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Evaluation of hospital efficiency

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Abstract

Research background: Assessing the effectiveness and performance of decision-making units is important due to the constantly changing environment. Decision-making units must be able to assess their strengths, weaknesses, opportunities, and threats and use them to predict their future situation. Hospitals are among such decision-making units. Understanding of hospitals' financial performance and the ability to address issues promptly can improve both their sustainability and competitiveness.
Purpose of the article: The aim of the paper is to analyze the efficiency of 11 large hospitals in the Slovak Republic using the data envelopment analysis.
Methods: When calculating the efficiency of large Slovak hospitals, two-stage data envelopment analysis was used in variants: input-oriented data envelopment analysis with constant returns to scale, output-oriented data envelopment analysis with constant returns to scale, input-oriented data envelopment analysis with variable returns to scale, and output-oriented data envelopment analysis with variable returns to scale. The efficiency of selected large hospitals in the Slovak Republic was analyzed using data from two years, 2019 (before the COVID-19 pandemic) and 2023 (after the COVID-19 pandemic).
Findings & Value added: Based on the analysis, Louis Pasteur University Hospital Kosice is among the least efficient large hospitals. Among the most efficient large hospitals are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica and Central Military Hospital – Teaching Hospital Ruzomberok. The presented results can provide valuable information for the financial and medical management of healthcare facilities across the entire healthcare sector in Slovakia.

Keywords: data envelopment analysis; hospitals; Slovakia; COVID-19

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1. Introduction

The data envelopment analysis (DEA) model is a non-parametric method for measuring the relative technical efficiency of decision-making units and belongs to the group of mathematical methods based on linear programming procedures (Kocisova, 2012). The term decision-making unit (DMU) was introduced to name the evaluated units, enabling the application of the DEA model across

various areas. It describes any entity (not just a company) in which the process of converting inputs into outputs occurs. As an empirical production function is constructed during the solution of the DEA model, the conceptual apparatus used in the DEA model is closely linked to the production issue. The basic principle of the DEA model is the production possibility frontier (PPF). We consider the efficiency frontier to be one of the most important concepts in DEA. This frontier is created by the set of units considered most efficient within the production possibilities frontier. If a certain unit lies outside the PPF, it is considered inefficient (Monelos et al., 2014).

DEA models can be classified according to various categories. The first category is the classification by model orientation (Mendelova and Bielikova, 2017): input-oriented models, output-oriented models, and non-oriented models. Another division of DEA models is based on the nature of the production process: some assume constant returns to scale (e.g., CRS, CCR), while others assume variable returns to scale (e.g., VRS, BCC). The original CCR and BCC models in DEA were introduced by Charnes et al. (1979) and Banker et al. (1984).

The input-oriented CRS DEA model assumes constant returns to scale. It is independent of changes in output weights and dependent on changes in input weights. In this model, we determine enterprise efficiency based on input variables. Enterprises that achieve an optimal efficiency value of 1 can be considered efficient. Conversely, enterprises that achieve an efficiency value below 1 are inefficient. The value we calculate points to the need for a proportional reduction or improvement in the inputs. We should reduce inputs so that a certain inefficient enterprise becomes efficient (Horvathova and Mokrisova, 2018).

The construction of the output-oriented CRS DEA model is directly analogous to the input-oriented model. This model also assumes constant returns to scale. The difference is that it is independent of changes in input weights and dependent on changes in output weights (Jablonsky and Dlouhy, 2004). In this model, we assess enterprise efficiency using output variables. Enterprises that have achieved an optimal efficiency value of 1 are efficient. If we wish to "improve" the performance of inefficient enterprises, we should increase some or all output variables (Horvathova and Mokrisova, 2018).

The VRS DEA model is like the CRS DEA model. While the CRS model assumes constant returns to scale, the VRS model assumes variable returns to scale. The main difference between the VRS and CRS models is the addition of a limiting condition. In this model, the conical envelope of the data changes to a convex one, which leads to the fact that when using the VRS model, a higher number of units are marked as efficient and bankrupt (Horvathova and Mokrisova, 2019).

The DEA method measures relative efficiency across units; therefore, it requires certain assumptions about these units. We can consider the assumptions as (Jablonsky and Dlouhy, 2004):

- Homogeneous production units – this means that certain units use the same or similar inputs to produce the same (or similar) outputs. These units are then compared with each other.
- Preference for lower inputs and higher outputs.
- Appropriately selected inputs and outputs.
- Semi-positivity – each production unit must have at least one positive input and one positive output.

Some studies have combined the DEA method with other statistical methods. Jackson and Fethi (2000) used DEA to evaluate the technical efficiency of individual Turkish banks and the Tobit model to investigate the determinants of efficiency. Mostafa (2009) examined the efficiency levels of prominent Arab banks using two quantitative methodologies: data envelopment analysis and neural networks. According to Xu and Wang (2009), the DEA model helped reduce the misclassification rate. These authors used the DEA model as a predictor in discriminant analysis, logistic regression, and MPV. In his work, Ferus (2010) applied the CCR model and used classical DEA, with the DEA score subsequently approximated using linear regression. He pointed out that the accuracy of the DEA classification is comparable to that of the discriminant analysis and linear regression models. In a study by Duman et al. (2017), the authors combined the DEA and TOPSIS

methodologies to evaluate retail performance in the food industry. Qasim et al. (2017) examined the performance of Islamic banks in Jordan from 2010 to 2013, employing three measurement methods, including the DEA approach. Rouyendegh et al. (2020) evaluated the performance of the retail industry in Turkey using the IF–TOPSIS and data envelopment analysis methods. A study by Le and Lu (2022) integrated multiple methods, such as data envelopment analysis, rough set theory, and TOPSIS, to examine the competitiveness of pharmaceutical multinational companies listed in the Forbes Global 2000.

Data envelopment analysis in the healthcare sector is a relatively frequently used method. Table 1 provides an overview of studies in which the DEA method was applied to evaluate healthcare facilities.

Table 1: Literature review

Author(s)	Research sample	Input variables	Output variables
Zaim et al. (2008)	12 hospitals in Turkey	Number of beds, number of physicians, and key aspects of total quality management in healthcare	Number of outpatients and patient days
Soares et al. (2017)	21 public hospitals in Brazil	Number of medical and non-medical staff, annual revenue, number of beds, and average length of patient hospitalization	Number of outpatient care services, number of hospitalizations, number of surgeries, number of exams
Lin et al. (2022)	19 medical centers in Taiwan	Total hospital beds, total number of physicians, total number of equipment, net fixed assets, rate of emergency transfer of impatient stays over 48h	Surplus or deficit of appropriation, length of hospital stay, total relative value units of outpatient service, total relative value units of inpatient service, and income from self-paid services
Omir et al. (2024)	Healthcare sector of the Republic of Kazakhstan	Number of medical facilities, number of beds, number of beds for sick children, number of doctors, number of secondary medical staff	Child mortality rate, maternal mortality rate, and mortality rate of the population from infectious and parasitic diseases
Sendek et al. (2014)	Czech and Slovak hospitals	Number of beds, working hours and overtime hours of physicians and nurses, bed days, and cost of medicine and medical products	Number of hospitalizations and outpatient visits in hospitals
Stefko et al. (2018)	8 hospitals in Slovakia	Number of beds, number of medical staff, number of CTs, number of MRs, number of medical equipment	Bed occupancy rate, average nursing time in days
Gavurova and Kocisova (2020)	Slovak hospitals	Number of doctors/nurses/beds per hospitalized patient	Health care, staff access to patients, patient information, and the hotel services

Source: own processing

Other authors have used the DEA method to evaluate other industries. Achi (2023) utilized DEA to evaluate the efficiency of Algerian banks and examined the effects of explanatory factors on their performance. The study by Istaiteyeh et al. (2024) explored the efficiency landscape of the Jordanian banking industry from 2006 to 2021. They assessed the efficiency scores of 15 commercial banks, comprising 13 conventional and 2 Islamic institutions, through data envelopment analysis. Their dataset spanned 240 observations over 16 years. The aim of the paper by Cikovic et al. (2024) was to evaluate the relative efficiency of insurance companies in the North Macedonian market from 2018 to 2022. Employing the input-oriented BCC DEA model, the study integrates capital and labour as inputs, while assessing risk-pooling/bearing services and intermediate function as

outputs. The study by Flores-Ureba et al. (2024) analyzed the efficiency of 229 public-private urban transport operators over the period 2012–2021 using data envelopment analysis.

2. Methodology

The aim of the paper is to analyze the efficiency of 11 large hospitals in the Slovak Republic using the data envelopment analysis. When calculating the efficiency of large Slovak hospitals, two-stage DEA was used in variants: input-oriented DEA with constant returns to scale, output-oriented DEA with constant returns to scale, input-oriented DEA with variable returns to scale, and output-oriented DEA with variable returns to scale. The variables used in the models are shown in Table 2.

Table 2: List of variables

Variable	Source
Output variables	
Patient satisfaction	Ministry of Health of the Slovak Republic, Institute for Economic and Social Reforms
Quality	Ministry of Health of the Slovak Republic
Input variables	
Personal Costs to Sales Ratio	Register of Financial Statements of the Slovak Republic, Financial statements of hospitals
No. of Employees / No. of Beds	Register of Financial Statements of the Slovak Republic

Source: own processing

The research sample consists of 11 large hospitals according to SK NACE 86 – Healthcare and SK NACE 861 - Hospital activities (Table 3). The efficiency of selected large hospitals in the Slovak Republic was analyzed using data from two years, 2019 (before the COVID-19 pandemic) and 2023 (after the COVID-19 pandemic).

Table 3: Analyzed hospitals

Name of hospital	Code
University Hospital Bratislava	BA
Louis Pasteur University Hospital Kosice	KE
F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica	BB
University Hospital Martin	MT
Faculty Hospital of J. A. Reiman Presov	PO
Central Military Hospital – Teaching Hospital Ruzomberok	RK
Faculty Hospital Trencin	TN
Faculty Hospital Nitra	NT
Faculty Hospital and Polyclinic Zilina	ZA
Faculty Hospital Trnava	TR
Faculty Hospital and Policlinic Nove Zamky	NZ

Source: own processing

Stata 15.1 software was used to calculate hospital efficiency.

2.1. Data envelopment analysis

Data envelopment analysis is based on linear programming. This analysis evaluates the efficiency of decision-making units. When evaluating the efficiency of a decision-making unit, we evaluate the efficiency of converting inputs into outputs relatively in relation to other units, i.e. the essence of the classification of DEA models is their orientation to inputs or outputs.

In CRS models, the efficiency frontier and the set of production possibilities form a conical data envelope. Enterprises that achieve an optimal efficiency value of 1 can be considered efficient. Conversely, enterprises that achieve an efficiency value below 1 are inefficient (Horvathova and Mokrisova, 2018). Inefficient units that want to reach this frontier must either (Mendelova and Bielikova, 2017), maximize the value of output at the same level of inputs, models that try to achieve the efficiency frontier by maximizing outputs are referred to as output-oriented models, or minimize the value of inputs at the same value of outputs - models that try to achieve the efficiency

frontier by minimizing inputs are referred to as input-oriented models, or use a combination of the previous two options, this approach is used in models called additive models.

In VRS models, according to Horvathova and Mokrisova (2019), the variable returns to scale assumption holds when an increase or decrease in inputs does not lead to a proportional increase or decrease in outputs. This assumption leads to a modification of the efficiency frontier. The efficiency frontier is the convex envelope of the data. Under this assumption, the efficiency rate of the evaluated units is higher (more accurate, not lower) than under the assumption of constant returns to scale.

2.1.1. CCR model

CCR model – an input-oriented model

The characteristics of the model are: radial model (Phase I), non-radial model (Phase II), independent of changes in the output scale, dependent on changes in the input scale, and constant returns to scale.

Phase I – Input-oriented dual model (Jablonsky and Dlouhy, 2004).

Minimize

$$\theta \tag{1}$$

under conditions

$$\begin{aligned} \theta_{x_0} - X\lambda &\geq 0 \\ Y\lambda &\geq y_0 \\ \lambda &\geq 0 \end{aligned} \tag{2}$$

where λ is the vector of weights assigned to units, X represents inputs, Y denotes outputs, θ is the efficiency measure, x_0 are inputs of the evaluated unit, y_0 – outputs of the evaluated unit.

Phase II is given by the relation (Jablonsky and Dlouhy, 2004).

Maximize

$$\omega = es^- + es^+ \tag{3}$$

under conditions

$$\begin{aligned} s^- &= \theta_{x_0} - X\lambda \\ s^+ &= Y\lambda - y_0 \\ \lambda \geq 0, s^- &\geq 0, s^+ \geq 0 \end{aligned} \tag{4}$$

The second phase identifies input excesses and output shortfalls that remain after the radial efficiency adjustment.

CCR model – an output-oriented model

The characteristics of the model are: radial model (Phase I), non-radial model (Phase II), independent of changes in the input scale, dependent on changes in the output scale, and constant returns to scale.

Phase I – Output-oriented dual model (Jablonsky and Dlouhy, 2004).

Maximize

$$\eta \tag{5}$$

under conditions

$$\begin{aligned} x_0 - X\mu &\geq 0 \\ \eta y_0 - Y\mu &\leq 0 \\ \mu &\geq 0 \end{aligned} \tag{6}$$

The efficiency rate can take values $\eta \geq 1$, the effective unit has a value $\eta = 1$, and μ represents technical efficiency.

Phase II (Jablonsky and Dlouhy, 2004).

Maximize

$$\omega = et^- + et^+ \tag{7}$$

under conditions

$$\begin{gathered} t^- = \theta^* x_0 - X\,\mu \\ t^+ = Y\,\mu - \eta y_0 \\ \mu \geq 0, t^- \geq 0, t^+ \geq 0 \end{gathered} \tag{8}$$

This phase identifies the remaining input and output slacks after the radial adjustment.

In addition, the following relationships exist between the input-oriented model and the output-oriented model (Cooper et al., 2007):

$$\begin{gathered} \eta^* = \frac{1}{\theta^*}, \mu^* = \frac{\lambda^*}{\theta^*} \\ t^{-*} = \frac{s^{-*}}{\theta^*}, t^{+*} = \frac{s^{+*}}{\theta^*} \end{gathered} \tag{9}$$

2.2.2. BCC model

The BCC model is a modified CCR model, differing in that it assumes non-constant returns to scale. The conditions for returns to scale of the input-oriented model for:

$$e\,\lambda \tag{10}$$

Constant returns to scale correspond to the CCR model, while variable returns to scale are ensured by the condition $e\,\lambda = 1$. Decreasing (non-increasing) returns to scale are represented by the condition $e\,\lambda \leq 1$, and increasing (non-decreasing) returns to scale by the condition $e\,\lambda \geq 1$.

The CCR and BCC models differ in the condition for returns to scale. The BCC model can also be divided into two phases, namely the input-oriented model and the output-oriented model.

BCC model – an input-oriented model

The characteristics of the model are: radial model (Phase I), non-radial model (Phase II); independent of changes in the output scale, dependent on changes in the input scale; variable, non-increasing, non-decreasing returns to scale.

Phase I – Input-oriented dual model.

Minimize

$$\theta \tag{11}$$

under conditions

$$\begin{gathered} \theta_{x_0} - X\,\lambda \geq 0 \\ Y\,\lambda \geq y_0 \\ \lambda \geq 0 \end{gathered} \tag{12}$$

Phase II

Maximize

$$\omega = es^- + es^+ \tag{13}$$

under conditions

$$\begin{gathered} s^- = \theta_{x_0} - X\,\lambda \\ s^+ = Y\,\lambda - y_0 \end{gathered} \tag{14}$$

$$\lambda \geq 0, s^{-} \geq 0, s^{+} \geq 0$$

3. Results

We analyzed 11 large hospitals in 2019 (before the COVID-19 pandemic) and in 2023 (after the COVID-19 pandemic). As part of the analysis, we first focused on the input-oriented DEA model with constant returns to scale. Table 4 provides an overview of the DEA model results for 2019. As can be seen, three hospitals ranked first, namely F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Faculty Hospital Trencin, and Faculty Hospital Nitra. These hospitals can be considered the most efficient because they achieved a Theta value of 1 and slack values of 0 for both the input and output variables. Faculty Hospital and Polyclinic Zilina and Louis Pasteur University Hospital Kosice were identified as the least efficient hospitals in the input-oriented DEA model with constant returns to scale because they achieved the lowest Theta values. The reference hospitals in this model were F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Faculty Hospital Trencin, and Faculty Hospital Nitra. The slack values of the input and output variables indicate how far a given unit is from the efficient frontier.

Table 4: Input-oriented DEA model with constant returns to scale (CCR-I-OM 2019)

2019	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	5	1		0.349	0.888			26.610	
KE	11	0.682	0.229	0.136	0.495				
BB	1	1	1				0		
MA	4	1	0.878	0.258					10.245
PO	8	0.875	0.10	0.489	0.465			3.25e-06	
RK	6	0.990	1.071	0.112					0.564
TN	1	1	0	1					
NR	1	1	0	0	1				
ZA	10	0.718	0.141	0.308	0.407			2.11e-06	
TR	9	0.725		0.257	0.576			3.777	
NZ	7	0.972	0.054	0.555	0.498				

Source: own processing

Table 5 provides an overview of the ranking results under the input-oriented model with constant returns to scale for 2023. In the post-pandemic period of 2023, the best-performing hospitals were F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Central Military Hospital – Teaching Hospital Ruzomberok, Faculty Hospital Presov, and Faculty Hospital Trencin.

Table 5: Input-oriented DEA model with constant returns to scale (CCR-I-OM 2023)

2023	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	5	1			0.348	0.619			28.54
KE	11	0.609		0.300	0.294	0.046			
BB	1	1	1		0			0	
MA	4	0.902		0.0716	0.759	2.6e-7			
PO	8	1		1	0	0			
RK	6	1			1			0	
TN	1	1			0	1			0
NR	1	0.928			0.420	0.435			21.609
ZA	10	0.975		0.573	0.349				3.461
TR	9	0.764		0.0501	0.127	0.592			
NZ	7	0.989		0.579		0.388	0.0071		

Source: own processing

Another model applied in the analysis is the output-oriented DEA model with constant returns to scale. An overview of the results of this model for 2019 is provided in Table 6. The most efficient hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, University Hospital Martin, and Faculty Hospital Trencin. These hospitals are considered the most efficient because they achieved a Theta value of 1 and slack values of 0 for both the input and output variables. The least efficient hospitals in this model are Faculty Hospital and Polyclinic Zilina and Louis Pasteur University Hospital Kosice, as they achieved the lowest Theta values. The reference hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, University Hospital Martin, and Faculty Hospital Trencin.

Table 6: Output-oriented DEA model with constant returns to scale (CCR-O-OM 2019)

2019	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	5	1	0.759		0.453			46.239	0
KE	11	0.682	0.652		0.195			9.271	0
BB	1	1	1				0	0	0
MA	4	1	0	1	0				0
PO	8	0.875	0.499		0.544			8.725	0
RK	6	0.990	1.023	0.055	0.098				0.0000321
TN	1	1	0		1			0	0
NR	1	1	0.855		0.117			18.725	0
ZA	10	0.718	0.489		0.556			7.621	0
TR	9	0.725	0.493		0.325			14.571	0
NZ	7	0.972	0.480		0.614			9.325	0

Source: own processing

In 2023, the output-oriented model with constant returns to scale (Table 7) shows that three hospitals ranked first: Central Military Hospital – Teaching Hospital Ruzomberok, Faculty Hospital Presov, and Faculty Hospital Trencin. F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica dropped to fourth place, Faculty Hospital Nitra to eighth place, and University Hospital Martin to ninth place.

Table 7: Output-oriented DEA model with constant returns to scale (CCR-O-OM 2023)

2023	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	5	1			0.348	0.619			28.54
KE	11	0.609		0.300	0.294	0.046			
BB	4	1	0		0.719			0.301	8.435
MA	9	0.902		0.0716	0.759	6.39e-7			
PO	1	1		1	0	0			
RK	1	1			1			0	
TN	1	1			0	1			0
NR	8	0.928			0.420	0.435			21.609
ZA	7	0.975		0.573	0.349	0			
TR	10	0.764		0.0501	0.127	0.592			
NZ	6	0.989		0.579		0.388	0.0071		

Source: own processing

The third model applied in the analysis is the input-oriented DEA model with variable returns to scale. An overview of the results of this model for 2019 is provided in Table 8. The most efficient hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Central Military Hospital – Teaching Hospital Ruzomberok, Faculty Hospital Trencin, and Faculty Hospital Nitra. These hospitals are considered the most efficient because they achieved a Theta value of 1 and slack values of 0 for both the input and output variables. The least efficient hospitals in this model are Louis Pasteur University Hospital Kosice and Faculty Hospital and Polyclinic Zilina, as they achieved the lowest Theta values. The reference hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Central Military Hospital – Teaching Hospital

Ruzomberok, Faculty Hospital Trencin, Faculty Hospital Nitra, and Faculty Hospital and Polyclinic Nove Zamky.

Table 8: Input-oriented DEA model with variable returns to scale (BCC-I-OM 2019)

2019	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	7	1		0.5			0.499	0.034	
KE	11	0.785	0.751		0.224				
BB	1	1	1					0	
MA	6	1	0.118	0.702	0.179				
PO	8	0.886	0.193	0.288	0.518				
RK	1	1		1	0		0	0	
TN	1	1	0		1				
NR	1	1	0		0	1			
ZA	10	0.833	0.568		0.413				
TR	9	0.869	0.591		0.389				
NZ	1	1	0	0	0		1		

Source: own processing

We also consider F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, Central Military Hospital – Teaching Hospital Ruzomberok, and Faculty Hospital Trencin to be the most efficient hospitals in the model for 2023 (Table 9). Compared to 2019, Faculty Hospital and Polyclinic Nove Zamky fell to fifth place, and Faculty Hospital Nitra fell to ninth place.

Table 9: Input-oriented DEA model with variable returns to scale (BCC-I-OM 2023)

2023	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	7	1			0.348	0.619			28.540
KE	11	0.775			0.422	0.433			8.667
BB	1	1	1		0			0	
MA	8	0.973			0.829	0.075			4.503
PO	1	1		1	0	0		0	
RK	1	1			1				
TN	1	1			0	1			0
NR	9	0.948			0.429	0.444			22.641
ZA	6	1		0.305	0.393	0.278			
TR	10	0.931			0.162	0.781			6.889
NZ	5	1		0.511		0.484	0.0021		

Source: own processing

The last model applied in the analysis is the output-oriented DEA model with variable returns to scale. An overview of the results of this model for 2019 is provided in Table 10. The most efficient hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, University Hospital Martin, Central Military Hospital – Teaching Hospital Ruzomberok, and Faculty Hospital Trencin. These hospitals are considered the most efficient because they achieved a Theta value of 1 and slack values of 0 for both input and output variables. The least efficient hospitals in this model are Louis Pasteur University Hospital Kosice and Faculty Hospital Trnava, as they achieved the lowest Theta values. The reference hospitals in this model are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica, University Hospital Martin, Central Military Hospital – Teaching Hospital Ruzomberok, and Faculty Hospital Trencin.

Table 11 presents the DEA model results for the year 2023. In this model, the most efficient hospitals are Faculty Hospital J. A. Reiman Presov, Central Military Hospital – Teaching Hospital Ruzomberok, and Faculty Hospital Trencin. The least efficient hospitals include Louis Pasteur University Hospital Kosice and Faculty Hospital Trnava.

Table 10: Output-oriented DEA model with variable returns to scale (BCC-O-OM 2019)

2019	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	7	1			0.736	0.263	0.045		43.845
KE	11	0.720			0.66	0.060	0.0301		10.287
BB	1	1	1					0	0
MA	1	1	0	1		0			
PO	8	0.929			0.528	0.401	0.049		9.550
RK	1	1	0	0	1	0			
TN	1	1	0			1			0
NR	6	1	0.855			0.117			18.725
ZA	9	0.749			0.491	0.257	0.0248		8.202
TR	10	0.740			0.466	0.273	0.0022		15.066
NZ	5	1			0.472	0.527	0.021		9.961

Source: own processing

Table 11: Output-oriented DEA model with variable returns to scale (BCC-O-OM 2023)

2023	Rank	Theta	Ref			Slacks			
			BB	TN	NR	PC/S	E/B	PS	Q
BA	7	1		0.348	0.619			28.540	
KE	11	0.615	0.153	0.364	0.0967	0.026			
BB	6	1		0.719			0.301	8.435	0
MA	8	0.953		0.812	0.0744			3.152	6.931
PO	1	1	1	0	0				0
RK	1	1		1	0	0		0	0
TN	1	1		0	1			0	0
NR	9	0.929		0.420	0.435			21.63	0
ZA	5	1	0.305	0.393	0.278				7.894
TR	10	0.765	0.0262	0.138	0.600	0.0044			3.27e-6
NZ	4	1	0.511		0.484	0.0211			1.712

Source: own processing

Table 12 provides a summary view of the DEA models for the pre-pandemic and post-pandemic periods. The blue cells in the table indicate a tie for 1st place in the pre-pandemic and post-pandemic periods. The grey cells in the table indicate the final ranking position of large hospitals.

Table 12: DEA models

Hospital	CCR-I-OM		CCR-O-OM		BCC-I-OM		BCC-O-OM	
	2019	2023	2019	2023	2019	2023	2019	2023
BA	5	5	5	5	7	7	7	7
KE	11	11	11	11	11	11	11	11
BB	1	1	1	4	1	1	1	6
MA	4	9	1	9	6	8	1	8
PO	8	1	8	1	8	1	8	1
RK	6	1	6	1	1	1	1	1
TN	1	1	1	1	1	1	1	1
NR	1	8	4	8	1	9	6	9
ZA	10	7	10	7	10	6	9	5
TR	9	10	9	10	9	10	10	10
NZ	7	6	7	6	1	5	5	4

Source: own processing

4. Discussion

Multi-criteria evaluation of objects in space can be applied in many areas, including healthcare and healthcare facilities, either as a final solution or as a product for other analyses.

Eleven large hospitals were evaluated in the paper. Large hospitals were state-funded terminal hospitals. On average, state hospitals handle more complex cases than facilities in the small- and medium-sized hospital category. At the same time, they are the largest hospitals in terms of annual

hospitalizations, number of beds, and revenue. The largest state hospital in the Slovak Republic is University Hospital Bratislava, with 5,912 employees and 2,571 beds. The smallest state hospital is Faculty Hospital Trnava, with 1,447 employees and 694 beds, followed by Faculty Hospital and Polyclinic Nove Zamky, with 1,463 employees and 746 beds.

Economic efficiency was defined using relative indicators that reflected the ratio of outputs to inputs, thereby eliminating the influence of various factors. In the analysis of efficiency, efficiency indicators whose objective is desirable growth and demandingness indicators whose objective is a desirable decrease were selected.

To analyze the efficiency of large hospitals in the Slovak Republic using the DEA method, we used input- and output-oriented DEA models with constant and variable returns to scale. Based on the analysis, Louis Pasteur University Hospital Kosice is among the least efficient large hospitals. The most efficient large hospitals include F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica and Central Military Hospital – Teaching Hospital Ruzomberok.

For comparison, according to the Institute for Economic and Social Reforms (2024), before and during the pandemic (2018–2021), F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica ranked first among state hospitals. In the post-COVID period (2022–2023), in the overall ranking of large hospitals, F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica dropped to second place. Central Military Hospital – Teaching Hospital Ruzomberok ranked first in the ranking of the best hospitals in 2022–2023. The third position is held by University Hospital Martin, the fourth by Faculty Hospital and Polyclinic Zilina, and the fifth by Faculty Hospital Presov. Faculty Hospital Trencin, which is currently one of the most innovative hospitals, ranked seventh. Faculty Hospital Trencin has undergone extensive and significant reconstruction of several departments, including technological modernization. The hospital received a certificate awarded to the Gynecology and Obstetrics Clinic by the European Society of Gynecological Oncology, making it the only certified workplace in Slovakia and placing the hospital among leading institutions worldwide in the treatment of uterine cancer. The hospital also operates an MRI workplace equipped with a top 3T device, which is available in only two hospitals in Slovakia.

According to OECD (2024), the number of hospital beds in Slovakia is decreasing. However, there are still 6.0 beds per 1,000 inhabitants, which is significantly above the EU average of 5.0 beds per 1,000 inhabitants. According to Kalis and Stracova (2019), the hospital sector is characterized by excessive capacity in total bed numbers due to inherited infrastructure. These authors applied the DEA method to optimize bed capacity across 62 hospitals. According to the DEA model analysis, the number of beds should be reduced by 68 to 113 per hospital, which in absolute terms represents a reduction from 24,944 to 20,729 according to the BCC model and up to 17,828 according to the CCR model.

To increase hospital efficiency, a detailed mapping of hospital capital structures and equipment is essential. Stefko et al. (2017) used DEA to evaluate the efficiency of healthcare facilities in Slovakia at the regional level over the period 2008–2015. Medical technologies are the main driver of growth in real healthcare expenditure, accounting for 38–62% of growth (Smith et al., 2000). Slovakia still lags behind in the implementation of new technologies, digitization, and electronification.

5. Conclusions

Analysis of multivariate statistical data is one of the most common tasks in data processing across management, economics, the social sciences, and the natural sciences. The efficiency of using information from the data in processing with multivariate statistical tests is significantly higher than that of inputs based on univariate data. Precise and comprehensible data analysis using multi-criteria methods often brings new perspectives on problems that would likely escape the attention of healthcare managers with simple processing methods.

The aim of the paper was to analyze the efficiency of 11 large hospitals in the Slovak Republic using data envelopment analysis. For the analysis, we applied both input- and output-oriented DEA

models with constant and variable returns to scale. Based on the analysis, Louis Pasteur University Hospital Kosice is among the least efficient large hospitals. Among the most efficient large hospitals are F. D. Roosevelt University Hospital with Polyclinic Banska Bystrica and Central Military Hospital – Teaching Hospital Ruzomberok.

The study conducted also has several limitations. The limitation is that we only considered four variables. Future research could assess whether incorporating additional variables improves the accuracy of the DEA model. Another limitation is the availability of data for the analysis. We can also use other methods to measure hospital efficiency.

The presented results can provide valuable information for the financial and medical management of medical facilities across the entire healthcare sector in Slovakia.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that no generative AI and AI-assisted technologies were used in the writing process.

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