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Research Paper

Data Envelopment Analysis for Estimate Efficiency and Ranking Operating Rooms: A Case Study

Sh. Ghasemi[1], A. Aghsami[2], M. Rabbani[3,*]

[1]School of Industrial and Systems Engineering, College of Engineering, University of Tehran, Tehran, Iran.
[2]School of Industrial Engineering, Khajeh Nasir Toosi University of Technology, Tehran, Iran.
[3]School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran.
[*] mrabani@ut.ac.ir

ABSTRACT

Data Envelopment Analysis (DEA) is one of the non-parametric methods for evaluating each unit's efficiency. Limited resources in the healthcare system are the main reason for measuring the efficiency of hospitals. Because Operating Rooms (OR) are the most vital part of any hospital, we determine the factors affecting operating rooms' efficiency and evaluate the performance and ranking of operating rooms in 10 of Tehran's largest hospitals. This model's inputs include accuracy in scheduling surgeries, average turnover time, number of successful surgeries and live patients, number of canceled surgeries, number of surgical errors, and number of emergency surgery. Also, outputs consist of the number of operating rooms and equipment, the average number of beds, the number of employees, and the patient satisfaction rate. First, we determine the weight of inputs and outputs by Group Analytic Hierarchy Process (GAHP) with considering experts' ideas in 10 hospitals; then, we utilize three types of DEA model which are input-oriented CCR (CCR-I), output-oriented CCR (CCR-O), input-output oriented CCR (CCR_IO) and AP models to estimate the efficiency of ORs and rank them.

Keywords: Performance evaluation, Data envelopment analysis, Ranking operating rooms, Sensitivity analysis.

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1. Introduction

Health care organizations are one of the most critical parts of each country. Furthermore, hospitals are the most significant healthcare system elements because of the increasing population and aging of communities, increasing healthcare demands, and hospital competition in the private sector for better service delivery [1]. The Operating Room (OR) suites play a crucial role in the hospital, directly and indirectly affecting other parts of the hospital's performance. Moreover, more than 33% of the total cost and 60%–70% of hospitals' total revenue related to these suites [2]. Due to this fact, any upgrading of the OR department significantly increases in improving hospitals' utilization. Maximizing ORs' efficiency means maximizing the number of surgeries to be performed each day while minimizing the resources and costs involved. So, it is crucial to find the most important indicators related to ORs for evaluating operating room performance.

Performance evaluation and productivity assessment are essential for the viability of any system. Many researchers have evaluated hospitals' performance by using a variety of methods and techniques, which will be addressed in Section 2. Their model depends on several input indicators, including the number of personals, number of medical equipment, number of operational beds [3], administrative staff hours, nursing hours, and surgery costs [4]. Performance evaluation of ORs is a complex issue. Many external and internal factors, such as staffing speed, cancellation of surgery, availability of beds in a Post-Anesthesia Care Unit (PACU), Intensive Care Unit (ICU), ward, etc. can all affect the performance of ORs.

This study aims to evaluate ORs' performance in 10 hospitals in Tehran, which plays a crucial role in guiding the future decisions of OR management. In this study, an appropriate model for performance evaluation of ORs was attempted using Data Envelopment Analysis (DEA) models. Indeed appropriate indicators for evaluating the operating room's efficiency are defined by asking the experts in this field. The inputs and outputs' significance is calculated by using the Group Analytic Hierarchy Process (GAHP) method. The next step is applying the DEA model.

The DEA is a non-parametric mathematical procedure based linear programming method used to evaluate the relative performance of Multiple Homogeneous Decision units (DMUs). In DEA models, selecting suitable indicators as inputs and outputs play an essential role. In general, the DEA model assumed that each input and output are equal. Nevertheless, in reality, the impact of different indicators on performance is different. So as mentioned before, we consider different weights for each index.

Questions which should be addressed in this research are as follows:

- What are the most critical inputs and outputs related to ORs efficiency?
- What indicators have been useful in OR performance in different hospitals?
- What is the most efficient hospital in Tehran?
- How much does the availability of beds in PACU and ICU effect on ORs performance?

Based on our knowledge, no research determines ORs' performance evaluation in different hospitals by using DEA and group AHP, with weighted multiple inputs and outputs. Furthermore, we also consider different parts related to OR. We also consider the ORs' relationship to other parts of hospitals (PACU, ICU, and ward) and consider their relevant indicators. Which considering all of these items together make our issue more realistic and reasonable.

The remainder is as follows: Section 2 investigates the literature review of related articles that help us achieve the literature gap. In Section 3, we define our problem. In Section 4 we describe the mathematical model. Section 5 contains our case study and the results of measure efficiency for ORs in 10 different hospitals. Moreover, finally, the conclusion is in Section 6.

2. Literature Review

DEA was first introduced by Charnes, Cooper, and Rhodes [5]. This method is used in various fields (education systems [6], managing systems [7], investment projects [8], health care units [9], agricultural production [10], transportation [11], logistics system [12], and performance evaluation of organizations [13]). One of the most important advantages of this method is its ability to use different inputs and outputs. Although DEA developed by the business world, it applied to healthcare organizations too. For instance, O'neill [9] applied DEA to analyze productivity in 27 hospitals, Butler and Li [14] analyzed return to scale in Michigan rural hospitals by using DEA, Burgess compare the productivity of hospitals in terms of the type and structure of their ownership [15], Ozcan et al. applied DEA to mental health organizations [16], Min and Scott [17] evaluated technical efficiency of nursing care using DEA. Ketabi [18] used DEA method for evaluating the performance of Cardiac Care Units (CCU) in Isfahan hospitals. Hatef try to estimate the capability of hospitals through a mixed model of balanced scorecard-fuzzy data envelopment analysis [19]. Li et al. [20] takes into account the nonhomogeneity between hospitals. Khushalani and Ozcan [21] utilize the dynamic network DEA for evaluation hospitals. Zare et al. [22] applied an aggregation of DEA and game theory to assess the health centers' performance in Iran. Omrani et al. [23] provided a DEA model form on clustering for each DMUs by considering uncertainty. Ozcan [24] reviews the applications of DEA in different healthcare systems. Many researchers have evaluated the performance of hospitals with various indicators as input or output. For instance, Liao et al. [25] consider the number of employees who work in the hospital inclusive of doctors, nurses, etc. The number of beds for inpatient in hospital considered by Wang et al. [26]. Fiallos et al. [27] considered different parts of hospitals include in ED, laboratory tests, and diagnostic imaging, but they did not consider the operating room.

As mentioned before, ORs play a critical role in the hospital. Many researchers try to optimize the performance of OR by scheduling ([28] and [29]), planning ([30] and [31]), and resource allocation [32] and [33]. But few studies have evaluated the performance of operating rooms.

The first and necessary step in performance evaluation is, identifying the most compelling indicators that can be used in ORs. For this work, in this section, we investigate the various indicators which are related to OR in previous articles. Some of these indicators include in cost of using OR outside of working hour, patient satisfaction [34], the profit margin of OR per hour [34] and [37], patient waiting time [36] and total delays [35]. Basson and Butler [36] applied the DEA method to ORs suite efficiency. They collected information as input and output by questionnaires and with email. Their measures included in numbers of hours of OR time per room, numbers of cases per room, and the cost of surgeries that surgeons have to work out of time. Nevertheless, they did not consider some external constraints such as patient availability, lack of hospital or intensive care unit beds, or recovery room size. So sometimes their model points to the inefficiency of OR, which is actually due to a number of external constraints that they ignored, which it makes their model impossible. One of the most critical indicators is the full use of operating room facilities. Although there is no clear definition of the optimal use of ORs, Tyler et al. [37] tried to define the optimal use of ORs by simulation. The operational goals of this article are to have surgical operations started at most 25 minutes after the scheduled time, and completed at least 25 minutes after scheduled time reach. For these purposes, maximize the use of the operating room (without delay in initiating surgeries and completing surgeries at the time of planning) is 85% to 95%. However, they did not consider the cancellation rate of surgery. Turnover times are another important indicator for evaluating OR performance [38]. Turnover time is the time interval from when a patient leaves the operating room until another patient enters the same operating room, which includes clearing time and startup time (The delay between surgeries is not calculated at this time). They collected data from 31 hospitals in the USA and concluded that the best operating sets' turnover times were less than 15 minutes. Cost reductions can only be achieved by reducing turnover time if the allocation of OR staff and facilities is in an optimum state. In general, reducing turnover time results in a slight increase in operating room efficiency. Hamid presented a multi-objective model for weekly planning and scheduling problem of surgeries of elective patients in operating rooms. In the first step, they try to solve their model for a case study using the ε-constraint method. Afterward, they applied the DEA model of the BCC input-oriented for ranking nondominated solutions obtained by the ε-constraint method [39].

As mentioned earlier, determining useful indicators in evaluating operating room performance is the first and most crucial step in implementing DEA. After reviewing articles in this field, we understood that no research considers some critical indicators like the number of emergency surgery, the number of canceled surgeries and the availability of beds (In PACU, ICU, and Ward); which are supposed to significant issue in the efficiency of OR. This section's importance is that if there are no vacant beds, there causes cancelation of the scheduled surgery. If OR manager does not know how vital emergency patients are, they may not correctly manage them. Also, if the number of canceled surgeries in a hospital is high, it will cost the hospital a lot and cause patient dissatisfaction. Therefore, it is necessary to consider these three indicators in evaluating operating rooms' performance, and it will give a magnificent managerial view to the management. We consider beds' availability in different hospital parts associated OR such as PACU, ICU, and ward. Furthermore, we take in to account the indicator of emergency surgery as an input indicator, because the arrival of emergency patients for surgery will cause the cancellation or postponement of scheduled operations and will negatively affect the level of hospital performance and patient satisfaction. To the best of our knowledge, there is no study that estimates efficiency and ranking ORs by considering weighted multiple input and output indicators. So, in this study, we propose a comprehensive weighted multiple input and output indicators to use in the DEA method, which are gathered by questionnaires from experts in 10 different hospitals. We utilize three types of DEA models, which are input-oriented CCR (CCR-I), output-oriented CCR (CCR-o), input-output oriented CCR (CCR_IO), and AP models to estimate the efficiency of ORs and rank them. For determining the importance of inputs and outputs, we use the GAHP method and expert choice software. Considering these indicators and the operating room relationship with the upstream and downstream resources make our problem closer to the real world and is very useful for managers' decisions about planning and allocating resources in operating rooms.

3. Problem Description

This study aims to provide a suitable model for evaluating the operating room's efficiency in 10 different hospitals in Tehran. Due to the variables' quality, the proposed model is a data envelopment analysis. In order to use this model, indicators such as DEA inputs and outputs must be identified. By reviewing the researches were done in this area, a list of indicators identifies (***Tables 1 and 2***). In the next step, by designing a questionnaire and referring to experts in this field, the mentioned indicators were evaluated, and the importance of each indicator was determined. To this end, they were asked to rate each input and output's importance using a questionnaire on a nine-choice spectrum [39] (***Table 3***). Experts that used to collect information are 10 OR's experts, including one head nurse, four nurses, one anesthesiologist, two general surgeons, and 2 OR technicians. In the next step, the experts' opinions are entered into the expert choice software, and we try to find the weight of criteria through the GAHP, which is used in the DEA model. Furthermore, we also used the GAHP method to determine ranking of hospitals too, and in the numerical results section, we compared the ranking of those two methods. After that, we evaluate the efficiency of OR by using the DEA method and the GAHP method. You can see the diagram of problem in ***Figure 1***.

Table 1. Input indicators.

I	Input indicators	Unit
A	Accuracy in scheduling surgeries.	Minutes
B	Average turnover time (average time from patient entry to patient discharge).	Minutes
C	Number of successful surgeries and live patients.	Number
D	Number of canceled surgeries.	Number
E	Number of surgical errors.	Number
F	Number of emergency surgery.	Number

Table 2. Output indicators.

O	Output indicators	Unit
G	Number of the operating rooms and equipment.	Number
H	The average number of beds (In PACU, ICU and Ward).	Number
I	Number of employees (surgeons, nurses, anesthesia technicians, etc.).	Number
J	Patient satisfaction rate.	percentage

Table 3. Preferences for couple comparisons.

Intensity of intensity of importance	Definition	Explanation
1	same	Neither of the two alternatives is superior to the other.
3	weak	One alternative is slightly superior to another.
5	clear	One alternative is clearly superior to another.
7	strong	One alternative is far superior to another.
9	very strong	One alternative is preferred very strongly over the other.
2,4,6,8	compromise	Can be used for graduation between evaluation.

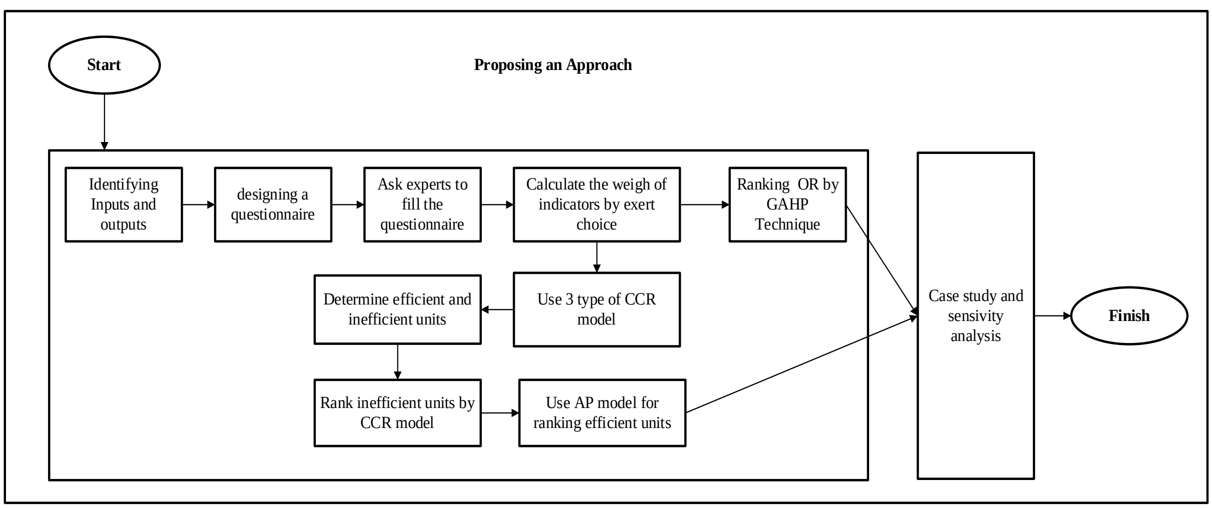

Figure 1. Diagram of proposed ranking OR.

4. Mathematical Modelling

We use DEA model for performance evaluation of operating room. The DEA method aims to evaluate the relative performance of units comparable to DMU [40]. There are two kinds of DEA models which are, the BCC and CCR model. According to the type and number of indicators in this research, the CCR model is used to evaluate operating rooms' performance. The first data envelopment analysis model was proposed by Charnes, Cooper, and Rhodes [5]. To understand the concepts of CCR model, it should be noted that we consider n DMU which receives outputs (Y_{rj}) from inputs or resources (X_{ij}), due to the unknown input (v_i) and output (u_r) weights, they suggested the following fractional model:

$$\text{Max } z_j = \sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \tag{1}$$

s.t:

$$\sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \leq 1, \quad j = 1,2,\ldots,n.$$

$$i = 1,2,\ldots,m \qquad r = 1,2,\ldots,s \qquad v_i, u_r \geq 0.$$

4.1. Fractional Programming Model of CCR

In the above relation, the j indicates the number of units under evaluation, z_j indicates the efficiency of the j_{th} unit, which is under study. The restrictions indicate the ratio of outputs to input, and this ratio should not be more than one for each unit. The efficiency border in the DEA method consists of units with an efficiency of 1. In general, there are two types of strategies for improving inefficient units and bringing them to the efficiency border. One is the reduction of inputs without reducing output until the unit reaches the border called input-oriented CCR. The other strategy is increasing the number of outputs until reaching a unit on the efficiency border without attracting more inputs which is called output-oriented CCR. These two improvement patterns are shown in ***Figure 2***. As shown in the figure, unit A is inefficient. A1 is an improved A with input-oriented, and A2 is an improved A with output-oriented.

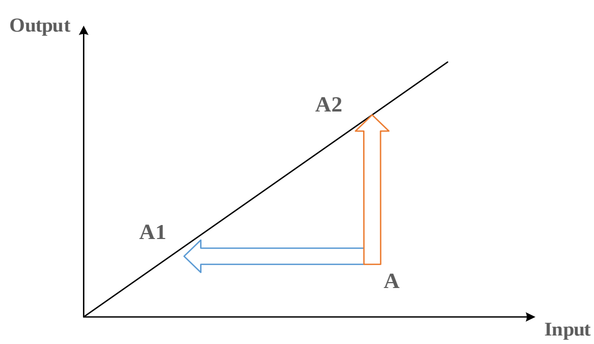

Figure 2. Performance improvement pattern.

Charnes, Cooper, converted fractional CCR model to linear programming, by applying this restriction, $\sum_{i=1}^{m} v_i X_{ij} = 1$ this model is known as the input-oriented CCR (CCR.I):

$$\text{Max } z_j = \sum_{r=1}^{s} u_r Y_{rj} \tag{2}$$

s.t.

$$\sum_{i=1}^{m} v_i X_{ij} = 1$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0 \quad j = 1,2,\ldots,n$$

$$i = 1,2,\ldots,m \qquad r = 1,2,\ldots,s \qquad v_i, u_r \geq 0.$$

We can use another method to convert a CCR fractional model to a linear programming model, by applying this restriction, $\sum_{r=1}^{s} u_r Y_{rj} = 1$. This model is known as the output-oriented CCR (CCR.O), which is presented by Charnes, Cooper [41].

$$\text{Min } z_j = \sum_{i=1}^{m} v_i X_{ij} \tag{3}$$

s.t.

$$\sum_{r=1}^{s} u_r Y_{rj} = 1,$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0 \quad j = 1,2,\ldots,n,$$

$$i = 1,2,\ldots,m \qquad r = 1,2,\ldots,s \qquad v_i, u_r \geq 0,$$

In this part, the goal is to provide a model that improves inefficient units' performance, which has both the input and output together. In other words, the goal is to provide a model that suggests reducing inputs and increasing outputs as a solution to the inefficiency of inefficient units. The input-output CCR model is defined as follows:

$$\text{Max } z_j = \left(\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij}\right)/m \tag{4}$$

s.t.

$$\sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \leq m \quad j = 1,2,\ldots,n,$$

$$i = 1,2,\ldots,m \qquad r = 1,2,\ldots,s \qquad m, v_i, u_r \geq 0.$$

In the above model, the variable m indicates the maximum value of the difference in the weighted composition of the outputs minus the weighted combination of the inputs, between the n units of the decisions. In other words, it can be stated that the unit's efficiency under this approach is equal to:

$$\frac{\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij}}{\mathrm{Max}\{\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij}\}} \quad , j = 1,2, \dots , n.$$

Because the model above is nonlinear, it has to be modified to a linear model. In this study, for this purpose, we divide both sides of constraints on variable m. So that the model changes as follows:

$$\mathrm{Max}\ z_j = \sum_{r=1}^{s} \frac{u_r}{m} Y_{rj} - \sum_{i=1}^{m} \frac{v_i}{m} X_{ij} \qquad (5)$$

$$\text{s.t.}$$

$$\sum_{r=1}^{s} \frac{u_r}{m} Y_{rj} - \sum_{i=1}^{m} \frac{v_i}{m} X_{ij} \le 1 \quad j = 1,2, \dots , n\ ,$$

$$i = 1,2, \dots , m \qquad r = 1,2, \dots , s \qquad m, v_i, u_r \ge 0.$$

Now in this new model, we apply these two variables:

$$up_r = \frac{u_r}{m} \quad , \quad vp_i = \frac{v_i}{m}, \qquad (6)$$

$$\mathrm{Max}\ z_j = \sum_{r=1}^{s} up_r\, Y_{rj} - \sum_{i=1}^{m} vp_i\, X_{ij}$$

$$\text{s.t.}$$

$$\sum_{r=1}^{s} up_r\, Y_{rj} - \sum_{i=1}^{m} vp_i\, X_{ij} \le 1 \quad j = 1,2, \dots , n,$$

$$i = 1,2, \dots , m \qquad r = 1,2. \dots , s \qquad vp_i, up_r \ge 0.$$

These basic CCR models cannot compare efficient units with each other, due to the lack of complete ranking of units. In other words, these models divide the units into two groups, "efficient units" and "inefficient units." Inefficient units can be ranked by earning performance points, but efficient units cannot be ranked because they have equal performance scores. Some researchers have proposed methods for ranking efficient units, the most famous model is the AP model, which presented by Andersen and Petersen [42]. They remove the expected constraint with the unit under review, from their evaluation. This limitation causes the maximum value of the objective function to be one. By removing this restriction, the efficiency of the unit under review could be more than 1. In this way, efficient units can also be ranked.

Section 5 presents a real case study and reviews the numerical results obtained from a different type of CCR model, AP model, and the GAHP model by using expert choice software.

5. Case Study and the Numerical Result

Ten real public hospitals in Tehran is considered as a case study. These ten hospitals include in 1) Milad, 2) Khatamol-Anbia, 3) Emam-Khomeini, 4) Dr-Shariati, 5) Shohadaye-Yaftabad, 6) Shohadaye-Tajrish, 7) Shohadaye-Haftome-Tir, 8) Shahid-Rajae, 90 Baghiyatillah, and 10) Farabi. Each ORs of these hospitals are considered as DMUs. This study evaluates the operating room's performance in these hospitals by experts' opinions (10 ones, one head nurse, four nurses, one anesthesiologist, two general surgeons, and 2 OR technicians). As mentioned before, we consider ten indicators for our model (6 inputs and 4 outputs) and use three types of CCR model, AP, and GAHP to ranking ORs. To determine the importance of each indicators, a standard questionnaire is distributed among all ten experts in those ten hospitals. Then the expert's opinions are entered into the expert choice software, and we try to find the weight of criteria through the GAHP method, which is used in the DEA model. In addition to determining the importance of the criteria, we also used the GAHP method to determine hospitals' ranking. For determining the weight of criteria in expert choice, we should design a pair-wise comparisons matrix. Moreover, for ranking OR, we need a pair-wise comparisons matrix and decision matrix. The provisions of the comparison matrix state the importance of one criterion over other criteria in terms of the problem's purpose. To this end, the experts considered ten criteria for the ten alternatives, which are OR's hospital. In the decision matrix, the score of each alternative is determined for different criteria. Multiple pair-wise comparisons, in GAHP, are based on a standard 9-point scale.

After we enter a 10-pair pair-wise comparison matrix for each hospital in expert choice, the software first calculates the importance of each indicator based on each point of expert's view and then integrates their views with the GAHP technique by using geometric mean. In this way, we will have the importance of indicators for each hospital based on 10 experts' aggregation. Based on ten expert's opinions, the aggregate weights of each hospital's indicators are given in ***Table 4***. Also, the average weight of the indicators in these ten hospitals is shown in ***Table 5***. These data are beneficial for the DEA model. The decision matrix must be filled according to the expert's ideas to rank hospitals in the next step. ***Figure 3*** shows the ranking of hospitals with expert choice software. You can see the bar chart of ranking hospitals in terms of each ten indicators in ***Figures 4-12***, and ***Figure 16***. For example, ***Figure 4*** compares hospitals in terms of accuracy in scheduling surgeries and shows that Tajrish, Hafte Tir and Rajae Hospitals are the first three hospitals in terms of this index.

In the next step, the weighted indicators of GAHP (***Table 4***) are entered into the three CCR model (CCR.I, CCR.O, CCR.IO) for ranking hospitals. As shown in ***Table 6***, efficient hospitals are the same in all four approaches (Tajrish, Haftetir, Rajae, and Farabi). And the results of the CCR. I and CCR.O are the same too. However, there is a little difference between these two approaches and CCR.IO. The average efficiency calculated by the CCR.I and CCR.O are 0.7177, but in CCR.IO is 0.7505.

Table 4. Weights of each hospital's indicators.

	A	B	C	D	E	F	G	H	I	J
Milad	0.043	0.044	0.341	0.066	0.168	0.050	0.044	0.027	0.037	0.180
Khatamol Anbia	0.036	0.044	0.333	0.025	0.169	0.060	0.039	0.042	0.060	0.192
Emam Khomeini	0.065	0.062	0.347	0.053	0.199	0.060	0.032	0.050	0.021	0.113
Dr Shariati	0.072	0.052	0.293	0.050	0.177	0.063	0.020	0.033	0.041	0.198
Shohadaye Yaftabad	0.060	0.059	0.341	0.055	0.172	0.062	0.032	0.040	0.059	0.120
Farabi	0.025	0.036	0.039	0.042	0.044	0.060	0.060	0.169	0.193	0.332
BaghiatAllah	0.066	0.060	0.386	0.053	0.162	0.059	0.029	0.044	0.024	0.118
Shahid Rajae	0.060	0.060	0.186	0.024	0.036	0.048	0.041	0.086	0.218	0.242
Shohadaye HaftomeTir	0.025	0.028	0.030	0.036	0.038	0.044	0.058	0.179	0.203	0.360
Shohadaye Tajrish	0.172	0.062	0.031	0.040	0.059	0.120	0.060	0.059	0.341	0.056

Table 5. The average weight of the indicator.

Indicators	The average weight of the indicator
Accuracy in scheduling surgeries.	0.033
Average turnover time.	0.045
Number of successful surgeries and live patients.	0.361
Number of canceled surgeries.	0.065
Number of surgical errors.	0.154
Number of emergency surgery.	0.050
Number of the operating rooms and equipment.	0.049
The average number of beds.	0.030
Number of employees.	0.041
Patient satisfaction rate.	0.172

Table 6. Ranking of DMUs.

	CCR.I			CCR.O			CCR.IO			GAHP	
DMU	performance of DMUs	Performance of efficient DMUs by AP	Ranking of DMUs	performance of DMUs	Performance of efficient DMUs by AP	Ranking of DMUs	performance of DMUs	Performance of efficient DMUs by AP	Ranking of DMUs	performance of DMUs	Ranking of DMUs
Milad	0.6676		6	0.6676		6	0.733		5	0.085	5
Khatamol Anbia	0.9447		5	0.9447		5	0.666		6	0.084	6
Emam Khomeini	0.4046		7	0.4046		7	0.538		8	0.074	9
Dr Shariati	0.3958		8	0.3958		8	0.55		7	0.078	8
Shohadaye Yaftabad	0.3915		9	0.3915		9	0.533		9	0.083	7
Farabi	1	1.0345	4	1	1.0345	4	1	1.0345	4	0.087	4
BaghiatAllah	0.3729		10	0.3729		10	0.485		10	0.063	10
Shahid Rajae	1	1.386	3	1	1.386	3	1	1.4929	2	0.124	3
Shohadaye HaftomeTir	1	1.4786	2	1	1.4786	2	1	1.4786	3	0.151	2
Shohadaye Tajrish	1	1.6256	1	1	1.6256	1	1	1.6256	1	0.171	1
Average	0.7177			0.7177			0.7505				

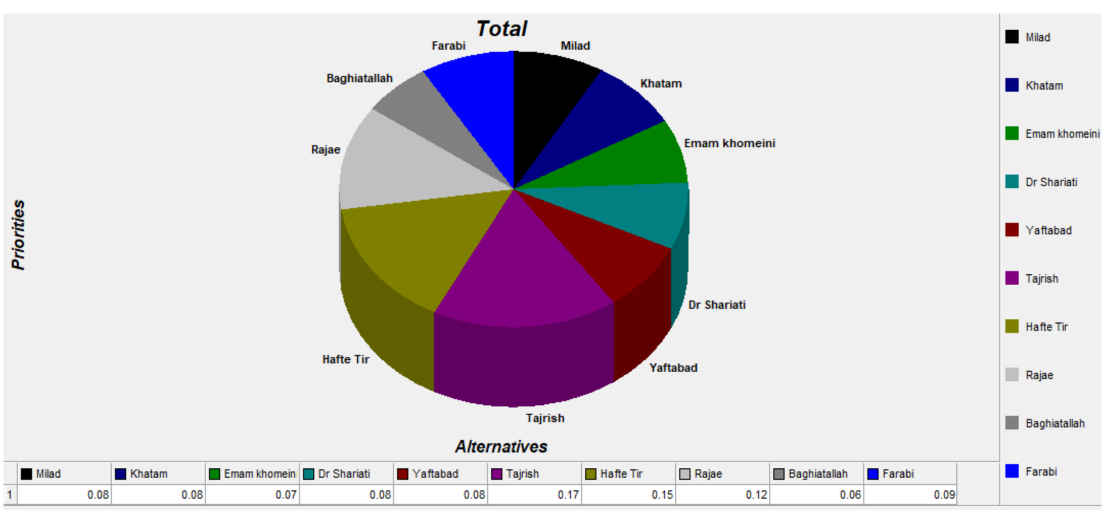

Figure 3. Ranking of hospitals with expert choice software.

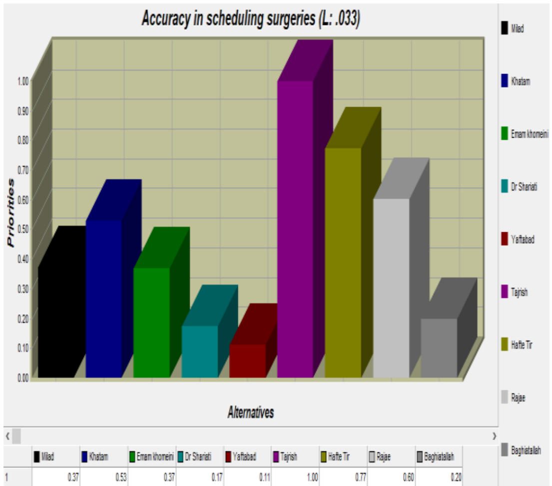

Figure 4. Ranking hospitals in terms of index. A

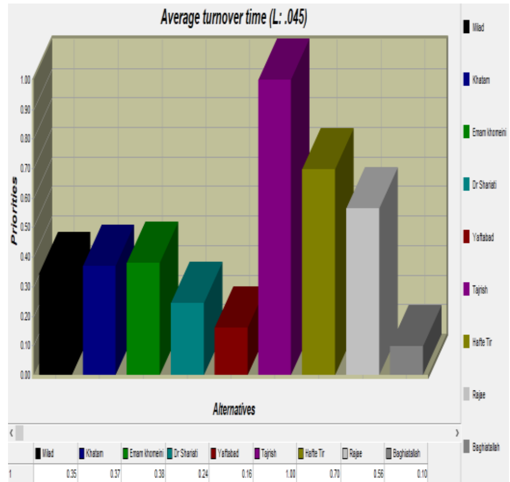

Figure 5. Ranking hospitals in terms of index B.

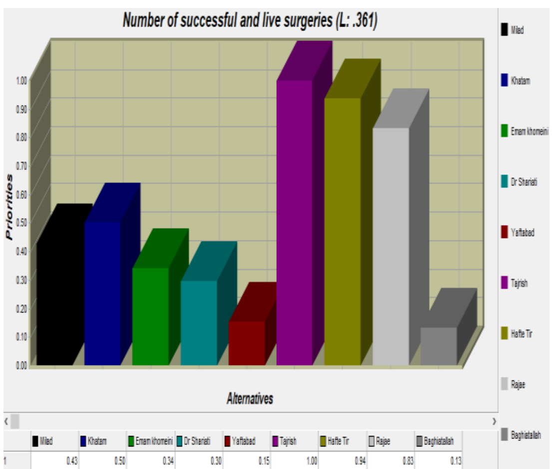

Figure 6. Ranking hospitals in terms of index C.

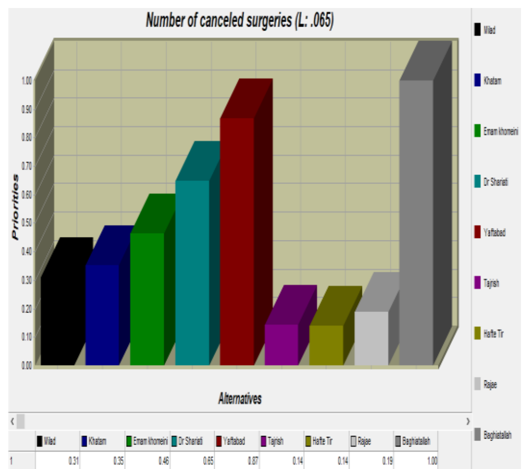

Figure 7. Ranking hospitals in terms of index D.

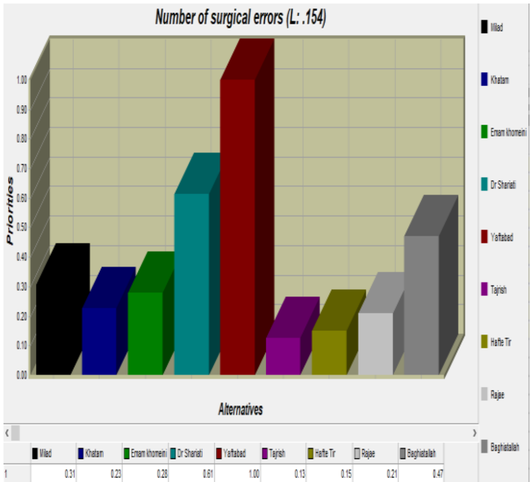

Figure 8. Ranking hospitals in terms of index E.

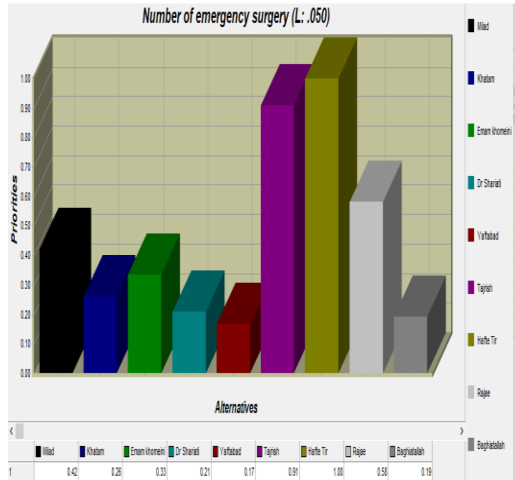

Figure 9. Ranking hospitals in terms of index F.

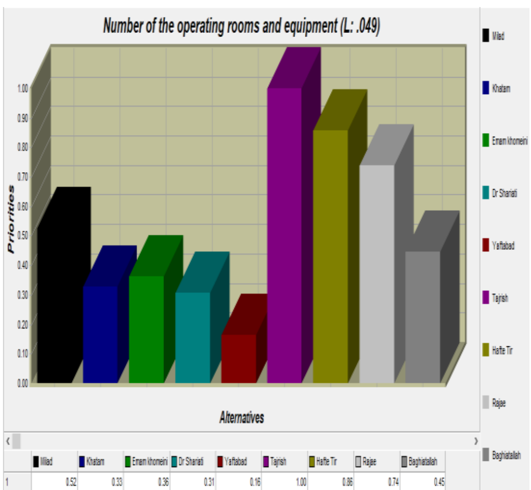

Figure 10. Ranking hospitals in terms of index G.

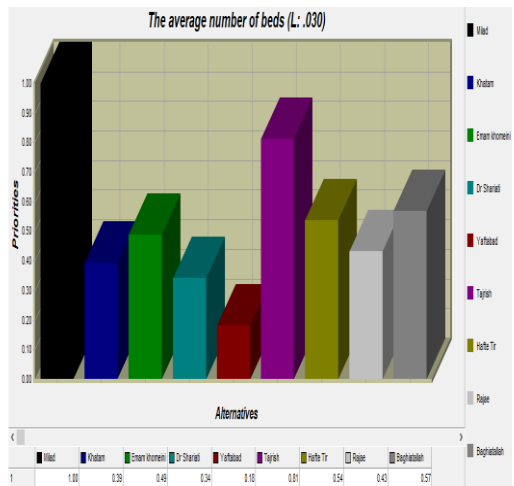

Figure 11. Ranking hospitals in terms of index H.

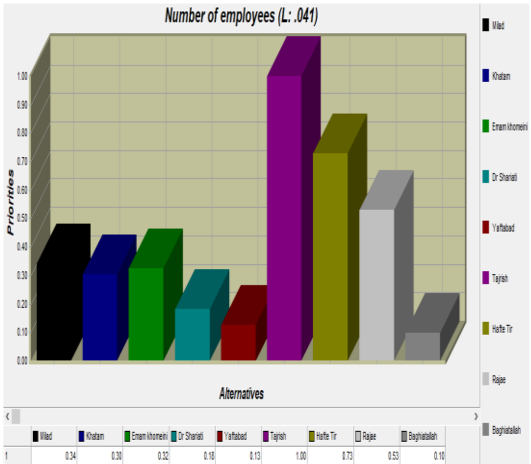

Figure 12. Ranking hospitals in terms of index I**.**

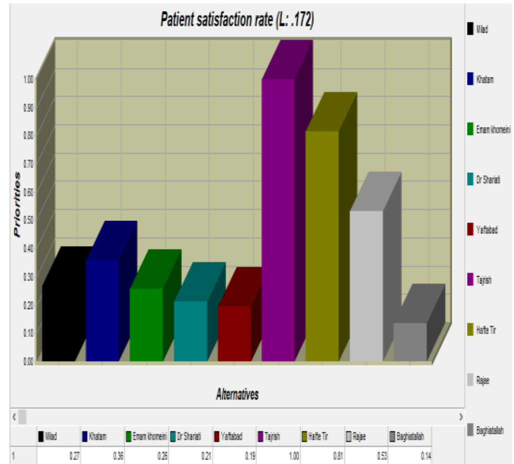

Figure 13. Ranking hospitals in terms of index J.

6. Sensitivity Analyses

In this section, the sensitivity analysis of the model is performed. The performance sensitivity analysis, displayed in ***Figure 14***, prioritizes alternatives over other alternatives with respect to each objective as well as overall. To know how the best alternative works compared to the other alternative read the general priority from the right y-axis. In this case, Tajrish is approximately 0.17, Haftome Tir is approximately 0.15 and so on. Furthermore, in order to know each objective's priority, the left y-axis should be used. For example, ‘Number of successful surgeries and live patient’ is about 0.36 while ‘Number of surgical errors’ is about 0.15 and so on.

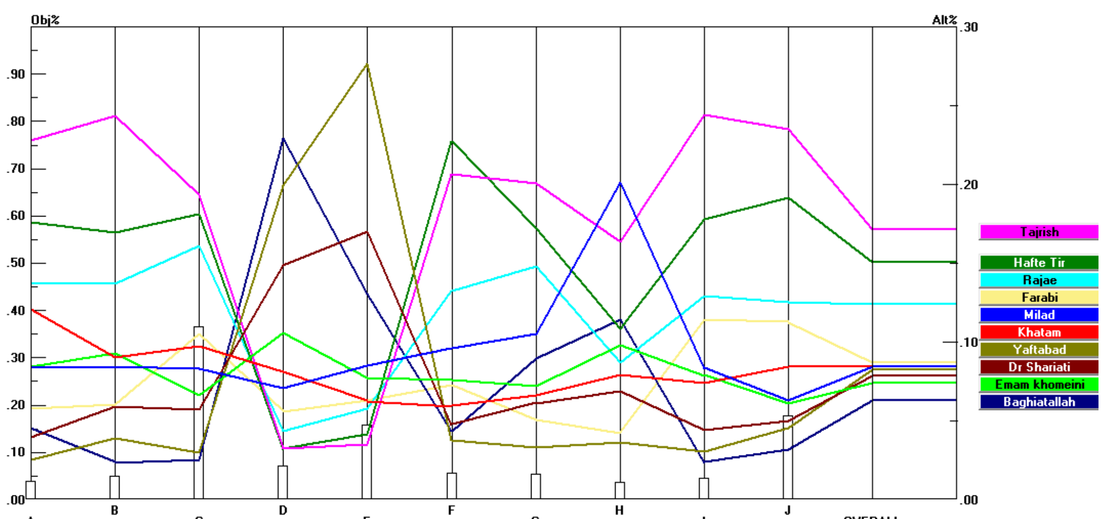

Figure 14. Performance sensitivity graph.

Moreover, to know the alternative priorities with respect to each objective, see the right y-axis. In this case, using 'number of successful surgeries and live patient', Tajrish has a priority of approximately 0.19, while Rajae is about 0.16 and so on.

The 'gradient sensitivity' graph use to know the alternatives' priorities with respect to one indictor. For example, ***Figure 15*** shows this graph in terms of 'number of successful and live surgeries. The objective's priority is indicated by the red vertical line. ***Figure 15*** shows that increasing the priority of 'number of successful and live surgeries' from 0.16 to 0.46 changes the choice of the alternative with respect to 'number of successful and live surgeries' and so on.

The 'head-to-head sensitivity' graph compares hospitals in pairs and in terms of all ten indicators and gives an overall perspective for decision making. If the left alternative is preferred to the right alternative due to an indicator, the horizontal bar will be on the left and vice versa. If the two choices are equal, no bar is displayed. ***Figure 16*** shows that Tajrish hospital is better than Emam Khomeini in terms of all indicators except in 'number of canceled surgeries' and 'number of surgical errors'.

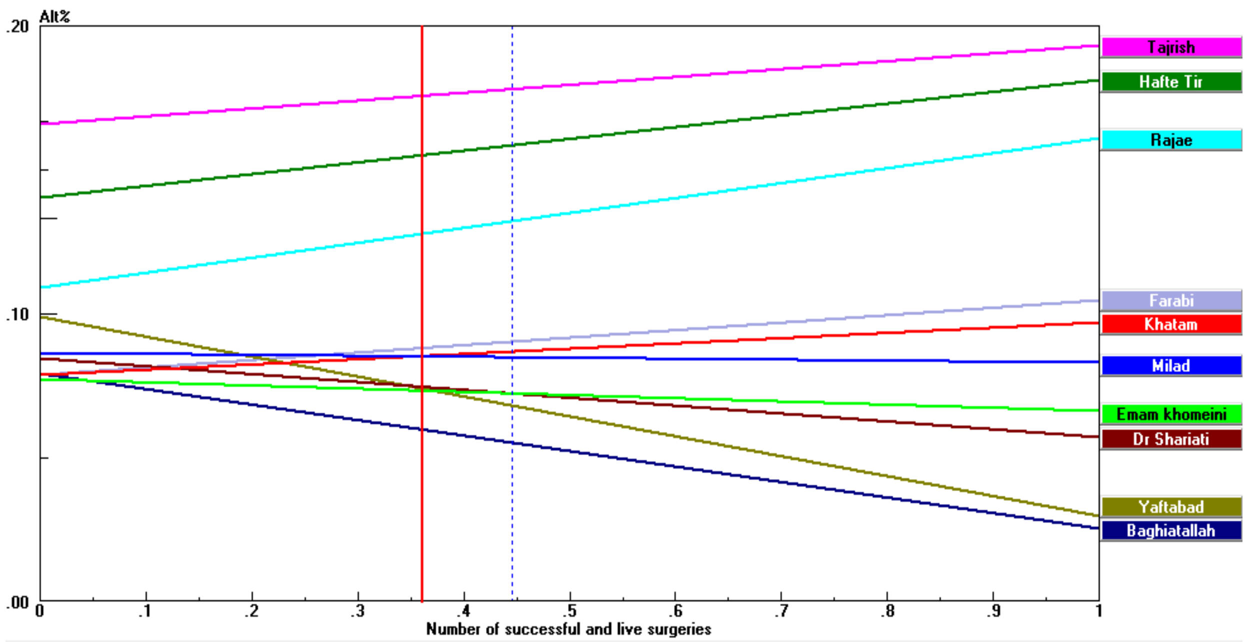

Figure 15. Gradient sensitivity with respect to 'Number of successful and live surgeries'.

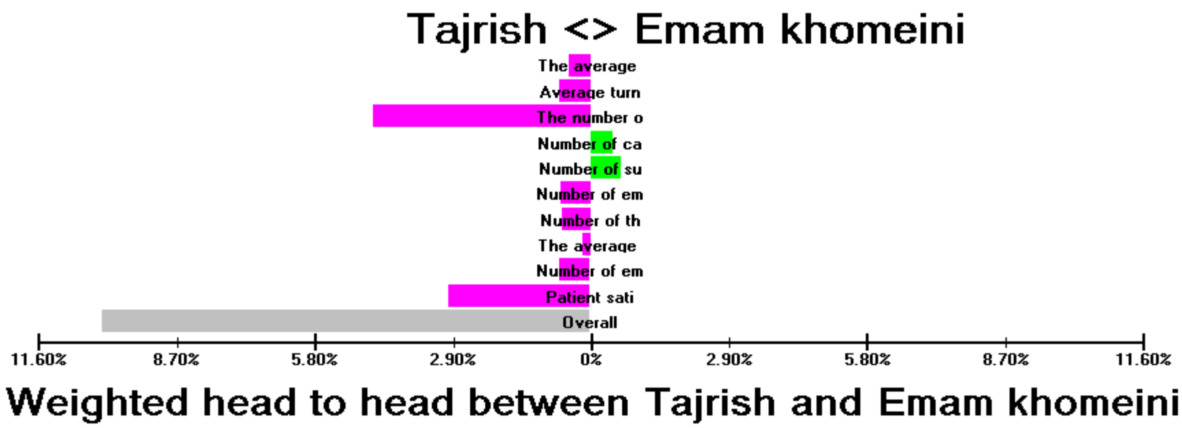

Figure 16. Head-to-head sensitivity' graph for Tajrish and Emam Khomeini hospitals.

7. Discussion and Conclusions

This research proposes a suitable model for evaluating the operating room's efficiency in 10 different hospitals in Tehran. We use three different types of CCR model, which is kind of DEA. To determine the importance of indicators, such as DEA inputs and outputs, we use GAHP. The result of CCR.I and CCR.O are the same, but the result of the CCR.IO method, which has both the input and output together, show a different and more accurate result, due to reducing inputs and increasing outputs as a solution to the inefficiency of inefficient units. The advantages of this research over other similar works are:

- Consider all different hospital parts associated with the operating room, such as PACU, ICU, and ward.
- We are proposing a comprehensive weighted multiple input and output indicators to use in the DEA method, which are gathered by questionnaires from 10 different hospitals.
- Determining the importance of inputs and outputs by group AHP method and applying the DEA method for performance evaluation of ORs in 10 different hospitals in Tehran.
- Considering emergency surgery and the possibility of canceling surgeries and surgical errors.

According to the proposed questionnaire and a survey of experts in the field of OR, ten practical factors in operating room efficiency were identified, which are shown in ***Figure 4***. The two critical indicators are accurate and correct management of emergency surgeries and the reduction of the surgical team's medical errors, which cause successful surgeries per day and patient satisfaction.

Indeed, we identified two hospitals in Tehran that performed better than other hospitals, by three types of CCR models, which are Tajrish and Hafte Tir hospital.

After reviewing these two hospitals and talking to their OR management, we reached useful results that we express them as management recommendations. To reduce medical errors in surgeries, which is an important indicator in OR, OR managers should try to form a surgical team by considering their decision-making-style, which cases more team members' compatibility. Indeed by holding different training courses for novice surgeons, try to train more experienced surgeons. Furthermore, one of the critical factors in these errors is the fatigue of the surgical team. The OR manager should try to reduce these errors by strictly observing the teams' shifts and considering the allowed surgical time for each surgeon per day.

To manage emergency surgery and reduce the number of cancellation surgery, data mining techniques and statistical methods can predict emergency patients' probability of arriving on different days and allocate some capacity of operating rooms to such cases before schedule inpatient surgery. It is also essential to have proper scheduling and planning of OR by considering beds' availability in other parts related to OR. For future studies, we suggest the following directions extend the current study:

- Consider more indicators related to OR.
- Using fuzzy and robust DEA for evaluating OR.
- Considering the correlation between different indicators.

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