{CCR} – CCR efficiency and E_{BCC} – BCC efficiency.

2. System DMU model (a unit is an element of a system of *N* diverse elements, among which there are connections):

$$DMU1,..., DMUn \in SISTEMA\ (E1, E2,...,EN) \qquad (4)$$

where are the links between *N* elements:

$$E1 \leftrightarrow E2,\ E1 \leftrightarrow E3, \ldots, E1 \leftrightarrow EN,\ E2 \leftrightarrow E3,..., E2 \leftrightarrow EN,...$$

In the set approach, the DEA mathematical method and the classical DEA models - CCR, BCC and SE - are applied. In the systems approach, system theory and a multi-component transportation system are applied. How to adequately mathematically model railway stations? Defining inputs and outputs in the DEA procedure is a complex and crucial issue. In the example of railway stations, it is known that inputs and outputs are economic, commercial activities, invested or realized, in the goods transport sector. How to select, re-select or not select them? What are inputs and outputs? Indeed, what is a railway station?

Railway station as an element of a set and a system

A railway station is seen here as an element of a set of railway stations and, more broadly, as an element of the railway transportation system.

A railway station is an element of a set of official places on the railway network, which consists of a set of supervisory and a set of subordinate official places, Figure 1. Official places that deal with loading/unloading (in tons of transported goods) in the respective year of the analyzed period are called active official places.

The end stations of the traffic route are called terminuses and determine the type of traffic:
1. Domestic traffic (initial and final terminuses in the RS);
2. International traffic:
- import (initial terminus abroad, final terminus in the RS);
- export (initial terminus in the RS, final terminus abroad); and
- transit (both terminuses abroad).

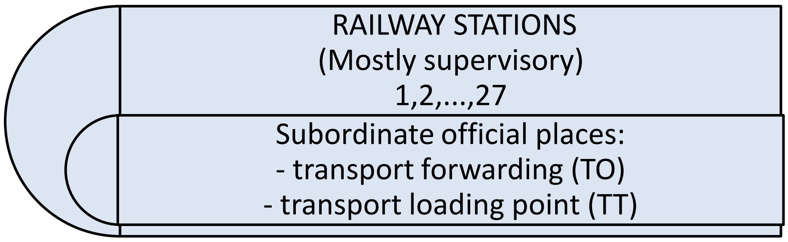


Figure 1 – Railway station as an element of the set of railway stations of RS

The railway station is an element of the transportation system according to model (4), where the transportation system has *N*=5 basic elements (Filipović, 2013):
1. Vehicles (V);
2. Traffic roads (TR);
3. Terminals (T);
4. Energy (E); and
5. Organization and management (OM).

Specifically, in the goods transport sector, the railway transportation system has the following five elements, Figure 2:
V – freight cars;
TR – railway lines;
T – railway stations (there are 27 stations on the RS railway network);
E – diesel and electric energy, facilities, equipment and people; and
OM – station (executive) staff.

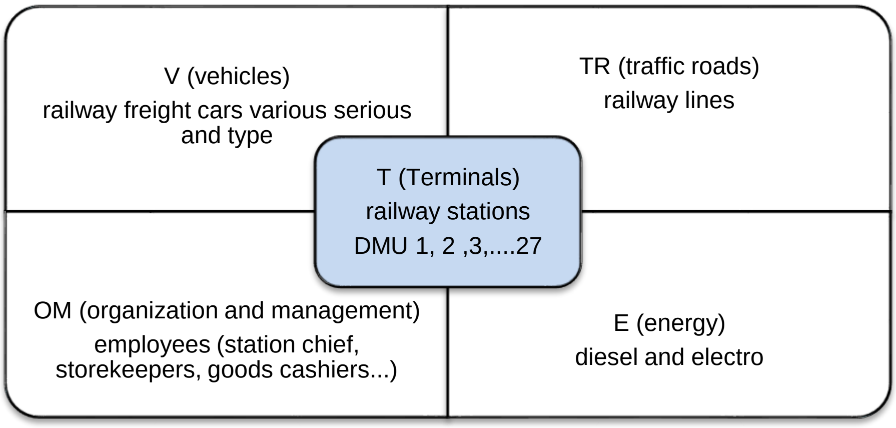


Figure 2 – The railway station as an element of the RS transportation system

"A transportation system has several components. First, it can be defined in terms of infrastructure, vehicles, operations, and policies." (Sinha, 2007, p.3)

The assessment of the efficiency and re-efficiency of the railway station (T) in the business course of the newly formed company is an assessment of the ratio of activities achieved and invested, for each decision-making unit, by years. If the station, T, is defined as an element of the transportation system, then the activities invested and the service provided are simply determined.

The invested activities are:
- resource activities: work of employees, in the number of executors, OM and E; and
- operational activities: reception/dispatch of freight cars, in the number of cars, V.

The accomplished activities are:
- transport flows – transport service: import, export, transit and domestic transport of goods, in tons of transported goods, as a transport indicator; and
- traffic flows – tariff kilometers per car, as a traffic indicator, TR.

Therefore, as an element of the set, as an element of the system and as a unit of efficiency decision making, when applying the DEA method, the railway station has two inputs and two outputs.

Literature review

Efficiency and DEA begin with the first DEA authors: Charnes, Cooper and Rhodes, and the first DEA paper from 1978, as well as the first basic CCR model. (Charnes et al, 1978) Many decades later, the first published paper is the first in the ranking list of cited papers. As stated in the bibliometric report: "The most cited paper is also the most cited paper of all time in the field of OR and MS and was published by Charnes, Cooper and Rhodes". (Laengle et al, 2017, p.812) A brief review of the literature contains the papers published in the relatively recent period of 2013-2023 from the field of DEA, a subfield of traffic and transport engineering, with data on efficiency decision-making units as a research subject, listed in Table 1.

Table 1 – Literature review

Journal	Autor(s)	No. DMU	DMU Sample
Military Technical Courier/Vojnotehnički glasnik	Andrejić (2013)	20	Distribution centers[1] in Serbia
Transportation Research Part D	Park et al. (2018)	50	The transport sector of the US states
Transport Policy	Kyriacou et al. (2018)	34	Transport infrastructure investments of countries
Transport	Zeng et al. (2020)	20	Airports in Eastern China
International Journal Technology, Policy and Management	Ghanem et al. (2020)	28	Turkish and EU railways
Case Studies on Transport Policy	Fancello et al. (2020)	9	Italian city roads
Axioms	Nguyen et al. (2022)	24	Maritime transport in EU countries
Discrete Dynamics in Nature and Society	Shang et al. (2022)	40	Airports in China
Journal of Navigation and Port Research	Bernal et al. (2022)	17	Container terminals in Spain
Procedia Computer Science	Jiang et al. (2022)	30	Transport in Chinese provinces

[1] A distribution center consists of (Andrejić, 2013): a storage subsystem and a transport subsystem.

Journal	Autor(s)	No. DMU	DMU Sample
Transport Policy	Tomikawa & Goto (2022)	6	Railway passenger companies
Research Square	Niu et al. (2022)	38	Railway operators
Energy	Lee & Kim (2023)	6	Road passenger vehicles in EU countries

In a broader sense, the listed similar units from each sample are additionally similar to the units of the other samples as components of the transportation system, which according to Sinha (2007) constitute:
1. Infrastructure: distribution centers (Andrejić, 2013), airports (Zeng et al, 2020), (Shang et al, 2022), roads (Fancello et al, 2020) and container terminals (Bernal et al, 2022);
2. Vehicles: electric vehicles and internal combustion engine vehicles (Lee & Kim, 2023);
3. Operations: rail transport of passengers and goods (Ghanem et al, 2020), (Tomikawa & Goto, 2022), (Niu et al, 2022) and maritime transport of passengers and goods (Nguyen et al, 2022); and
4. Policies: transport infrastructure investments (Kyriacou et al, 2018), or the entire transport sector (Park et al, 2018), (Jiang et al, 2022).

According to Andrejić (2013, p.86), "it is possible to make a difference among the following efficiency measurement aspects in logistic: activity efficiency, process efficiency, subsystem efficiency, system efficiency and chain efficiency", viewed vertically, from the bottom up. But the activities, processes, subsystems and systems themselves are different, for the same level of observation, viewed horizontally. Therefore, we distinguish vertical and horizontal structures when measuring efficiency of diverse and few/many decision-making units.

Thanks to the research studies of earlier authors, today there are numerous multivariate DEA models and numerous theoretical/practical examples of application. At the world level, according to the State of the Art from 2011 (Markovits-Somogyi, 2011), the share of studies with the DEA application in the railway transport sector, in the total number of studies in the field of transport, is 9 out of 69 analyzed.

In the article, a triple comparative analysis was chosen, the determinants of which are: 27 real decision-making units, three DEA models and five years of business. Hence, this article is a new theoretical contribution to the application of the DEA method in the field of railway transport – (1) a new real sample: railway stations, transport of goods, 2018-22, (2) knowledge about efficiency, and (3) the possibility of corrective actions, to improve the company's operations and survival in the open market.

And the concrete challenge in the theoretical contribution is to know the individual practical contribution of each railway station to the functioning of the company. Accordingly, which stations should only be considered as role models, and which should be actively improved for the efficient operation of the company as a whole.

This article examines the efficiency of 27 railway stations in the RS in the function of transporting goods after the division of the ŽS company, in the five-year period of 2018-2022. More precisely, the efficiency of railway stations, in relation to the remaining stations in the set, and the remaining elements in the system and the model applied following the complex mathematical DEA system achieved/invested.

The next section deals with another example in the Republic of Serbia, a new non-monopoly company "Srbija Kargo" JSC, in the official places in the function of goods transportation: railway stations and the issue of efficiency.

Railway stations in the Republic of Serbia

In this article, the subject of research are concrete railway stations on the railway network of the Republic of Serbia, open for the transportation of goods. According to the latest data, there are 27 railway stations in the RS, in the function of transporting goods, most of which are supervisory for subordinate official places (transport forwarding and transport loading points) on the railway network of the RS.

Introductory analysis

Railway station, train station, Bahnhöfe, Les gares, Stazioni ferroviarie, Σιδηροδρομικοί σταθμοί, Vasútállomások, Železničné stanice, Železniške postaje, Железнодорожные станции, Järnvägsstationer, Estaciones de ferrocarril[2] - the words are different but they all mean the same: railway stations. In accordance with the system theory, they are part of the economic subsystem, part of the transportation subsystem, part of the transport subsystem, and here we analyze them as part of the railway, more precisely the railway transport subsystem.

[2] Respectively, in the languages: British English, American English, German, French, Italian, Greek, Hungarian, Slovak, Slovenian, Russian, Swedish and Spanish.

The subject of analysis – the railway stations (in the Republic of Serbia) – has been singled out for operational research theoreticians as well as traffic and transport practitioners. Since the first railway station until today, through decades of continuous innovation, the most modern stations have been built in developed European and world countries. In terms of such a tendency, the example that follows reflects a more recent state and is not a rounded whole, but open to new ideas, new examples, and future stations as the most valuable and prominent objects of the railway infrastructure, the beginning and the end of the transport service - loading and unloading stations in the process of transporting goods.

The main means of transporting goods are railway freight cars with different capacities (maximum amount of goods in tons). Hence, in the sample that follows, there are adequate inputs and outputs for each railway station:
- inputs: the number of executors and the number of received/dispatched freight cars from loading/unloading, and
- outputs: the quantity of transported goods (as a transport indicator) and the number of tariff kilometers traveled (as a traffic indicator).

As practitioners, we look for operational efficiency i.e., efficiency of functioning[3] where real empirical data is used, to find out the effects of disintegration. We look for the situation in the practice of rail transport of goods after the milestone in 2015 in order to identify target actions.

As an example of an activity where the creation of a service has several mutually competitive options, the activity of transport is given here, namely: (1) road transport, (2) rail transport, (3) air transport, (4) water transport, and (5) integral transport. Each of the listed transports has a passenger transport sub-option and a goods transport sub-option.

In practice, transport companies usually provide transport service exclusively in one way, e.g. rail transport service through railway transport technology. Further channeling of rail transport or disintegration into passenger transport and goods transport is a new practice in Serbia, understudied and insufficiently known. Hence, a challenge in the new period is to assess the situation after the disintegration in terms of the efficiency of each particular station in the years after the division.

3 (Min & Jong Joo, 2006), (Andrejić, 2015)

Numerical pre-analysis

Merged into the rail transportation system, the passenger rail transport subsystem and the goods rail transport subsystem existed in the railway network of the Republic of Serbia until August 10, 2015, as the company Serbian Railways (ŽS). Since then, four separate companies have been operating: Srbija Kargo JSC (Joint Stock Company for Railway Transport of Goods), here the subject of research, Srbija Voz JSC (Joint Stock Company for Railway Passenger Transport), as well as ŽS Infrastructure (IŽS) and ŽS Holding.

In the sample that follows, the decision-making units are all 27 railway stations in the function of goods transportation (including their subordinate offices: TO and TT on the IŽS. The analyzed official places are terminuses, i.e., final official places of traffic routes in the RS (departure and/or end in the process of vehicle movement; departure or destination; entry and/or exit to/from the system[4]). The research includes: internal traffic (starting and ending places are at IŽS), import (ending places are at IŽS) and export (starting places are at IŽS).

How to divide one set (of 27 units) into two sets (a set of efficient units and a set of inefficient units)? Theoretically, this is possible to be achieved in 27 ways; therefore, there are 27 options, i.e., potential solutions, Table 2.

Table 2 – Potential solutions

Option	Efficient units		Inefficient units		Total units	Efficient /Total units
O_1	1		26		27	1/27
O_2	2		25		27	2/27
O_3	3		24		27	3/27
O_4	4		23		27	4/27
O_5	5		22		27	5/27
O_6	6		21		27	6/27
O_7	7		20		27	7/27
O_8	8		19		27	8/27
O_9	9		18		27	9/27
O_{10}	10		17		27	10/27
O_{11}	11		16		27	11/27
O_{12}	12		15		27	12/27
O_{13}	13		14		27	13/27
O_{14}	14	+	13	=	27	14/27
O_{15}	15		12		27	15/27
O_{16}	16		11		27	16/27
O_{17}	17		10		27	17/27

[4] An entry or an exit station is a place where goods enter or leave the selected transport system. (Filipović, 2013)

Option	Efficient units	Inefficient units	Total units	Efficient /Total units
O_{18}	18	9	27	18/27
O_{19}	19	8	27	19/27
O_{20}	20	7	27	20/27
O_{21}	21	6	27	21/27
O_{22}	22	5	27	22/27
O_{23}	23	4	27	23/27
O_{24}	24	3	27	24/27
O_{25}	25	2	27	25/27
O_{26}	26	1	27	26/27
O_{27}	27	0	27	27/27

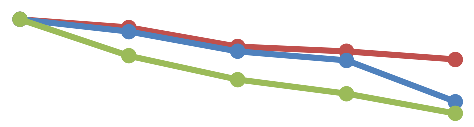
The optimal option is O_{27}, with all 27 efficient units, followed by option O_{26}, with 26 efficient units, then O_{25}, O_{24}… In the numerical sample, the efficiency is calculated for each of 27 decision-making units, a set of efficient units and a set of inefficient units are obtained, and a particular option is identified.

In the process of the movement of freight cars, the aim is to transport as many loaded cars as possible (Output1 maximum) and on the longest possible distance (Output2 maximum[5]). At the same time, it should be achieved with as few executors as possible and as few cars as possible – Input1 and Input2 should be minimal. Therefore, for calculating efficiency with classic DEA models, there are two inputs and two outputs here.

In general, various types of goods are transported by rail: articles of human nutrition, military equipment, containers, various types of oil, ores, coal, etc., in various series and types of cars, for various clients/shippers in import, export, domestic traffic, and transit. Empty cars also run, sent for loading or returning from unloading.

At the very beginning of the research, the business indicators are known – total results by year: tons of transported goods, the number of traffic cars (which generate income) and the number of active official places on the railway – which slightly decrease from year to year, according to data normalized between zero and one, Figure 3.

[5] When the income is received, i.e., so-called transportation fee.



	2018	2019	2020	2021	2022
tons of goods	1	0,9553	0,8496	0,8236	0,7780
freight cars	1	0,9326	0,8234	0,7727	0,5453
active official places	1	0,7984	0,6667	0,5891	0,4806

Figure 3 – Business indicators, 2018-22

In more detail, the percentage share of freight car traffic by year is divided by type of traffic, Table 3. A higher share of international traffic is observed, which is in line with growing globalization.

Table 3 – Freight car transportation, by year and type of traffic

Type of traffic	2018	2019	2020	2021	2022
Domestic	34	33	31	26	26
International	66	67	69	74	74
- import	23	24	23	25	29
- export	19	20	21	24	23
- transit	24	23	25	25	22
∑	100	100	100	100	100

The initial data (inputs and outputs) are real statistical data for the five-year period of 2018-22. Transit was not analyzed because there are no loading/unloading operations at the stations on the IŽS railway network (the final official places, loading or unloading, are abroad). The table of descriptive statistics of the initial data consists of (Aparicio & Zofio, 2021): minimum, median, average, maximum, and standard deviation. For the sample of the RS railway stations, descriptive statistics are given by year for the five-year period 2018-22, Table 4.

For a better trend, it is necessary to determine exactly which units of the organization are not functioning optimally. Hence, in the next section, the efficiency of each railway station is analysed, as follows: Effstation = f [Input1, Input2, Output1, Output2, *u*1, *u*2, *υ*1, *υ*2, model (1), (2), (3)]. At the same time, the dependence function is not known, and consequently, the non-parametric DEA method is applied.

Table 4 – Descriptive statistics of the initial data for 2018-22

Type	2018	2019	2020	2021	2022
			Minimun		
Input1	5	5	5	5	5
Input2	193	108	26	0	0
Output1	4,617	2,964	1,224	0	0
Output2	50,764	23,714	11,414	0	0
			Median		
Input1	19	21	21	21	21
Input2	11,809	8,214	7,840	5,058	3,189
Output1	266,382	247,441	249,238	192,106	136,539
Output2	2,212,381	1,486,651	1,636,987	918,934	559,322
			Average		
Input1	22	21	21	21	21
Input2	15,032	14,004	12,387	11,618	10,901
Output1	463,853	443,365	394,314	382,254	371,003
Output2	2,741,357	2,368,649	2,255,948	2,111,191	2,095,982
			Maximum		
Input1	55	53	53	53	53
Input2	115,084	120,416	84,054	90,766	90,807
Output1	4,100,475	4,209,062	2,938,645	3,240,929	3,261,823
Output2	15,247,532	14,410,170	10,088,444	10,782,367	11,594,050
			Standard deviation		
Input1	12	12	12	12	12
Input2	21,597	22,477	16,211	18,084	17,883
Output1	772,382	784,148	562,298	630,782	645,382
Output2	3,139,907	2,908,017	2,413,276	2,763,524	2,911,553

Source: (1) information: own research, (2) data: "Srbija Kargo" JSC, Traffic and Transport Sector, Center for Commercial Affairs, Center for Calculation and Control of Income.

Numerical DEA analysis

This subsection calculates the numerical value of the efficiency of 27 railway stations in the Republic of Serbia in the function of transporting goods after the 2015 division of the company Serbian Railways (ŽS) for the period of 2018-22.

The computational procedure was performed using the non-commercial software OSDEA-GUI (an acronym for Open Source Data Envelopment Analysis Graphical User Interface), version 0.2, more precisely, the CCR input and BCC input models (Open Source DEA, nd). For the specific sample of railway stations, where n=27, m=2, and s=2, a series of 27 linear programming (LP) problems is programmed. Each LP for each decision-making unit and each resulting unit efficiency, relative to the remaining DMUs. Inputs and outputs are the elements of the system, according to model (4), where N=5, namely: *N1=V, N2=TR, N3=T, N4=E and N5=OM.*

In order to have a broader overview, a three-way comparative analysis was performed with the above-mentioned, so-called classical[6] DEA models, Table 5.

Table 5 – Triple comparative analysis

Station	Year	Model	Acronym of	Orientation	Result
1 2 3 … … 27	2018 2019 2020 2021 2022	CCR	Charnes-Cooper-Rhodes	input	Technical efficiency TE
		BCC	Banker-Charnes-Cooper	input	Pure technical efficiency PTE
		SE	Scale Efficiency	input	TE/PTE

The result of the mentioned triple comparative analysis is the information on the efficiency (for station 1, year 2018, model CCR...), the average efficiency, as well as the number of the efficient units, Table 6.

Table 6 – Efficiency, input-oriented, stations-models-years

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
			2018			
1	Beograd R.	0.4830	0.4878	0.9902	0.6537	
2	Bor Teretna	0.5736	0.5738	0.9997	0.7157	
3	Brasina	0.4352	0.5652	0.7700	0.5901	
4	Crveni Krst	0.8919	0.8942	0.9974	0.9278	
5	Dimitrovgrad	0.6500	0.6595	0.9856	0.7650	
6	Kragujevac	0.5986	0.6003	0.9972	0.7320	
7	Kraljevo	0.5583	0.6318	0.8837	0.6913	
8	Lapovo R.	0.9857	0.9977	0.9880	0.9905	
9	Niš R.	0.5129	0.5254	0.9762	0.6715	
10	Novi Sad R.	0.6484	0.6594	0.9833	0.7637	
11	Pančevo G.	1	1	1	1	1
12	Požega	0.9420	0.9591	0.9822	0.9611	
13	Prahovo P.	0.8725	0.8878	0.9828	0.9144	
14	Prijepolje T.	0.9867	1	0.9867	0.9911	
15	Radinac	1	1	1	1	2
16	Ristovac	1	1	1	1	3
17	Ruma	1	1	1	1	4
18	Sombor	1	1	1	1	5

6 (Panwar et al, 2022)

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
19	S. Mitrovica	0.5975	0.6351	0.9408	0.7245	
20	Subotica	0.5337	0.5404	0.9876	0.6872	
21	Surčin	0.6015	0.6317	0.9522	0.7285	
22	Šabac	1	1	1	1	6
23	Šid	0.7411	0.7606	0.9744	0.8254	
24	Vrbas	0.6558	0.7306	0.8976	0.7613	
25	Vreoci	0.9925	0.9946	0.9979	0.9950	
26	Vršac	1	1	1	1	7
27	Zrenjanin	0.9081	0.9117	0.9961	0.9386	
	Average	0.7840	0.8017	0.9729	0.8529	
			2019			
1	Beograd R.	0.3663	0.3693	0.9919	0.5758	
2	Bor Teretna	0.5946	0.6649	0.8943	0.7179	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.6935	0.7319	0.9475	0.7910	
5	Dimitrovgrad	0.1937	0.4312	0.4492	0.3580	
6	Kragujevac	0.6348	0.7199	0.8818	0.7455	
7	Kraljevo	0.4652	0.4924	0.9448	0.6341	
8	Lapovo R.	0.6842	0.8049	0.8500	0.7797	
9	Niš R.	0.3691	0.4059	0.9093	0.5614	
10	Novi Sad R.	0.4860	0.5076	0.9574	0.6503	
11	Pančevo G.	0.7895	0.9235	0.8549	0.8560	
12	Požega	0.5564	0.5747	0.9682	0.6998	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	0.4100	1	0.4100	0.6067	
15	Radinac	1	1	1	1	3
16	Ristovac	1	1	1	1	4
17	Ruma	0.7237	0.9737	0.7432	0.8135	
18	Sombor	1	1	1	1	5
19	S. Mitrovica	0.9508	0.9852	0.9651	0.9670	
20	Subotica	1	1	1	1	6
21	Surčin	0.3906	0.5484	0.7123	0.5504	
22	Šabac	1	1	1	1	7
23	Šid	0.4086	0.4277	0.9553	0.5972	
24	Vrbas	0.7972	1	0.7972	0.8648	
25	Vreoci	0.7706	0.8163	0.9440	0.8436	
26	Vršac	0.7651	0.9714	0.7876	0.8414	
27	Zrenjanin	0.6809	0.7047	0.9662	0.7839	
	Average	0.6937	0.7798	0.8863	0.7866	
			2020			
1	Beograd R.	0.2367	0.2445	0.9681	0.4831	
2	Bor Teretna	0.4944	0.6090	0.8118	0.6384	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.7125	1	0.7125	0.8083	
5	Dimitrovgrad	0.1405	0.3751	0.3746	0.2967	
6	Kragujevac	0.5815	0.6796	0.8557	0.7056	
7	Kraljevo	0.3513	0.3527	0.9960	0.5667	
8	Lapovo R.	0.4688	0.7162	0.6546	0.6132	
9	Niš R.	0.1608	0.3194	0.5034	0.3279	

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
10	Novi Sad R.	0.3127	0.3616	0.8648	0.5130	
11	Pančevo G.	0.6754	0.9194	0.7346	0.7765	
12	Požega	0.3983	0.4148	0.9602	0.5911	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	1	1	1	1	3
15	Radinac	0.8494	1	0.8494	0.8996	
16	Ristovac	0.5316	0.5538	0.9599	0.6818	
17	Ruma	0.5267	0.7846	0.6713	0.6609	
18	Sombor	1	1	1	1	4
19	S. Mitrovica	1	1	1	1	5
20	Subotica	1	1	1	1	6
21	Surčin	0.4452	0.5416	0.8220	0.6029	
22	Šabac	1	1	1	1	7
23	Šid	0.2526	0.2851	0.8860	0.4746	
24	Vrbas	0.7520	1	0.7520	0.8347	
25	Vreoci	0.5365	0.5937	0.9037	0.6780	
26	Vršac	1	1	1	1	8
27	Zrenjanin	0.6109	0.6904	0.8848	0.7287	
	Average	0.6310	0.7201	0.8580	0.7364	
			2021			
1	Beograd R.	0.1695	0.1851	0.9157	0.4234	
2	Bor Teretna	0.6320	1	0.6320	0.7547	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.5436	0.7680	0.7078	0.6731	
5	Dimitrovgrad	0.1677	0.3481	0.4818	0.3325	
6	Kragujevac	0.6837	0.7330	0.9327	0.7831	
7	Kraljevo	0.2968	0.3158	0.9398	0.5175	
8	Lapovo R.	0.4073	0.4164	0.9781	0.6006	
9	Niš R.	0.2497	0.2867	0.8709	0.4691	
10	Novi Sad R.	0.3450	0.3501	0.9854	0.5602	
11	Pančevo G.	0.8091	0.9332	0.8670	0.8698	
12	Požega	0.3562	0.3567	0.9986	0.5705	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	0.4226	0.5556	0.7606	0.5796	
15	Radinac	0.9788	1	0.9788	0.9859	
16	Ristovac	0.0451	0.3846	0.1173	0.1823	
17	Ruma	0.4226	0.7225	0.5849	0.5767	
18	Sombor	1	1	1	1	3
19	S. Mitrovica	1	1	1	1	4
20	Subotica	1	1	1	1	5
21	Surčin	0.4043	0.5364	0.7537	0.5648	
22	Šabac	1	1	1	1	6
23	Šid	0.2789	0.2874	0.9704	0.5122	
24	Vrbas	0.6763	1	0.6763	0.7842	
25	Vreoci	0.3898	0.4029	0.9675	0.5867	
26	Vršac	0	0.8333	0	0.2778	
27	Zrenjanin	0.3464	0.4229	0.8191	0.5295	
	Average	0.5417	0.6607	0.8125	0.6716	
			2022			

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
1	Beograd R.	0.4088	0.4109	0.9949	0.6049	
2	Bor Teretna	1	1	1	1	1
3	Brasina	1	1	1	1	2
4	Crveni Krst	0.8496	0.8602	0.9877	0.8992	
5	Dimitrovgrad	0.0052	0.3846	0.0135	0.1344	
6	Kragujevac	0.6518	0.7542	0.8642	0.7567	
7	Kraljevo	0.8999	0.9089	0.9901	0.9330	
8	Lapovo R.	1	1	1	1	3
9	Niš R.	0.2503	0.2618	0.9561	0.4894	
10	Novi Sad R.	0.7038	0.7111	0.9897	0.8015	
11	Pančevo G.	0.9031	0.9272	0.9740	0.9348	
12	Požega	0.9106	0.9141	0.9962	0.9403	
13	Prahovo P.	0.8898	0.8987	0.9901	0.9262	
14	Prijepolje T.	0.9049	0.9258	0.9774	0.9360	
15	Radinac	0.9484	1	0.9484	0.9656	
16	Ristovac	0.4508	0.4618	0.9762	0.6296	
17	Ruma	0.8351	0.8799	0.9491	0.8880	
18	Sombor	1	1	1	1	4
19	S. Mitrovica	0.7411	0.8125	0.9121	0.8219	
20	Subotica	0.5833	1	0.5833	0.7222	
21	Surčin	0.5091	0.5154	0.9878	0.6708	
22	Šabac	0.6873	0.8034	0.8555	0.7821	
23	Šid	0.3598	0.3746	0.9605	0.5650	
24	Vrbas	0.7970	1	0.7970	0.8647	
25	Vreoci	0.8822	0.8964	0.9842	0.9209	
26	Vršac	0	0.8333	0	0.2778	
27	Zrenjanin	0.6089	0.6172	0.9866	0.7376	
	Average	0.6956	0.7834	0.8768	0.7853	

As it can be seen from Table 6, "CCR efficiency score is always less and equal to the BCC efficiency score" (Panwar et al, 2022, p.5401). The average efficiency from the average efficiencies by model, year and station is the final efficiency which is 0.7666, Tables 7 and 8.

The integration of multiple models can be important in determining corrective actions in order to achieve efficiency. For inefficient units, target actions? They are those that affect the complex input-output connection, to which the stations are differently sensitive, and the actions are smaller or larger. Also, actions are smaller or larger depending on the applied model. Opting for multiple models, this can be understood as a phased (gradual) increase in efficiency, from smaller to larger changes. Hence, for each inefficient station, the best target actions are determined post-DEA by Sensitivity Analysis. This results in a decrease in input and/or an increase in output, with which the inefficient station achieves its efficiency.

Table 7 – Efficiency, input, stations – average models – years

DMU No.	Average model 2018	2019	2020	2021	2022	Average Figure 4
1	0.6537	0.5758	0.4831	0.4234	0.6049	0.5482
2	0.7157	0.7179	0.6384	0.7547	1	0.7653
3	0.5901	1	1	1	1	0.9180
4	0.9278	0.7910	0.8083	0.6731	0.8992	0.8199
5	0.7650	0.3580	0.2967	0.3325	0.1344	0.3773
6	0.7320	0.7455	0.7056	0.7831	0.7567	0.7446
7	0.6913	0.6341	0.5667	0.5175	0.9330	0.6685
8	0.9905	0.7797	0.6132	0.6006	1	0.7968
9	0.6715	0.5614	0.3279	0.4691	0.4894	0.5039
10	0.7637	0.6503	0.5130	0.5602	0.8015	0.6577
11	1	0.8560	0.7765	0.8698	0.9348	0.8874
12	0.9611	0.6998	0.5911	0.5705	0.9403	0.7526
13	0.9144	1	1	1	0.9262	0.9681
14	0.9911	0.6067	1	0.5796	0.9360	0.8227
15	1	1	0.8996	0.9859	0.9656	0.9702
16	1	1	0.6818	0.1823	0.6296	0.6987
17	1	0.8135	0.6609	0.5767	0.8880	0.7878
18	1	1	1	1	1	1
19	0.7245	0.9670	1	1	0.8219	0.9027
20	0.6872	1	1	1	0.7222	0.8819
21	0.7285	0.5504	0.6029	0.5648	0.6708	0.6235
22	1	1	1	1	0.7821	0.9564
23	0.8254	0.5972	0.4746	0.5122	0.5650	0.5949
24	0.7613	0.8648	0.8347	0.7842	0.8647	0.8219
25	0.9950	0.8436	0.6780	0.5867	0.9209	0.8048
26	1	0.8414	1	0.2778	0.2778	0.6794
27	0.9386	0.7839	0.7287	0.5295	0.7376	0.7437
Average	0.8529	0.7866	0.7364	0.6716	0.7853	0.7666

Table 8 – Efficiency, input, average, years-models

Model / Year	CCR	BCC	SE	Average Figure 5
2018	0.7840	0.8017	0.9729	0.8529
2019	0.6937	0.7798	0.8863	0.7866
2020	0.6310	0.7201	0.8580	0.7364
2021	0.5417	0.6607	0.8125	0.6716
2022	0.6956	0.7834	0.8768	0.7853
Average	0.6692	0.7491	0.8813	0.7666

Based on Tables 7 and 8, for each station, the average efficiency per station and the average efficiency per year of the analyzed period are shown graphically, Figures 4 and 5, respectively. The research showed that the analyzed period of 2018-22 is characterized by an annual change in the number of efficient units in the set of railway stations as decision-making units. The result is a relatively small number of efficient units (7, 7, 8, 6 and 4, respectively, out of 27 units) in an open, dynamic market, where the number of licensed/active freight operators is growing year by year (14 licensed / 5 active in 2018, 14/6, 15/9, 16/10 and 19/13 of the operators in 2022). (Directorate for Railways, 2019; 2020; 2021; 2022; 2023). Efficiency was decreasing by year until 2021, and then it increased slightly. If the result is connected with the pandemic, then a return of the average annual efficiency to the pre-pandemic level can be noticed for the year 2022.

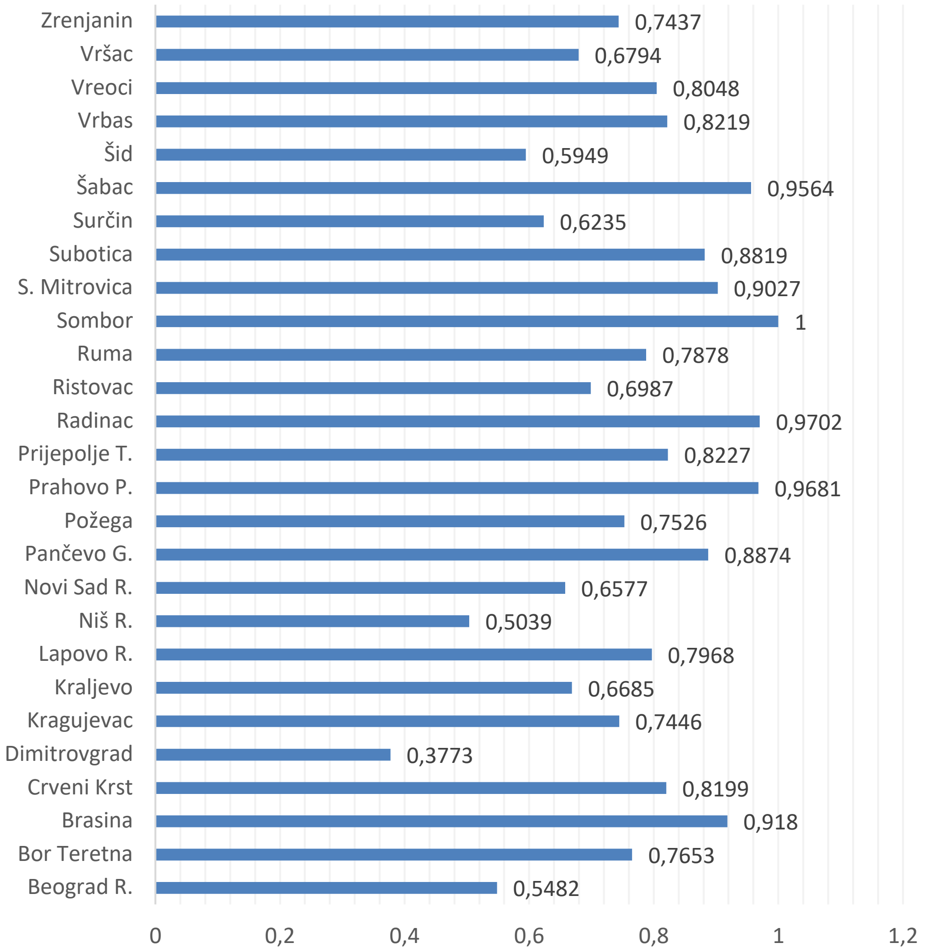


Figure 4 – Efficiency by station, average, 2018-22, model (1)-(3)

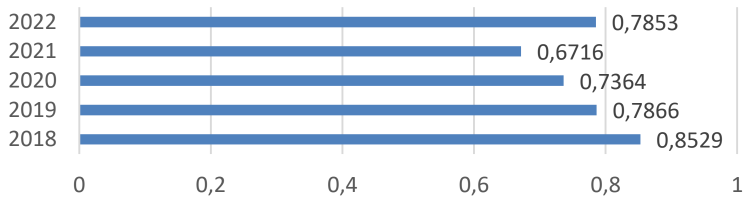


Figure 5 – Efficiency by year, average, DMU 1-27, model (1)-(3)

Finally, the obtained information on efficiency is also relative to the assigned weight coefficients of the input-output parameters, Table 9. For the analyzed years and from the aspect of particular stations, the most important is the number of freight cars loaded or unloaded at respective stations, and the least important is the number of kilometers traveled by car. This means that with such assigned input-output weights, the efficiency is maximal. For further improvement of efficiency (up to the value "1", in the case of inefficient units) a change of the initial (input/output) data is required, i.e., a change in business practices.

Table 9 – Weights of the input-output parameters

Year	Model	u_1	u_2	υ_1	υ_2
		staff	cars	tons	km
2018	CCR	0.4637	2.6454	0.0559	0.0078
2019		0.6902	2.9984	0.0299	0.0192
2020		1.0638	6.4583	0.0339	0.0210
2021		1.1511	1.3942	0.0173	0.0187
2022		0.3510	7.9415	0.1800	0.0053
∑		3.7198	21.4378	0.3170	0.0720
2018	BCC	0.6612	1.4292	0.0269	0.0140
2019		0.7828	1.9940	0.0198	0.0045
2020		0.9163	5.9992	0.0307	0.0183
2021		1.1181	1.4230	0.0141	0.0098
2022		0.6540	3.8519	0.0795	0.0103
∑		4.1324	14.6973	0.1710	0.0569

This can be seen in Figures 4 and 5, where the efficiency as a indicator of the business practice of the railway station – as a decision-making unit, as a set and as a system – can be further improved, up to the value of "1". From a transport functional to an efficiently functional unit, assembly and system, it is necessary to balance the input-output connection.

However, while the required information for several years has been obtained by applying different DEA models and while corrective actions are part of the results of the used program, DEA still does not solve the question: how to practically implement the measures? "While DEA can be used to set targets for improvement of desired outputs, it does not instruct the user on how to reach those targets." (Avkiran, 2001, p.74)

Conclusion

In the newly opened free transport market, operators need to function efficiently in order to better serve, attract, and retain clients.

The purpose of this article is to calculate the efficiency of the decision-making units in relation to the remaining elements of the set, the selected elements of the system and the applied DEA models. Specifically, the aim is the set-system-model DEA analysis of a set of 27 railway stations in the RS, in the function of transporting goods, including subordinate official places, on the five-year path after the reorganization, from 2018 to 2022. Each railway station was observed threefold, namely, as:

1. An element of the set of IŽS stations, in the function of transporting goods (set analysis);
2. An element of the RS railway transportation system (system analysis); and
3. A DMU efficiency decision-making unit (mathematical DEA analysis).

Such a demanding goal was achieved by obtaining triple-relative efficiency which comes to the fore through the application of 27 decision--making units, four input-output parameters and three mathematical models.

The initial data (inputs and outputs) with which the efficiency is calculated, are the reflection of the state in the set, in the system and outside the system. Specifically, the inputs are the number of executors and the number of freight cars (for which the respective station is loading/unloading). The outputs are transport and traffic services: tons of goods loaded/unloaded and tariff kilometers traveled per car. The data on inputs and outputs are at the 2018-22 annual level.

The mathematical models (CCR/BCC/SE), used to calculate the efficiency based on the initial data, express an average technical/pure-technical/scale efficiency of 0.6692, 0.7491, and 0.8813, respectively.

At the very end of the research, by applying the set-system-model DEA analysis, as a result of the overall situation in practice, the following is obtained: (1) final efficiency value of 0.7666 as an average of 27 DMU, five analyzed years of operation, and three DEA models (2) total weights of the initial data, where the number of cars has the highest weight, and the number of kilometers has the lowest.

For full efficiency (27/27), a new business practice and additional, corrective, target actions are advised as a proposal for future research.

The target actions are the amount (reduction and/or addition) of the same considered activities (inputs or outputs) with which inefficient decision-making units become efficient; thus re-efficiency or regained efficiency is obtained, which is now equal to the one, and railway stations in the function of transporting goods by traffic and transport function efficiently. However, there is no unique efficiency. It is always an assessment, relative to the analyzed set of similar decision-making units, the analyzed multi-component system of various elements and the applied Data Envelopment Analysis model.

An extension of the sample, in addition to the implemented set-system-model DEA analysis of railway stations, is a step forward that considers the railway (1) against other, competitive modes of transport, such as road, water and air transport, and (2) together with other, complementary modes, such as combined, multimodal transport, primarily rail-road and rail-water, with a multifaceted advantage.

"For both passenger and freight movements, portal-to-portal transportation should be considered that may include various modes and interfaces. This is particularly crucial for freight, domestic as well as international." (Sinha, 2007, p.12)

The final and common conclusion is that in order to work successfully, strengthen efficiency and increase competitiveness, as well as after the implemented measures, it is necessary to monitor business parameters over and over again, refresh information, and innovate efficiency measures.

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Estaciones de ferrocarril en la República de Serbia en la función de transporte de mercancías: eficiencia según el sistema DEA

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CAMPO: matemáticas
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/propósito: El Análisis Envolvente de Datos (DEA - por sus siglas en inglés) es comúnmente utilizado para calcular la eficiencia de Unidades de Toma de Decisiones similares (DMU - por sus siglas en inglés), que como tales son elementos de un conjunto. En el artículo, se considera que cada elemento de un conjunto (de elementos similares) es al mismo tiempo un elemento de un sistema (de varios elementos). Un ejemplo de DMU son 27 estaciones de ferrocarril en la República de Serbia (RS) como elemento de un conjunto de estaciones de ferrocarril y como elemento del sistema de transporte ferroviario, en función de transporte de mercancías, tras la división de la empresa Serbian Railways (en pasajeros y mercancías). Por el bien de un mejor servicio, atracción y retención de clientes, en el nuevo, libre, mercado del transporte, el propósito de este artículo es encontrar la eficiencia de las estaciones de la RS en el periodo 2018-2022.

Métodos: Análisis DEA comparativo de modelos sistémicos de sistemas ferroviarios. estaciones como DMU. Una unidad es un elemento del conjunto, la unidad es un elemento del sistema, y una unidad es el tema de la matemática. Modelo DEA-CCR/BCC/SE. Análisis DEA comparativo de modelos sistémicos de sistemas de estaciones ferroviarias como DMU. Una unidad es un elemento del conjunto, la unidad es un elemento del sistema y una unidad es el tema del modelo matemático DEA-CCR/BCC/SE.

Resultados: La eficiencia final, el promedio de todos los valores medios, es 0.7666, como resultado de un triple análisis comparativo de la DEA: 27 DMU, tres modelos DEA y cinco años de funcionamiento.

Conclusión: Las estaciones son funcionalmente diferentes en términos de eficiencia, y cada estación difiere funcionalmente, por años y por modelo. El objetivo final es lograr un equilibrio entrada - salida y la Opción 27/27 que se logra con acciones correctivas de reducción/adición, entrada o salida.

Palabras clave: eficiencia, DEA-CCR/BCC/SE, estaciones ferroviarias, sistema de configuración, transporte de mercancías.

Железнодорожные станции в Республике Сербия в функции грузоперевозок: эффективность по системе DEA

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РУБРИКА ГРНТИ: 27.47.19 Исследование операций
28.29.00 Системный анализ
73.29.21 Железнодорожные станции и узлы. Вокзалы,
73.29.51 Грузовое хозяйство железнодорожного транспорта
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Анализ охвата данных (DEA) обычно используется для расчета эффективности аналогичных подразделений по принятию решений (DMU), которые как таковые являются элементами одного множества. В данной статье такие элементы рассматриваются как часть множества (из сходных элементов), но одновременно и как часть системы (из различных элементов).

Примером DMU в данной статье являются 27 железнодорожных станций в Республике Сербия в качестве элемента множества железнодорожных станций, а также в качестве элемента системы железнодорожного транспорта, которая выполняет функцию грузоперевозок, после разделения компании «Сербские железные дороги» (на «пассажирские» и «товарные»). Целью данной статьи является определение эффективности работы станций Сербских железных дорог в период с 2018 по 2022 год для улучшения обслуживания, привлечения и удержания клиентов на недавно открывшемся свободном транспортном рынке.

Методы: В ходе исследования проведен сравнительный DEA-анализ групповых системных моделей железнодорожных станций как DMU. Причем, единица − это элемент множества, единица − это *элемент системы, и единица − это объект математической модели DEA-CCR/BCC/SE.*

Результаты: В результате тройного сравнительного анализа DEA: 27 железнодорожных станций, трех моделей DEA в течение пяти лет работы получена итоговая эффективность, выраженная средним значением всех средних значений, которое составляет 0,7666.

Заключение: Станции функционально различаются с точки зрения эффективности. Каждая станция функционально отличается в зависимости от года и модели. Конечной целью является баланс доходов и расходов и опция 27/27, которая достигается корректирующими действиями: уменьшением/увеличением, доходов и расходов.

Ключевые слова: эффективность, DEA-CCR/BCC/SE, железнодорожные станции, система множеств, грузоперевозки.

Железничке станице у Републици Србији у функцији превоза робе: ефикасност по систему DEA

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ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Data Envelopment Analysis (DEA) уобичајено се користи за израчунавање ефикасности истоврсних јединица одлучивања (DMU), које су елементи једног скупа. У раду се сматра да је сваки такав скуп (истоврсних елемената) уједно и елемент система (разноврсних елемената). Пример DMU представља 27 железничких станица у Републици Србији (РС), као елемент скупа железничких станица и као елемент система железничког транспорта, у функцији превоза робе после поделе предузећа Железнице Србије (ЖС) (одвојено „путници” и „роба”). Ради квалитетнијег опслуживања, привлачења и задржавања комитената на новоотвореном, слободном и транспортном тржишту, циљ овог рада био је налажење ефикасности станица РС, у периоду 2018–2022. година.

Методе: У раду је примењена скуповно-системска моделна компаративна DEA анализа железничких станица као DMU. Јединица је елемент скупа, елемент система и предмет математичког DEA-CCR/BCC/SE модела.

Резултати: Коначна ефикасност, просек свих просека, износи 0,7666, као резултат тројне компаративне DEA анализе: 27 железничких станица, три DEA модела и пет година пословања.

Закључак: Станице су различито функционалне по питању ефикасности; једна иста станица је различито функционална по годинама и по моделу. Крајњи циљ је баланс улаз-излаз и опција 27/27 која се постиже уз корективне акције – смањење/повећање улаза, односно излаза.

Кључне речи: ефикасност, DEA-CCR/BCC/SE, железничке станице, скуп-систем, превоз робе.

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