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Hospital Evaluation and Ranking by the Anderson-Peterson Method: A Case Study

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Abstract

In this study, we evaluated the performance of various hospitals using a method known as Data Envelopment Analysis (DEA). We collected indicators and data by researching in libraries and consulting directly with the hospitals. To analyze the data, we used the DEA SOLVER software. The findings revealed that all the hospitals examined showed high efficiency. After assessing the hospitals' efficiency, we used the Anderson-Peterson (AP) model to rank the most efficient units.

Keywords: Performance evaluation, Hospital ranking, Data envelopment analysis, Anderson-Peterson model.

1 | Introduction

In addition to providing services, hospitals account for approximately 50% to 80% of the total cost of the healthcare sector. However, despite the large number of resources allocated, there is a significant disparity between the growth of available resources and the resources required in this sector [1]. The poor management of the hospital results in the inefficient use of resources, including money, human resources, buildings, and equipment.

Wastage inflates operational costs and negatively affects patient service quality and accessibility. The Decision-Making Units (DMUs) (i.e., hospitals) can enhance service quality by expanding without expenses via waste minimization and scarce resource optimization. Considering the importance of hospitals in providing medical services and their significant impact on the country's health system efficiency, continuous improvement of hospital performance is necessary.

This study employed a fractional programming method known as Data Envelopment Analysis (DEA) to evaluate the technical efficiency of hospitals affiliated with Lorestan University of Medical Sciences. Because

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all units were efficient, the Anderson-Peterson (AP) model was applied to compare and rank the efficient units.

Section 2 reviews the literature on DEA in hospital performance evaluation and ranking. Section 3 presents the method and discusses its advantages and disadvantages. Section 4 presents the case study. And Section 5 concludes the study.

2 | Literature Review

Salehzadeh and Ketabi [2] evaluated the relative efficiency of public and private hospitals in Qom in 2007 using DEA. They examined data from 8 hospitals in the city, and the input variables included the number of general practitioners, specialist physicians, paramedical personnel, and active beds. Three hospitals were efficient, and five were inefficient, based on the CCR model, while the BCC model identified four hospitals as efficient and four as inefficient. The results showed that most hospitals are inadequate, and improving their performance requires better financial and human resource management, as well as modeling from reference hospitals.

Mitropoulos et al. [3] presented a methodology aimed at improving statistical inference in DEA by integrating a Chance-Constrained Data Envelopment Analysis (CCDEA) model with Bayesian techniques. They employed Bayesian methods to create a statistical model and simulate alternative data sets. Then, they solved the CCDEA problem for each data set to compute efficiency measures, which were then analyzed to estimate the sampling distribution. They applied the methodology to cross-sectional data from 117 Greek public hospitals, categorized into primary, secondary, and tertiary care groups based on the hierarchical structure of the health system. Additionally, they introduced a meta-frontier analysis to evaluate the overall technical efficiency of these hospitals.

Amirteimoori et al. [4] discussed the importance of energy, particularly natural gas, in economic growth and development. It highlights the need to assess the efficiency and productivity of gas companies. While traditional DEA does not consider internal structures, Network DEA does. The efficiency of Iranian gas companies was evaluated from 2002 to 2004, and efficiency scores were determined and ranked using the Cross Efficiency technique.

Debata et al. [5] created a framework for benchmarking medical tourism in India. It involves evaluating 39 medical tourism service providers using the DEA to assess their efficiency. The research identified the weaknesses of less efficient providers and suggested strategies for improvement.

Ardalan et al. [6] evaluated the efficiency of Kermanshah health-treatment centers in 2010 using data collection forms. They employed DEA and DEA SOLVER software to rank the centers based on their efficiency. The study assessed the similarity of various efficiency models by applying them and using Spearman's rank correlation coefficient. The results suggest that healthcare treatment centers should enhance customer satisfaction by providing better service, information, and education to improve efficiency.

Nouraei Motlagh et al. [7] analyzed the productivity of hospitals affiliated with Lorestan University of Medical Sciences in Iran from 2010 to 2016. They evaluated changes in productivity, measuring total factors and marginal productivity using Kendrick-Karim indices. They employed the AP model to rank efficient DMUs. Results indicated a decrease in overall productivity (Average total productivity of 1.023), primarily due to technological changes.

Hatefi and Haeri [8] evaluated the efficiency of hospitals in Qazvin province using a combined model of Balanced Scorecard and Fuzzy Data Envelopment Analysis (BSC-Fuzzy DEA). It highlighted the crucial role of hospitals in healthcare and the need for effective performance evaluation systems. A descriptive-analytical study was conducted in 2018 involving eight hospitals, using data collected from experts, including hospital staff and patients. The analysis identified Amiralmomenin Hospital, Bu Ali Clinic, and 22 Bahman Hospital as the top performers, with technical efficiency scores of 1.72, 1.58, and 1.53, respectively, at an $\alpha = 0.75$ uncertainty level.

Monzeli et al. [9] focused on optimizing the allocation of human resources and resources in hospital emergency departments while maintaining service quality. The research employed DEA to assess the efficiency of these departments, considering both desirable and undesirable outputs. It also examines how DMUs impact efficiency. It defined appropriate production possibilities and utilized AP and Super-SBM models to analyze performance. A real example involving 30 hospital emergencies was analyzed.

Haseli Mofrad et al. [10] examined the efficiency of physical education departments in Tehran using a DEA approach. Despite advancements in performance appraisal frameworks, many organizations still use traditional metrics. The research identified input indicators (Like the ratio of students to physical education teachers, departmental budget, and sports facilities) and output indicators (Such as competitions and awards won) to evaluate departmental performance. The DEA models (BCC, CCR, and AP) were applied using DEA-SOLVER LV software, revealing that out of 19 regions, 11 were efficient while eight were inefficient. The study concludes that further modeling is needed to determine the necessary changes to improve the inefficient departments.

Ghasemi et al. [11] evaluated factors influencing Operating Room (OR) efficiency in ten of Tehran's largest hospitals, focusing on inputs like scheduling accuracy, turnover time, successful surgeries, cancellations, errors, and emergencies. The output included the number of ORs, equipment, beds, staff, and patient satisfaction. They use the Group Analytic Hierarchy Process (GAHP) to determine input and output weights based on expert opinions and apply various DEA models (Input-oriented, output-oriented, and input-output-oriented) to rank OR efficiency.

Hamzehzadeh et al. [12] evaluated a service-oriented nursing supervisor strategy to improve performance efficiency in 12 hospital wards using DEA. The efficiency of the wards was analyzed before and after implementing the strategy during two periods in 2020. Results indicated that, according to the CCR method, the Urology and Neurosurgery wards showed the highest efficiency, while the ENT ward had the lowest. The BCC method also identified Urology and Neurosurgery as efficient, with ENT again ranked lowest.

Barati et al. [13] evaluate organizational agility in the banking industry in Isfahan using DEA. It involved selected first-class branches from Saderat, Melli, Shahr, Maskan, Keshavarzi, Refah, and Tejarat banks, including five branches from each and two from the newly established Bank Shahr. An output-oriented DEA model was employed, with inputs derived from agility enablers based on the A.T. Kearney model, while the output reflected the results of agility. The findings revealed that out of 32 branches, only four were efficient, while 28 were inefficient. Efficient branches were subsequently ranked using the AP model. This research provides a framework for assessing and enhancing the agility of bank branches.

Ferreira et al. [14] examined the technical efficiency of observations by emphasizing the importance of accurate input and output data. It highlighted that biases can arise from data quality issues, particularly when using DEA, which compares observations against an empirically defined efficiency frontier. To address Imperfect Knowledge of Data (IKD), the researcher modeled IKD and implemented a Hit Run procedure to generate admissible observations based on specified probability density functions. This process involves multiple iterations to adequately sample the data domain. Each iteration utilized the DEA to estimate bootstrapped efficiency scores. An empirical application using data from Portuguese public hospitals from 2013 to 2016 illustrated the method's effectiveness.

Peykani and Pishvaee [15] discussed a new approach called Uncertain Common-Weights Data Envelopment Analysis (UCWDEA) for evaluating hospital performance in the presence of data uncertainty. Traditional performance measurement methods often struggle with this uncertainty; however, UCWDEA incorporates uncertainty theory and employs a common set of weights to provide a more accurate assessment. The key benefits of this approach include a consistent comparison of 20 hospitals in Tehran for realistic efficiency scores, linearity, enhancing its applicability, and the ability to work with various uncertainty distributions. The method improves the discriminatory power of results, facilitates hospital ranking, and assesses sensitivity to data uncertainty. *Table 1* reviews the literature on DEA-based hospital evaluation and ranking.

Table 1. Summary of the literature review on data envelopment analysis-based hospital evaluation and ranking.

Year	Author(s)	Method Used to Rank DMUs	Case Study Included?
2011	Salehzadeh and Ketabi [2]	DEA	Yes (Hospitals)
2015	Mitropoulos et al. [3]	CCDEA	Yes (Hospitals)
2015	Debata et al. [5]	DEA	Yes (Medical tourism)
2016	Ardalan et al. [6]	DEA	Yes (Health-treatment centers)
2019	Motlagh et al. [7]	DEA, AP	Yes (Hospitals)
2019	Hatefi and Haeri [8]	BSC-Fuzzy DEA	Yes (Hospitals)
2020	Monzeli et al. [9]	DEA	Yes (Hospitals)
2021	Ghasemi et al. [11]	AP, CCR Models, GAHP	Yes (Hospitals)
2022	Hamzehzadeh et al. [12]	AP with CCR/BCC Models	Yes (Hospitals)
2022	Barati et al. [13]	DEA, AP	Yes (Banking industry)
2023	Ferreira et al. [14]	DEA	Yes (Hospitals)
2024	Peykani and Pishvaee [15]	UCWDEA	Yes (Hospitals)
	This study	DEA, AP	Yes (Hospitals)

3 | Methods

Here, the collected information has been analyzed using DEA models assuming variable returns to scale. DEA is a mathematical technique used to evaluate the relative efficiency of DMUs (e.g., companies and organizations) based on multiple inputs and outputs. DEA SOLVER software was employed to solve the DEA models. A set of patterns that hospitals can pay attention to in order to improve their performance will be identified by examining the best practices that work effectively for hospitals. The output data table includes the number of admissions and outpatient visits, the number of admissions and inpatient visits, and the bed occupancy rate. The input data table includes the number of active beds, the number of specialist doctors, the number of general doctors and paramedics, the number of nurses, and the number of other employees [1]. This information was collected through direct reference to the hospitals and the university's vice-chancellor, as well as the university's statistical center. In a different context, Anderson and Peterson [16] proposed a procedure for ranking efficient units in DEA. Their method helps rank units based on their efficiency scores, considering technical and scale efficiency.

3.1 | Data Envelopment Analysis Method

Farrell [17] introduced a pioneering methodology for measuring efficiency by adapting engineering principles to assess the agricultural sector. While groundbreaking at the time, this initial approach was limited to single-input and single-output scenarios and did not accommodate situations with multiple input and output factors. Subsequently, Charnes, Cooper, and Rhodes [18] expanded upon Farrell's framework and developed an advanced model capable of evaluating efficiency in complex settings characterized by multiple inputs and outputs. This model, named DEA, was first used in Edward's doctoral dissertation to guide the academic progress of American national school students in 1976 at Carnegie University. DEA is a non-parametric method for evaluating the efficiency of homogeneous DMUs. A single decision is typically modeled as a single process that transforms input into outputs. The mathematical function of this conversion process is unknown, and the relative efficiency of the DMUs is evaluated solely based on the observed input and output data. The units under evaluation in data coverage analysis are called DMUs, and the functions are divided into two groups: input and output. A DMU is considered responsible for converting the performance evaluation output. In other words, the unit responsible is taken as a decision to indicate the units that consume the same inputs and produce the same outputs. Since the introduction of data overlay in 1978, this technique has been rapidly adopted as a powerful analytical tool for operational process modeling, performance improvement, and decision-making. The DEA evaluates the relative efficiency of DMUs – in this case, hospitals – by comparing how effectively they convert multiple inputs into multiple outputs. The growing application of

DEA in healthcare reflects the increasing emphasis on evidence-based management and performance measurement in hospital settings.

DEA is widely used for hospital performance evaluation, but it is one of several methodological approaches, such as Risk-Adjusted Outcome Measures, Simple Ratio Analysis, and Composite Indicators and Scorecards [19], [20]. Here's how DEA compares to other common methods: Risk-adjusted outcome Measures provide direct quality measures by adjusting patient characteristics, but they may oversimplify performance and rely on the accuracy of models. Simple Ratio Analysis is easy to calculate and interpret; however, it overlooks the multidimensional aspect of performance. Composite Indicators and Scorecards offer a broad overview for public reporting, but subjective weighting can obscure specific strengths or weaknesses.

3.1.1 | Advantages and limitations of data envelopment analysis

DEA has been employed as a method for evaluating and ranking the performance of DMUs (Such as hospitals). Due to the increasing pressure to allocate resources and improve the quality of care, understanding the DEA's strengths and weaknesses is crucial. Here, we review the advantages and limitations of the DEA in evaluating and ranking hospital performance [2]-[15].

Advantages:

I. DEA has been widely used to evaluate various aspects of hospital operations, from departmental efficiency to overall organizational performance. One of DEA's primary strengths is its ability to comprehensively evaluate hospital performance by simultaneously considering multiple dimensions.

II. In DEA, the unit of measurement is not sensitive, and the inputs can have different units of measurement. The flexibility of the non-parametric approach, DEA, in not requiring a functional form assumption, makes it particularly suitable for hospital settings where the relationship between resources and outcomes is complex and not easily modeled through parametric functions.

III. The DEA method is a management approach that measures the relative efficiency of units and provides management solutions. DEA enables the identification of inefficient hospitals and the assessment of potential improvement strategies. It supports identifying best practices by highlighting hospitals that achieve maximum output with minimum input. Insights generated through DEA analysis facilitate informed strategic decision-making and performance improvement initiatives. By identifying inefficient areas, hospital managers can target specific aspects of operations for improvement. DEA models provide actionable information to guide resource allocation and organizational development strategies generated through DEA analysis, facilitating informed strategic decision-making and performance improvement initiatives. Hospital managers can target specific aspects of operations for improvement. DEA models provide actionable information to guide resource allocation and organizational development strategies.

IV. The DEA method compares units with each other and is far from being purely idealistic.

V. The DEA method only determines efficiency and lacks the weaknesses of other measurement systems that follow a kind of absolutism; efficiency in a model is an achievable quantity.

Limitations:

I. Because DEA is a purely mathematical and numerical technique, measurement errors can cause significant changes in the results; therefore, after identifying the efficient unit, it is necessary to re-check the data and results to ensure their accuracy.

II. This method is only a mathematical method based on linear programming and cannot compare the qualitative variables of DMUs. The standard DEA models primarily use quantitative data to evaluate hospital performance, potentially overlooking crucial qualitative factors. Incorporating methods such as the Delphi technique allows the DEA to capture the subtle judgments of healthcare professionals that might be overlooked.

III. If only one of the data and outputs of the DMUs changes, fundamental changes will occur in the degree of efficiency of the DMUs.

IV. In this method, there is no consensus on the selection of data and output.

V. Traditional DEA models face significant challenges when dealing with uncertain or imprecise data, a common occurrence in hospital settings. Researchers have noted this limitation and proposed extended approaches, such as the UCWDEA, to address these concerns.

VI. Another limitation of conventional DEA is the potential for assigning zero weights to particular input or output variables. This situation can distort efficiency scores by effectively ignoring relevant performance dimensions. In response to this limitation, researchers have developed hybrid approaches to ensure all essential variables contribute meaningfully to the efficiency assessment [21].

VII. Traditional DEA models may struggle to provide a complete ranking of all evaluated units, particularly when multiple units achieve full efficiency scores. Enhanced models, such as the super-efficiency DEA with anti-entropy-Delphi combined weights constraints, have been developed to achieve more discriminative rankings. These advanced models enable analysts to differentiate among hospitals that appear equally efficient through more sophisticated mathematical techniques.

3.1.2 | Data envelopment analysis models

The use of data coverage for the relative evaluation of units requires the determination of two basic characteristics, the nature of the pattern and the return to the pattern, which have been identified in this research. Traditionally, DEA models include BCC models and CCR models. Also, DEA patterns can be input-oriented or output-oriented. The CCR model is the communication output used in this research to measure the efficiency or inefficiency, as described in *Eqs. (1)-(4)*.

x_{ij}	The ith input for the jth unit.
y_{rj}	The rth output amount for the jth unit.
u_r	The weight given to the rth output (Rth output price).
v_i	The weight is given to the ith input (Cost of the ith input).

$$\text{Min } Z_o = \sum_{i=1}^{m} v_i\, x_{io}. \tag{1}$$

s.t.

$$\textstyle\sum_{r=1}^{s} u_r y_{ro} = 1. \tag{2}$$

$$\textstyle\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \le 0,\ j = 1,2,\dots,n, \quad i = 1,2,\dots m. \tag{3}$$

$$u_r, v_i \ge 0. \tag{4}$$

The variable corresponding to the equal limit is in the free multiplicative form in the sign. In this pattern, the selection of any vector of λ creates an upper limit for the data and a lower limit for the DMU, and on the other hand, there are limits related to $\lambda_j \ge 0$ provides the optimal option to be associated with min $\theta = 0$. The overlay pattern provided a set of solutions. These solutions create an upper limit that encompasses all observations and provides objectivity through data envelope analysis. The envelope form makes it possible to determine the convex combination created for each inefficient unit and the extent of the involvement of efficient units in this λ_j combination. Therefore, the primary advantage of the envelope form is the type of answer it provides regarding the efficiency of different units.

If the efficiency value that comes from the above model is equal, a decision is made that the hospital in question becomes the efficiency unit. On the other hand, if the efficiency value is less than the desired decision

(Hospital), it is inefficient. Another output of the software used in this research is determining the surplus in inputs and outputs, as well as the goal of input and output in cases of inefficiency.

3.1.3 | The Anderson-Peterson model

DEA and the AP method are commonly used together to provide a more comprehensive and nuanced analysis of efficiency among DMUs. Combining DEA and AP methods is a well-accepted and practical approach to achieving a more comprehensive and differentiated efficiency analysis, particularly in contexts where ranking among efficient units is crucial [8]. In similar decision-making evaluations of units by DEA, each DMU is assigned an efficiency score between 0 and 1. If the efficiency value is one, this DMU is efficient. If a set of them is considered to be functional units, how can their performance be checked? To answer this question, researchers presented methods that help them arrange some or all effective DMUs. Anderson and Peterson presented a ranking model. After determining the effective and ineffective units, AP's model was solved for the effective units. This method's calculation time and amount are less comparable to the other methods [16].

$$\min Z_p = \theta. \tag{5}$$

$$\theta X_{ip} \geq \sum_{j=1, j\neq p}^{n} \lambda_j x_{ij}, \quad i = 1,2, \dots, m. \tag{6}$$

$$y_{rp} \leq \sum_{j=1, j\neq p}^{n} \lambda_j x_{rj}, \quad r = 1,2, \dots, m. \tag{7}$$

$$\lambda_j \geq 0; j = 1,2, \dots, n; j \neq p. \tag{8}$$

If the DEA model is input-driven, the goal is to bring an inefficient unit to the efficiency frontier by keeping input constant and increasing output. The Max function type is used here. If the DEA model is output-oriented, the goal is to bring an inefficient unit to the efficiency frontier by keeping output constant and reducing inputs. Min function type is used here. In the AP model, efficiency can be more than one due to the removal of restrictions related to the evaluated unit (which has an upper limit of one). Therefore, the efficient units can be rated with points greater than one.

4 | Case Study

DEA has emerged as a robust quantitative method for assessing and ranking hospitals' performance within various healthcare frameworks. This study evaluates the efficiency of six hospitals associated with Khorram Abad University of Medical Sciences. A comprehensive review of the existing literature enabled the identification of six input variables and three output variables relevant to assessing hospital performance using DEA techniques. *Tables 2* and *3* provide detailed information on the input and output variables.

Table 2. Input indices.

Hospitals Name	Active Bed No.	Expert No.	General Practitioner No.	Paramedic No.	Nurse No.	Other Employees No.
Shoja	17	15	4	40	8	23
Ashaier	307	160	17	430	160	91
Rahimi	320	120	15	425	115	0
Madani	90	16	9	200	25	73.5
Iran	20	10	7	50	4	40
Shafa	110	67	23	550	27	80

Table 3. Output indices.

Hospitals' Name	Outpatient admissions No.	Inpatient admissions No.	Bed occupancy rate
Shoja	40	8	23
Ashaier	430	160	91
Rahimi	425	115	0
Madani	200	25	73.5
Iran	50	4	40
Shafa	550	27	80

Utilizing the CCR model via the DEA SOLVER tool, the analysis indicated that all participating hospitals attained efficiency scores of 1. The results indicate that all units operate at optimal efficiency levels relative to one another under the CCR model. However, an efficiency score of 1 does not mean hospitals have uniform performance across DMUs. Rather, it highlights the need for a more in-depth examination of hospital performance measures. The employment of the AP ranking method in ranking the hospitals is illustrated in *Table 4*.

Table 4. Anderson-Peterson ranking.

Hospitals' Name	Efficiency	Rank
Shoja	0	5
Ashaier	2.289	3
Rahimi	1.114	4
Madani	5	1
Iran	0	5
Shafa	3.19	2

From a mathematical perspective, the similarity in efficiency scores implies that no individual hospital can be deemed superior solely based on efficiency; however, outputs exceeding inputs reveal varying levels of operational effectiveness. Sahid Madani Hospital emerged as the most efficient DMU in this analysis, demonstrating a greater ability to produce output than it consumes in inputs. Similar efficiency scores imply that no hospital can be deemed superior based purely on efficiency; however, output exceeding inputs reveals varied levels of operational effectiveness. Sahid Madani Hospital emerged as the most efficient DMU, showcasing a greater ability to produce outputs than inputs. In contrast, Shoja Hospital and Iran Hospital performed poorly, receiving zero efficiency scores according to the AP model during the evaluation period.

5 | Results and Discussions

Effectively assessing hospital performance and informing healthcare policies, providing comprehensive assessments, and flexibility are some of the special features of DEA. The DEA faces challenges such as data uncertainty and issues with weight allocation. Since healthcare systems deal with resource constraints and quality demands, progress in DEA techniques is crucial. Measuring the efficiency and ranking of hospitals under the jurisdiction of Khorramabad University of Medical Sciences is essential for hospital managers. One of the features of this mathematical method is the use of diverse and inconsistent input and output indicators, as well as determining the strengths and weaknesses of each DMU and its distance to reach the efficiency limit. According to the results, higher consumption increases output production in hospitals with an efficiency score of one. One of the decisions of the fourth unit, Shahid Madani Hospital, is ranked first compared to the other DMUs (Given that all six hospitals were selected as efficient hospitals) in the DMU. Future improvements should focus on enhancing integration with other methods, improving quality management, and establishing standardized practices for effective comparisons across healthcare settings.

References

[1] Nur Sofyana, N. (2022). The performance of public health sector in Aceh, Indonesia. *Jurnal ekonomi dan bisnis jagaditha*, *9*(1), 23–29. https://doi.org/10.22225/jj.9.1.2022.23-29

[2] Salehzadeh, R., & Ketabi, S. (2011). Measuring the efficiency of Qom hospitals with data envelopment analysis and analytic hierarchy process. *Health information management*, *8*(4), 479-489. (**In Persian**). https://him.mui.ac.ir/article_11097.html?lang=en

[3] Mitropoulos, P., Talias, M. A., & Mitropoulos, I. (2015). Combining stochastic DEA with Bayesian analysis to obtain statistical properties of the efficiency scores: An application to Greek public hospitals. *European journal of operational research*, *243*(1), 302–311. https://doi.org/10.1016/j.ejor.2014.11.012

[4] Amirteimoori, A. R., Shahroodi, K., & Shaker Mahmoodkiani, F. (2015). Network data envelopment analysis: Application to gas companies in Iran. *International journal of applied operational research*, *5*(1), 1–16. http://ijorlu.liau.ac.ir/article-1-440-en.html

[5] Debata, B. R., Patnaik, B., Mahapatra, S. S., & Sreekumar. (2014). Efficiency measurement in medical tourism: A DEA approach. *International journal of process management and benchmarking*, *5*(1), 90–112. https://doi.org/10.1504/IJPMB.2015.066000

[6] Alvani, S. M., Ardalan, O., & Moradi, Sh. (2015). Evaluation of Kermanshah health-treatment centers using data envelopment analysis (DEA). *International conference on modern research in management and engineering*. (**In Persian**). Tehran, Iran, Civilica. https://civilica.com/doc/435105/

[7] Nouraei Motlagh, S. N. M., Ghasempour, S. G., Yusefzadeh, H. Y., Lotfi, F. L., Astaraki, P. A., & Saki, K. S. (2019). Evaluation of the productivity of hospitals affiliated to lorestan university of medical sciences using the malmquist and the kendrick-creamer indices. *Shiraz e-medical journal*, *20*(7), e85222. https://doi.org/10.5812/semj.85222

[8] Hatefi, S. M., & Haeri, A. (2019). Evaluating hospital performance using an integrated balanced scorecard and fuzzy data envelopment analysis. *Health management & information science*, *6*(2), 66–76. https://jhmi.sums.ac.ir/article_45383.html

[9] Monzeli, A., Daneshian, B., Tohidi, G., Sanei, M., & Razavyan, S. (2020). Influence of undesirable output factor on efficiency determination in DEA: A case study of hospital emergency Tehran. *International journal of data envelopment analysis*, *8*(3), 1-14. https://www.researchgate.net/publication/349324322

[10] HaseliMofrad, S., MokhtariDinani, M., & RezaeiPandari, A. (2021). Measuring relative efficiency of physical education departments in tehran using data envelopment analysis. *New approaches in exercise physiology*, *5*(3), 127-148. (**In Persian).** https://www.noormags.ir/view/fa/articlepage/1830493

[11] Ghasemi, S., Aghsami, A., & Rabbani, M. (2021). Data envelopment analysis for estimate efficiency and ranking operating rooms: A case study. *International journal of research in industrial engineering*, *10*(1), 67–86. https://doi.org/10.22105/riej.2021.247705.1143

[12] Hamzehzadeh, F., Mirzaee, F., Jalali, A., Ahmadinejad, B., Shahmoradi, H., & Navand, A. (2022). Evaluation of service-oriented nursing supervisor strategy based on data envelopment analysis (DEA). *Asia pacific journal of health management*, *17*(1), 56–65. https://doi.org/10.24083/apjhm.v17i1.1061

[13] Barati, M., Heidari, E., & Karimi, A. (2022). Evaluating organizational agility in banking industry through data envelopment analysis: A case study of banks in Isfahan, Iran. *International journal of law and management*, *64*(5), 403-417. (**In Persian**). https://doi.org/10.1108/IJLMA-09-2021-0218

[14] Ferreira, D. C., Figueira, J. R., Greco, S., & Marques, R. C. (2023). Data envelopment analysis models with imperfect knowledge of input and output values: An application to Portuguese public hospitals. *Expert systems with applications*, *231*, 120543. https://doi.org/10.1016/j.eswa.2023.120543

[15] Peykani, P., & Pishvaee, M. S. (2024). Performance evaluation of hospitals under data uncertainty: An uncertain common-weights data envelopment analysis. *Healthcare*, *12*(6). https://doi.org/10.3390/healthcare12060611

[16] Andersen, P., & Petersen., N. C. (1993). A procedure for ranking efficient units in data envelopment analysis. *Management science*, *39*(10), 1261–1264. https://www.jstor.org/stable/2632964

[17] Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the royal statistical society. series a (General)*, *120*(3), 253. https://doi.org/10.2307/2343100

[18] Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

[19] Ghahremanloo, M., Hasani, A., Amiri, M., Hashemi-Tabatabaei, M., Keshavarz-Ghorabaee, M., & Ustinovičius, L. (2020). A novel DEA model for hospital performance evaluation based on the measurement of efficiency, effectiveness and productivity. *Engineering management in production and services*, *12*(1), 7–19. https://doi.org/10.2478/emj-2020-0001

[20] Wu, A. W. (1995). The measure and mismeasure of hospital quality: Appropriate risk-adjustment methods in comparing hospitals. *Annals of internal medicine*, *122*(2), 149–150. https://doi.org/10.7326/0003-4819-122-2-199501150-00013

[21] Xu, N. (2022). Super efficiency dea evaluation method with anti-entropy-delphi combined weights constraints cone. *Proceedings of the 5th international conference on computer science and software engineering* (pp. 702–706). Association for Computing Machinery (ACM). https://doi.org/10.1145/3569966.3571192