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A Unique Mathematical Framework for Optimizing Patient Satisfaction in Emergency Departments

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Abstract
In healthcare systems, emergency departments (EDs) are the most vital elements, in that they provide critical and immediate healthcare services to the patients 24 hours a day. Patient satisfaction is a crucial concept and a practical tool for evaluating the performance of the EDs. This study presents a unique framework for the performance optimization of an emergency department in a big general hospital in Iran based on the standard patient satisfaction indicators. Standard questionnaire is designed and used in a large and busy emergency department. The reliability and validity of the questionnaires are obtained by Cronbach's alpha and parametric and non-parametric analysis of variance (ANOVA), respectively. Afterwards, the most efficient data envelopment analysis (DEA) model is selected and employed to assess the performance of the emergency department based on the selected indicators. Results show that certain indicators such as quality of equipment, performance of physicians and treatment time have the greatest impact (weight) on overall patient satisfaction. The framework of this study is a practical approach for all types of emergency departments in the process of the improvement and optimization of patient satisfaction.

Keywords
Emergency department, Patient satisfaction, Data envelopment analysis (DEA), Analysis of variance (ANOVA), Sensitivity analysis

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Background

Nowadays, patient satisfaction as a concept has attracted extensive attention in healthcare systems. This concept is considered as one of the main goals and priorities of healthcare systems and is discussed as one of the most important results of attending to the quality and delivery of health services. Patient satisfaction can be a substantial source of information for the identification of problems and provision of comprehensive programs in order to develop and improve health services. The quality of services provided for the patients in a hospitals' emergency department (ED) and patients' satisfaction with the provided services can be used as a characteristic of the overall condition of delivery services in the hospital (Gibbons et al., 2018; Gupta, Rodeghier, & Lis, 2013; Schoenfelder, Klewer, & Kugler, 2011).

Also, patient satisfaction is one of the most important factors for the evaluation of the quality of the emergency department services, which is the outcome of the healthcare systems. Nowadays, EDs pay more attention to the patient satisfaction than any time, especially after the emergence of new managerial concepts and the verification of their significant role in the medical world. In comparison with the other hospital departments, EDs meet more intensive challenges which may lead to the decreased satisfaction of the patients. Satisfaction is the basis on which the patient decides to use the services provided by the ED next time or to recommend it to the other patients. Low patient satisfaction may lead to lower medical cooperation, which can cause resource loss and low quality of the clinical services. Thus, one of the main goals of all the medical care centers is to make the patients satisfied with their righteous demands, and this fact should be considered as an outcome indicator. Although the EDs can never satisfy all their clients, they can study some scales to attain the capability of making satisfaction for all the clients. Therefore, one of the key approaches for the improvement of the performance of the care units is to make the patients more satisfied and the EDs are not exceptions in this regard (Abo-Hamad & Arisha, 2013; Luscombe & Kozan, 2016; Newcomb et al., 2017; Taylor, Kennedy, Virtue, & McDonald, 2006).

Attention to the community health is a top priority of each country's development plans. Health practitioners always try to utilize available resources in order to provide the best and the highest quality services for the community. As the pillars of development, productivity and efficiency are the most common tools for measuring and evaluating the performance of an organization. In order to assess the productivity and efficiency of the organizations, various methods have been offered. In a general assortment, these methods can be classified into parametric and non-parametric groups. Parametric methods are based on the econometric models and microeconomics, and are generally on the basis of regression analysis that uses panel data production function or cost function estimation. By using the cost function estimation and taking into account the estimated function, the performance of the units is measured. In contrast, non-parametric methods do not follow these assumptions. Data envelopment analysis – as an efficient non-parametric method – includes techniques and procedures for evaluating the efficiency and productivity of decision making units (DMUs). In this method, unlike the other numerical methods, identifying the weights and assigning them to the inputs and outputs are not necessary. Also, this method does not require predefined functional forms such as statistical regression method or a clear form of production function such as parametric methods. Table 1 shows a classification of the efficiency measurement methods of the organization performance.

Table 1. Classification of the efficiency measurement methods

Measurement method	Parametric	Non-parametric
Deterministic	Parametric mathematical programming	Data envelopment analysis (DEA)
	Deterministic frontier analysis	
Stochastic	Stochastic frontier analysis	Stochastic data envelopment analysis (SDEA)

The main aims of this study are: (1) Presenting a new practical framework for assessing and optimizing the patient satisfaction in a large emergency department through standard patient satisfaction indicators; (2) Investigating the impact of patient satisfaction on overall performance of the emergency department; (3) Proffering effective solutions to increase the level of patient satisfaction and improve the performance of emergency department.

The remainder of this paper is organized as follows. Literature review is discussed in section 2. Section 3 presents the methodology of this study. Numerical tests and results of the case study are provided in Section 4 and finally, conclusion remarks about the obtained results are expressed in Section 5.

Literature Review

The performance of the hospitals and EDs in uninterrupted serviceability is their most important characteristic (Gul, Celik, Gumus, & Guneri, 2016). Extensive studies have been conducted about this subject, mostly in medical and medicinal fields. Valdmanis (1992) studied state hospital of Michigan in order to compare the performance of the private hospitals and state hospitals and to investigate the effect of the type of ownership. For these purposes, data envelopment analysis was employed and by using sensitivity analysis, it was demonstrated that the results are reliable. Grosskopf and Valdmanis (1993) compared the performance of Californian hospitals through non-parametrical approaches. They compared the hospitals in terms of the technical dimensions and productivity using the inputs and outputs of the hospital system; accordingly, the performance of all the hospitals was determined. The results of their research were divergent for all the hospitals. Their proposed method can be used as an efficient approach to estimate the performance of hospital. Zavras, Tsakos, Economou, and Kyriopoulos (2002) applied DEA to study the performance and efficiency of Grecian healthcare centers. Personnel size, various medical units, and number of clients were considered as the inputs. The obtained results indicated that the healthcare centers are equipped with the advanced technology, and utilizing the high quality equipment for performing the tests leads to the higher productivity. Evaluating the performance of organizations using data envelopment analysis requires exact inputs and outputs, but unfortunately the majority of the dates are not exact in reality. Hence, Lertworasirikul, Fang, Joines, and Nuttle (2003) used fuzzy data to examine the systems with fuzzy input(s) and output(s). They introduced a novel method to analyze such ambiguous data and accordingly, they presented a numerical experiment. Harrison, Coppola, and Wakefield (2004) employed DEA to examine the efficiency of the federal hospitals in United States. To assess the efficiency, they addressed four inputs including operating expenses, hospital beds, full time employees and service complexity and two outputs including admissions and outpatient visits. To measure the efficiency of Europe health systems, Popescu, Asandului, and Fatulescu (2014) considered health expenditure and immunization rate as the input variables and survival rate and tuberculosis rate as the output variables. The results of their study indicated that among 27 countries, the health systems of Finland, Greece and Luxembourg have the highest efficiency.

Many studies in the field of assessing the health systems have been carried out in Greece; and the methods used in these studies are mainly parametric. Kounetas and Papathanassopoulos (2013) aimed to measure the performance of the hospitals in Greece. They applied bootstrapped DEA and used different combinations of inputs and outputs to determine the factors that affect the efficiency of the hospitals. Also, Halkos and Tzeremes (2011), Mitropoulos, Mitropoulos, and Sissouras (2013), and Athanassopoulos and Gounaris (2001) have employed various models of DEA and non-parametric methods in order to assess and measure the efficiency of the public health systems in Greece.

Numerous performance assessment researchers have attempted to review the papers published in the field of health systems. Hollingsworth (2003) investigated 188 studies that had been conducted by the end of 2002 for assessing the efficiency of the healthcare systems using the frontier efficiency measurement. They found out that the non-parametric methods in performance evaluation were used more than the other methods. Moreover, O'Neill, Rauner, Heidenberger, and Kraus (2008) reviewed over 79 papers published from 1984 to 2004 which examined the performance of the hospitals by using the DEA. Their research displayed remarkable differences among the obtained results of various models of DEA and different combinations of inputs and outputs. Furthermore, in a systematic review, Hussey et al. (2009) examined remarkable papers from 1990 to 2008 which have been published in the context of the efficiency evaluation of the healthcare systems.

Paying sufficient attention to the patient satisfaction and soliciting their opinion are of grave importance for the activities that evaluate the performance of the healthcare (Kol, Arıkan, İlaslan, Akıncı, & Koçak, 2018; Li et al., 2016). Pink, Murray, and McKillop (2003) investigated the relationship between the healthcare's efficiency and patient satisfaction in the hospitals of Ontario, Canada. The results of their study showed that the practitioner intuition of higher patient satisfaction achieved at the expense of efficiency was borne out by the hospital-level data. Soares and Farhangmehr (2015) studied the patient satisfaction and concluded that factors of hospitalization duration, care quality, hospital personnel-patient encounter, and quality of equipment and technology have the greatest effect on the patient satisfaction. Draper, Cohen, and Buchan (2001) presented the patient satisfaction results of the healthcare centers and showed how one can use the results of analyzing patients' opinions for the purpose of planning and policy making in the related organizations.

In some cases, there is a lag between consumption inputs and production outputs. For instance, an effective approach was developed by Özpeynirci and Köksalan (2007) in order to allocate the efficiency value to DMUs regarding to the time lag between the input and output states.

According to three inputs including the average encounter time per patient visit, the average number of laboratory tests per patient visit and the average number of radiology orders per patient visit and also the rate of non-return patient visits within 72 hours as the output, Fiallos, Patrick, Michalowski, and Farion (2017) applied a DEA model to develop an efficient tool for evaluating the performance of pediatric emergency department physicians. Osman, Berbary, Sidani, Al-Ayoubi, and Emrouznejad (2011) offered a DEA model to assess and measure the performance of nurses in the intensive care unit of a hospital in Lebanon. Their proposed model classified nurses into two groups: efficient and non-efficient; and the efficient nurses were employed to train the non-efficient ones. Since overcrowding and long waiting time are among the most common problems of the patients in the emergency departments, Al-Refaie, Fouad, Li, and Shurrab (2014) utilized simulation and DEA to determine the best scenario. The aims of their proposed approach were to reduce the patient waiting-time, improve the nurses' performance, and enhance the number of patients receiving services.

According to the literature, many studies have evaluated the performance of the medical care centers, hospitals and emergency departments by using various methods and approaches. But, these studies have not considered the impact of patient satisfaction on the overall performance of the emergency departments. They have mostly concentrated on performance based on the medical and medicinal factors. In this paper, a new framework is presented based on DEA and ANOVA to optimize the patient satisfaction and consequently, to evaluate the performance of the medical care centers and hospitals. Better said, the indicators defined in the questionnaire assess their satisfaction by measuring important criteria for patients and their fellows. Hence, patient satisfaction will lead to the ED assessment according to what was mentioned in the previous articles. Patient satisfaction assessment and the subsequent evaluation of the ED provide a new framework that identifies the quality of the activities performed in the system. This framework is a unique framework due to the simultaneous evaluation of patient satisfaction and ED performance.

The most important features of this study versus other remarkable studies are shown in Table 2. Accordingly, the most important features are divided into two fundamental and technical categories. Fundamental categories include indicators for ED performance evaluation and technical categories are related to the evaluation technique.

Table 2. Features of This Study versus Other Studies.

Author(S)	Fundamental Indicators						Technical Indicators		
	Emergency environment	Treatment time	Doctors' performance	Nurses' performance	Equipment quality	Patient satisfaction	DEA	Sensitivity analysis	ANOVA
Valdmanis (1992)							✓	✓	
Draper Et Al. (2001)			-			✓	-		
Zavras Et Al. (2002)			-		✓		✓		
Harrison Et Al.			-				-		

(2004)						✓			
Taylor Et Al. (2006)			✓	✓		✓			
Abo-Hamad And Arisha (2013)		✓	✓	✓					
Al-Refaie Et Al. (2014)			✓	✓			✓		
Soares And Farhangmehr (2015)	✓	✓	✓	✓		✓			✓
Gul Et Al. (2016)		✓	✓	✓				✓	
Fiallos Et Al. (2017)			✓				✓		
This Study	✓	✓	✓	✓	✓	✓	✓	✓	✓

Research Methodology

The structure of this study has been briefly described in Figure. 1. This flowchart shows all the steps and procedures that have been carried out for doing this research. Step 1 shows the library research and the discussions about the topic. Step 2 specifies standard patient satisfaction indicators and their items for performance evaluation. Step 3, is the determination of the indicators as input and output variables based on their nature. Step 4 shows that how the questionnaire is designed. Step 5 indicates how to gather data. Step 6 examines the reliability and validity of the questionnaire. Step 7 is the selection of the most efficient DEA model between four different models. Step 8 measures the efficiency score for each DMU, then ranks all DMUs. Step 9 involves the sensitivity analysis and the identification of significant indicators. Finally, step 10 proposes the effective solutions for the ED studied to improve the overall performance.

Assessing the performance of the units and departments has been always an important issue for the managers of healthcare centers and hospitals. ‘‘Efficiency” is known as one of the most important indexes of this assessment and is measured by the DEA approach.

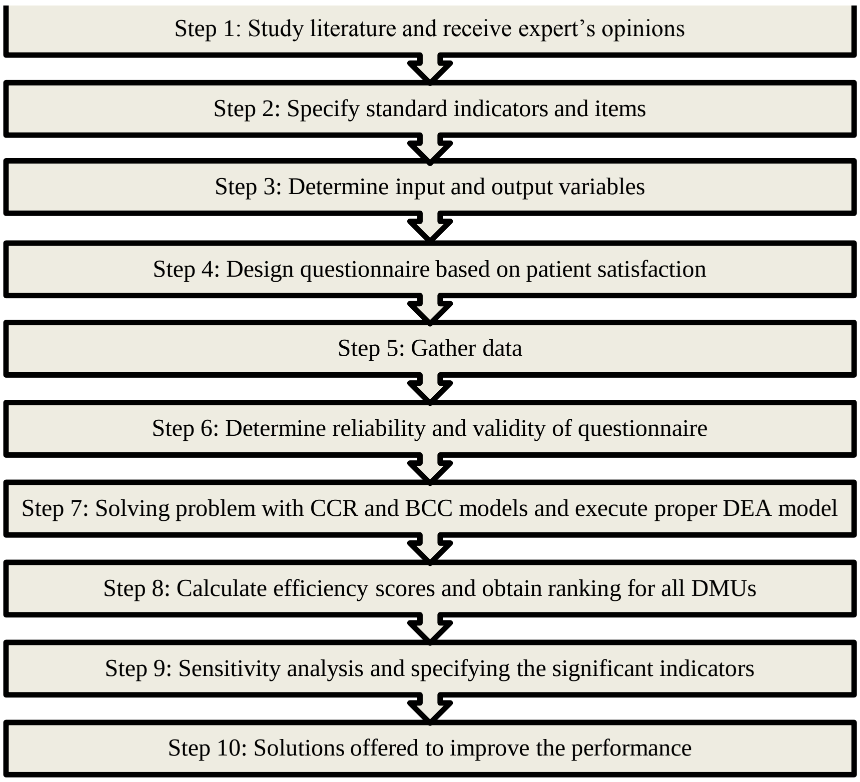

Figure 1. The steps of this study

Data Envelopment Analysis

In recent years, data envelopment analysis (DEA) method has been identified and applied as a useful tool for evaluating the performance of the service and manufacturing units. DEA is a non-parametric evaluation method that measures the relative efficiency of a set of comparable entities which are called decision making units (Azadeh et al., 2011; Nazari-Shirkouhi and Keramati, 2017; Rezaie et al.; 2013). With its freedom from the need to specify the hypothetical form of production function and solve optimization models using real data related to the inputs and outputs of DMUs, the DEA method studies a boundary function around the inputs and outputs. This boundary includes the linear sections which not only are the most efficient units of the current performance, but also provide the analysis of inefficient units.

The advantage of DEA method is that an efficient frontier can be generalized and used as a model for similar organizations. DMUs that are placed on this boundary are assigned a value of one as the efficiency rating. For the others, DMUs will be assigned a less than one efficiency rating. Efficiency rating is defined as follows (Eq. (1)):

$$Efficiency = \frac{Total\ weighted\ outputs}{Total\ weighted\ inputs} \quad (1)$$

In addition, to calculate the value of efficiency, the DEA method determines the amount and level of inefficiency for each input and output through comparison with a convex set of two or more DMUs on the efficient frontier.

DEA Models

To apply DEA models, it is necessary to determine two fundamental characteristics: pattern view and pattern of returns to scale. The first characteristic that should be determined is the pattern view which has two types including input view and output view.

Input view: In the evaluation process with constant output level, we try to minimize the input level. In the input-oriented model, the goal is to seek the technical inefficiency as an attribute that should reduce the inputs without changing the outputs and the unit is an efficient frontier.

Output view: In the evaluation process with constant input level, we try to maximize the output level. In the output-oriented model, we are looking for the need to increase the outputs of the unit without changing the inputs in order to reach the efficiency frontier.

The reason for choosing different pattern views in some cases is that management has no control over the output and its value is fixed and vice versa; in such conditions, the nature of the input and output is determined based on the principal control on each input and output. The second characteristic that should be determined is the pattern of returns to scale. Returns to scale indicates a link between changes in the inputs and outputs of a system. There are two types of returns to scale pattern.

Constant returns to scale: each number of inputs produces the same number of outputs.

Variable returns to scale: each number of inputs could produce the same number of outputs or less/more than the number of inputs.

The basic model of DEA, which is called CCR, was proposed by Charnes, Cooper, and Rhodes (1979). This model is constant returns to scale. By determining the optimal weight for the input and output variables of the studied unit, the CCR model tries to increase the efficiency of the unit in circumstances where the efficiency of the other units does not exceed 1. The basic model of DEA is presented as follows:

$$\max \ \mathrm{h}_p = \frac{\sum_{r=1}^{s} u_r . y_{rp}}{\sum_{i=1}^{m} v_i . x_{ip}} \tag{2}$$

S.t.

$$\frac{\sum_{r=1}^{s} u_r . y_{rj}}{\sum_{i=1}^{m} v_i . x_{ij}} \le 1, \qquad j = 1, \dots, n \tag{3}$$

$$v_i \ge 0, \qquad i = 1, \dots, m \tag{4}$$

$$u_r \ge 0, \qquad r = 1, \dots, s \tag{5}$$

Here, j, i and r show the index of DMUs, input variables and output variables, respectively, and for each DMU, there is m inputs and s outputs. Also, u_r and v_i are the weights applied to the outputs y_{rj} and inputs x_{ij}, respectively. The aim of the objective function (2) is to maximize the ratio of weighted sum of outputs to the weighted sum of inputs (efficiency score h_p) for DMU_p. Constraint (3) forces the efficiency score to be no greater than 1 for each DMU. Constraints (4) and (5) express that the weights v_i and u_r are nonnegative. To obtain the optimal weight for each DMU, an efficiency frontier including all data points in a convex hull is calculated. The DMU(s) located on the frontier represent an efficiency level of 1.0, and those located inside the frontier are operating at a less than full efficiency level, i.e. less than 1.0. This operation is performed for all DMUs and the optimal weight for each DMU is obtained. The output-oriented CCR model maximizes the outputs by the consideration of the inputs as fixed.

For computational convenience, the fractional programming model above is modified in a linear programming form (the output-oriented CCR model), as follows:

$$\max \ \mathrm{h}_p = \sum_{r=1}^{s} u_r . y_{rp} \tag{6}$$

S.t.

$$\sum_{i=1}^{m} v_i . x_{ip} = 1 \tag{7}$$

$$\sum_{r=1}^{s} u_r . y_{rj} - \sum_{i=1}^{m} v_i . x_{ij} \le 0 \qquad j = 1, \dots, n \tag{8}$$

$$v_i \ge \varepsilon, \qquad i = 1, \dots, m \tag{9}$$

$$u_r \ge \varepsilon, \qquad r = 1, \dots, s \tag{10}$$

Objective function (6) maximizes the efficiency of the outputs. Constraint (7) indicates that the inputs are fixed and constraint (8) shows the efficiency boundary of the outputs. Constraints (9) and (10) express that u_r and v_i have certainly positive values.

The modified version of CCR model, i.e. BCC, was represented by Banker, Charnes, and Cooper (1984) as a new model of DEA. Unlike the CCR model, in the BCC model the returns to scale characteristic have been assumed variable. The BCC model measures only technical efficiency for each DMU. That is, for a DMU to be considered as CCR efficient, it must have both scale and technical efficiency. But, for a DMU to be considered BCC efficient, it only needs to be technically efficient. For modeling input-oriented and output-oriented BCC models, the same principles of CCR model are used to improve the efficiency of the units. The input-oriented model increases the efficiency by minimizing the amount of inputs, but the output-oriented model improves efficiency by maximizing the amount of outputs. The fractional programming of the BCC model is shown as follows:

$$\max \text{h}_p = \frac{\sum_{r=1}^{s} u_r . y_{rp} - u_p}{\sum_{i=1}^{m} v_i . x_{ip}} \tag{11}$$

S.t.

$$\frac{\sum_{r=1}^{s} u_r . y_{rj} - u_p}{\sum_{i=1}^{m} v_i . x_{ij}} \le 1, \qquad j = 1, \ldots, n \tag{12}$$

$$v_i \ge 0, \qquad i = 1, \ldots, m \tag{13}$$

$$u_r \ge 0, \qquad r = 1, \ldots, s \tag{14}$$

$$u_p \quad \text{free}$$

Here, u_p indicates an optimal value determined by this model and shows the return to scale possibilities. An $u_p < 0$ demonstrates local increasing returns to scale; If $u_p = 0$, this implies local constant returns to scale and finally, an $u_p > 0$ indicates local decreasing returns to scale. The aim of objective function (11) is to maximize the ratio of the weighted sum of outputs to the weighted sum of inputs. Constraint (12) forces the efficiency score to be no greater than 1 for each DMU. Constraints (13) and (14) express that the variable weights are nonnegative. Also u_p is unconstrained in sign. The linear programming model of the foregoing fractional programming is:

$$\max\ h_p = \sum_{r=1}^{s} u_r . y_{rp} - u_p \tag{15}$$

S.t.

$$\sum_{i=1}^{m} v_i . x_{ip} = 1 \tag{16}$$

$$\sum_{r=1}^{s} u_r . y_{rj} - \sum_{i=1}^{m} v_i . x_{ij} - u_p \leq 0 \qquad j = 1, \ldots, n \tag{17}$$

$$v_i \geq 0, \qquad i = 1, \ldots, m \tag{18}$$

$$u_r \geq 0, \qquad r = 1, \ldots, s \tag{19}$$

$$u_p \quad \text{free}$$

Objective function (15) maximizes the efficiency of the outputs. Constraint (16) indicates that the inputs are fixed and constraint (17) shows the efficiency boundary of the outputs. Constraints (18) and (19) express that the variable weights are certainly positive values. Also u_p is unconstrained in sign.

Input and Output Variables Selection

After reading the literature and receiving expert opinions, we received experts' opinions through brainstorming technique to specify the standard patient satisfaction indicators. In the third step, the input and output variables were determined. To do this, a large number of emergency doctors, emergency head nurses, emergency nurses and the other specialist personnel discussed and commented on substantial considerations and standard indicators for the performance evaluation of the emergency department based on the patient satisfaction. Accordingly, five standard indicators and their 31 items were selected to evaluate the performance of emergency department based on the viewpoint of the patients. These standard indicators and items that have been sporadically evaluated in many studies are shown in Table 3.

Table 3. Standard indicators and their items for performance evaluation of the ED in this study

Author (s)	Indicator	Item
Boudreaux & O'Hea (2004); Hall & Press (1996)	Emergency environment (C_1)	Boards and signage in the department
		Behavior and guidance of information security personnel
		Yield sign for the patients
		Coordination and collaboration between medical and nursing staff
		Behavior and attention of emergency personnel
		Respect for privacy and patient confidentiality
		Health and cleanliness of the department
		Terms and services (green areas, buffet and amenities)
		Bathroom conditions (shower, washbasin and toilets)
		Facilities for patients’ caregivers (food, chairs, etc.)
		Silence and quietness
		Served food
		Emergency services fee
Soares & Farhangmehr (2015)	Treatment time (C_2)	Registration and admission time
		Waiting in the triage room
		Initial examination time
		Duration of the treatment
		checkout and clearance process
Taylor et al. (2006) Watson et al. (1999)	Doctors’ performance (C_3)	On-time medical care
		Presence of the doctors when needed
		Time devoted by the doctors for patient examination
		Doctors’ behavior and attention
		Doctors’ explanations about the patient medical actions
Welch (2010)	Nurses’ performance (C_4)	On-time nursing care
		Presence of nurses when needed
		Nursing skills (injections, dressings, etc.)
		Nurses’ behavior and attention
		Nurses’ explanations about the patient medical actions
Boudreaux et al. (2004)	Equipment quality (C_5)	Medical imaging
		Tests
		Availability of needed medical equipment

This paper considers five variables in estimating the efficiency of the ED. These variables should be divided into two parts, namely input and output, due to the nature of the DEA method. Accordingly, if with an increase in a variable, while other variables are assumed constant, the performance of a DMU is reduced, it is an input variable and vice versa. This means that if with an increase in a variable, while other variables assumed constant, the performance of a DMU is increased, it is an output variable. This study uses emergency environment, doctors' performance, nurses' performance, and equipment quality as the output variables. Also, in this study, the treatment time is considered as the only input variable. Therefore, we have:

- Input: Treatment time (X)
- Output (1): Emergency environment (Y_1)
- Output (2): Doctors' performance (Y_2)
- Output (3): Nurses' performance (Y_3)
- Output (4): Equipment quality (Y_4)

Questionnaire Design

In the next step, based on the indicators and items considered in this study, a standard questionnaire was developed for measuring the level of satisfaction of the patients. In order to collect data, the questionnaires were distributed among the patients or their caregivers in case they were unable to answer the questions themselves. First, general questions were asked about the age, gender, educational level, and the time of their visit to the ED; then, the respondents were asked to specify the level of their satisfaction with the items of each indicator, by answering the questions designed for each item. They were asked to assign a number from 1 to 5 to each question (where 1 means very low and 5 means very high). The questionnaires were completed by 117 patients and 43 caregivers on behalf of the patients . For examples of the questions in each indicator of the questionnaire, see Table 4.

Table 4. Sample questions of the questionnaire for each indicator

Indicator	Sample question
Emergency environment	How satisfied are you with the coordination and collaboration between medical and nursing staff?
	How satisfied are you with the boards and the signage in the department?
	How satisfied are you with the health and cleanliness of the department?
Treatment time	How satisfied are you with the registration and admission time?
	How satisfied are you with waiting in the triage room?
	How satisfied are you with the duration of the treatment?
Doctors' performance	How satisfied are you with the on-time medical care of the doctors?

	How satisfied are you with the doctors' behavior and attention?
	How satisfied are you with the doctors' explanations about the patient medical actions?
Nurses' performance	How satisfied are you with the on-time nursing care?
	How satisfied are you with the presence of the nurses when needed?
	How satisfied are you with the nurses' explanations about the patient medical actions?
Equipment quality	How satisfied are you with Medical imaging process?
	How satisfied are you with the tests?
	How satisfied are you with the availability of needed medical equipment?

Experiments and Results

In present study, a large and busy emergency department in a big general hospital in Iran has been assessed. Every day many patients visit this emergency department to receive treatments or other services. In this crowded ED, the staff works on different shifts, so that service is available 24/7 to satisfy the needs of the patients and other visitors. This study evaluates and optimizes the performance of the emergency department through assessing the views of patients about standard patient satisfaction indicators.

Data Gathering

The case study was conducted on the views of patients about each of the standard indicators and items using a standard questionnaire. In this case, patients or their caregivers answered the questions of the questionnaire. They rated each item from 1 to 5. After collecting the opinions of 160 DMUs (117 patients and 43 caregivers on behalf of the patients) in the studied emergency department, the overall score of each indicator (each input and output) is calculated. The score of each indicator is the mean scores given to its' items (the scale was determined from 1 to 5). Table 5 shows the raw data including the total mean and standard deviation of all DMUs for each indicator.

Table 5. Mean and standard deviation of 160 DMUs for each indicator

Indicator	X	Y_1	Y_2	Y_3	Y_4
Mean	3.7012	2.7569	3.7662	3.1144	3.7844
Standard deviation	0.6381	0.5554	0.5667	0.6018	0.6193

Reliability and Validity of Questionnaire

In step 6 and to check the reliability of gathered data, Cronbach's alpha test was used. Cronbach's alpha was calculated by SPSS and its value was 0.734. Since this number is larger than 0.6, it can be said that the reliability of the questionnaires' data is significant (Sharma & Sharma, 1996). Moreover, the values of Cronbach's alpha coefficient were calculated for each indicator separately, which are displayed in Table 6.

After evaluating and ascertaining the reliability of the questionnaire data , the validity of the data for all indicators has been investigated. The consistency of questionnaire must be examined.

One-way analysis of variance (ANOVA) is one of the most widely used analyses applied in all sciences. In other words, this test is used when there are more than two groups and the purpose is to compare the score of a variable in these groups. For this reason, this method has been used to measure the adaptability of questionnaire and validity of questionnaire in many articles (Soares & Farhangmehr, 2015). Hence, in the paper at hand, this method is utilized based on appropriate statistical hypothesis testing. The designed statistical hypothesis testing is as follows (Eq. (20)):

$$\begin{cases} H_0 : \text{The questionnaire is consistent} \quad (\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5) \\ H_1 : \text{Otherwise} \end{cases} \tag{20}$$

Here, regarding the number of indicators and DMUs, five independent samples (each sample contains 40 DMUs of each indicator) have been selected randomly in order to test the consistency of the questionnaire. As it can be seen in Table 6, by assuming equality of variances, after applying one-way ANOVA at confidence level 0.95, the obtained p-value for this test is 0.602. Therefore, there is no significant difference among the means of the samples and the null hypothesis cannot be rejected. This shows that there is consistency among DMUs for all indicators and the collected data are valid (Heiberger & Neuwirth, 2009).

Table 6. Results of the reliability and validity of questionnaire.

		C_1	C_2	C_3	C_4	C_5
Reliability	Cronbach's alpha:	0.814	0.668	0.618	0.706	0.602
	Number of items:	13	5	5	5	3
	Total Cronbach's alpha: 0.734					
Validity	P-value of one-way ANOVA: 0.602					

C1: Emergency environment; C2: Treatment time; C3: Doctors' performance; C4: Nurses' performance; C5: Equipment quality

Computational Results

To assess the performance of the emergency department, four different DEA models including input-oriented and output-oriented models of CCR and BCC were examined (Step 7). First, the efficiency of each DMU was calculated by these DEA models and then, the mean efficiency of all DMUs by each DEA model and the p-value of normality test for the results of each model were calculated, which are presented in Table 7. In this paper, DEA models are solved utilizing AutoAssess software (Azadeh et al., 2013).

Table 7. Mean efficiency and p-value of different DEA models

DEA model	Mean efficiency	P-value of normality test
BCC input-oriented	0.892173	0.011
BCC output-oriented	0.918626	0.069
CCR input-oriented	0.734555	<0.005
CCR output-oriented	0.776235	<0.005

According to Table 7, the BCC output-oriented model has maximum mean efficiency and p-value. Therefore, the BCC output-oriented model – as the most efficient DEA model – is selected and employed to calculate the efficiency of each DMU (Step 8). The efficiency value and rank of each DMU are shown in Table 8.

Table 8. DEA results by BCC output-oriented model for 160 DMUs

DMU	Efficiency	Rank	DMU	Efficiency	Rank	DMU	Efficiency	Rank
1	0.859673	124	55	0.967078	41	109	0.948004	53
2	1.012511	18	56	0.987654	32	110	0.830065	142
3	0.873166	111	57	0.990868	29	111	0.843621	137
4	0.834201	141	58	0.872795	112	112	0.965695	42
5	0.940933	63	59	0.796889	154	113	0.850730	130
6	0.969898	39	60	0.812466	150	114	0.938001	66
7	0.932919	72	61	0.848133	132	115	0.960677	46
8	0.803723	151	62	0.818004	148	116	0.892970	98
9	1.019539	15	63	0.929674	76	117	0.845750	136
10	0.950771	49	64	0.852704	128	118	0.941563	62
11	1.054206	4	65	0.883746	105	119	0.984585	119
12	0.954733	47	66	0.864460	120	120	0.929648	120
13	0.932872	73	67	0.762884	160	121	0.964809	121
14	1.010780	20	68	0.869253	114	122	0.877647	122
15	0.998474	26	69	0.905973	90	123	1.032070	123
16	1.029092	8	70	0.911035	89	124	0.940191	124
17	0.998087	27	71	0.843621	138	125	0.963223	125

DMU	Efficiency	Rank	DMU	Efficiency	Rank	DMU	Efficiency	Rank
18	1.037776	6	72	0.849354	131	126	0.963209	126
19	0.93911	65	73	0.856195	125	127	0.903063	127
20	0.884133	104	74	0.913407	87	128	0.912941	128
21	0.821789	147	75	1.003562	24	129	1.077886	129
22	0.871903	113	76	0.936303	68	130	1.000000	130
23	0.934551	70	77	0.829418	143	131	1.022071	13
24	0.878215	108	78	0.867374	115	132	0.841255	139
25	0.944485	57	79	0.865157	118	133	0.944253	60
26	0.918758	82	80	0.920643	81	134	1.105634	1
27	0.915135	86	81	0.845801	135	135	1.013879	16
28	1.013115	17	82	1.009164	21	136	0.988754	30
29	0.949840	50	83	0.993016	28	137	0.929790	75
30	0.916884	84	84	0.863584	121	138	0.826724	144
31	0.930635	74	85	0.987947	31	139	0.792226	156
32	0.954366	48	86	0.970748	38	140	0.802701	152
33	0.904202	93	87	0.918539	83	141	0.901811	95
34	0.937181	67	88	0.897240	97	142	0.925484	79
35	0.887912	103	89	1.025676	12	143	0.861130	123
36	1.027752	10	90	1.004326	23	144	0.822070	146
37	1.026452	11	91	1.020630	14	145	0.826087	145
38	0.949722	51	92	0.945205	55	146	0.851852	129
39	0.981265	34	93	0.927760	78	147	0.944475	58
40	1.049775	5	94	1.065306	3	148	1.028830	9
41	0.773248	159	95	1.011006	19	149	0.854131	126
42	0.891369	99	96	0.943870	61	150	0.888193	102
43	0.861440	122	97	0.933748	71	151	0.847435	134
44	0.792762	155	98	0.971216	37	152	0.853111	127
45	0.888958	101	99	0.847810	133	153	0.968137	40
46	0.949247	52	100	0.800770	153	154	0.944467	59
47	0.878630	107	101	0.781401	158	155	0.915938	85
48	0.897535	96	102	0.865873	117	156	0.946773	54
49	0.934672	69	103	0.905558	91	157	0.890292	100
50	1.005860	22	104	0.866368	116	158	0.883044	106
51	0.973741	36	105	0.838782	140	159	0.786545	157
52	0.921811	80	106	0.877785	109	160	0.864611	119
53	0.945122	56	107	0.816547	149	**Mean**	**0.918626**	-
54	0.977836	35	108	0.904944	92			

The Minimum, maximum and mean of efficiency scores for 160 defined DMUs are 0.762884, 1.105634 and 0.918626, respectively. DMU 67 has the lowest efficiency rating and DMU 134 has the highest efficiency rating based on the results presented in Table 8.

Accordingly, as mentioned before, the main contribution of this paper is the optimization performance of an ED in a hospital based on the standard patient satisfaction indicators. Since the design questions in the questionnaire measure the ED performance indicator of the DMUs, it can be said that a DMU with a higher efficiency score is more satisfactory than the other DMUs with regard to ED performance. In other words, DMU 134 has the highest level of satisfaction with ED performance among 160 DMUs.

On the other hand, the performance of a system depends on the efficiency score that a system has gained. In this study, the necessary condition for performance is that the average efficiency number is greater than 0.8. Hence, the mean efficiency of the DMUs (0.918626) demonstrates that the ED performance has in general a desirable and acceptable level based on the five important indicators mentioned above.

Next, to investigate the relationships among the selected indicators, we obtained correlations between all the pairs of indicators by using Pearson correlation coefficient and applying paired t-test. Table 9 indicates the statistical results.

Table 9. Statistical results of correlation among indicators

Measured value	Indicator	Emergency environment	Treatment time	Doctors' performance	Nurses' performance
Pearson's correlation	Treatment time	0.831***			
Pearson's correlation	Doctors' performance	0.728***	0.696***		
Pearson's correlation	Nurses' performance	0.915***	0.864***	0.795***	
Pearson's correlation	Equipment quality	0.691***	0.661***	0.607***	0.782***

***P<0.001

According to the obtained results in Table 9, since at 0.95 level of confidence , the p-values for all the pairs of indicators are less than 0.05 and also, all Pearson correlation coefficients belong to interval (0,1), there is a significant and positive correlation between each pair of the indicators. It means that by improving each indicator, other indicators will be improved.

Sensitivity Analysis

In step 9, to identify the most important indicator and also to rank the indicators based on their importance in the emergency department, first the DEA model for all the indicators (main DEA model) is considered. Then, DEA is run, each time by omitting one indicator. By assuming the equality of variances and performing paired t-tests, the amount of p-value is obtained for each indicator-omitted model. Since at 0.95 confidence level, all p-values are 0.000, we might contend that the removal of each indicator has a significant impact on the efficiency. Therefore, all standard indicators have a significant impact on the overall performance of the emergency department and are essential for performance evaluation. Next, the mean efficiency of each omitted indicator model is calculated and compared with the mean efficiency of the main DEA model. Then, in order to determine the percentage and the importance degree of each indicator, the difference between mean efficiency before and after omitted indicator is calculated. To obtain the percentage of each indicator, the absolute value of difference is used. Finally, by comparing the percentage of omitted indicators, the most important indicator is identified and the importance of the other indicators in the emergency department is determined according to the questionnaire data. All related results are provided in Table 10.

Table 10. Results of sensitivity analysis

Item	**Omitted indicator**				
	C_1	C_2	C_3	C_4	C_5
P-value	0.000	0.000	0.000	0.000	0.000
Mean efficiency	0.903205	0.942721	0.887811	0.907548	0.881176
Difference between mean efficiency before and after omitting the indicator	0.015421	0.024095	0.030815	0.011078	0.037450
Impact	positive	negative	positive	positive	positive
Percentage of omitted indicator (%)	12.97	20.27	25.93	9.32	31.51
Importance degree of omitted indicator	4	3	2	5	1

C1: Emergency environment; C2: Treatment time; C3: Doctors' performance; C4: Nurses' performance; C5: Equipment quality

As we can see in Table 10, the difference between mean efficiency before and after omitting treatment time is a negative value and so, the impact of this indicator on efficiency is negative. It means that in the absence of treatment time, efficiency has been increased and in the presence of this indicator, efficiency is decreased. Therefore, based on the patients' opinions, treatment time has a negative impact on the performance of the emergency department. Hence, by the reduction of treatment time, the performance will be improved and vice versa. While, by omitting other indicators, the efficiency is decreased. This shows that based on the patients' opinions, other indicators have a positive impact on the performance of the emergency department.

The weight of each indicator for this case study is indicated in Figure. 2. This Figureure demonstrates that based on the patients' opinions, certain indicators such as equipment quality, doctors' performance and treatment time (and their related items) encompass almost 78 percent of the total weights and are identified as critical indicators for the performance evaluation of the emergency department. While, according to the patients' opinions, emergency environment and nurses' performance have less influence on the overall performance and are recognized as less important indicators.

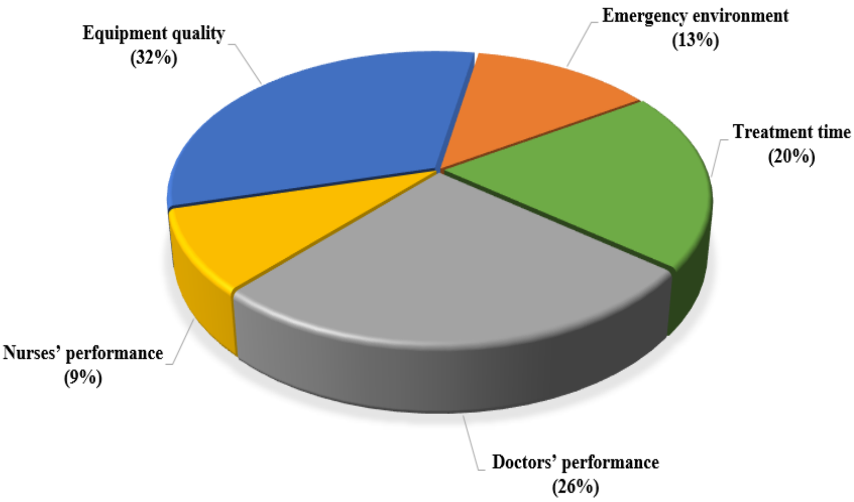

Figure 2. Weight of each indicator for this case study

Conclusion

The main aim of this study was to present a unique framework for the performance optimization of an emergency department based on the standard patient satisfaction indicators. For this purpose, statistical methods and mathematical programming were employed. First, by using the brain storming technique and receiving the opinions of the experts, five standard patient satisfaction indicators and their 31 related items were determined and accordingly, a standard questionnaire was designed. The questionnaire was completed by the patients of a large and busy emergency department of a big general hospital in Iran. The reliability and validity of the questionnaire were obtained using

Cronbach’s alpha test and analysis of variance (ANOVA), respectively. The results of these methods indicated the high reliability and validity of the gathered data. In this paper, by evaluating the different models of DEA method, the output-oriented BCC model – as the most efficient DEA model – was selected and utilized to assess the overall performance of the emergency department. After calculating the efficiency for each DMU by the selected DEA model, the mean efficiency of all DMUs was determined as 0.918626. The results of sensitivity analysis in this study showed that certain indicators such as equipment quality, doctors’ performance and treatment time have the greatest impact (weight) on overall patient satisfaction with regard to the performance of the emergency department. It emphasizes that the managers of the hospitals and healthcare centers must pay more attention to these critical indicators. We found that the evaluated emergency department seriously needs to improve its equipment quality and doctors' performance and to optimize its treatment time. The lack of or weakness of each of these indicators can lead to a low level of patient satisfaction and can affect the performance of the emergency departments. Because of the importance of treatment time for the patients, the proper performance of the emergency departments is largely dependent on this critical indicator. Every day, many patients refer to the emergency departments for treatment and medical care; so, the time to handle the patients in these care units should be optimized in order to treat the patients on time and transfer them to other departments of the hospital if needed. This paper presented a list of required indicators for patient satisfaction and a practical and structured methodology for the evaluation and decision making in the realm of the optimization and improvement of the patient satisfaction in EDs.

As to the future research, the interested rsearchers might set out to evaluate the performance of the emergency departments using the opinions of the staff and personnel about the indicators such as funding emergency department, the equipment of the emergency department, ambulance conditions, etc. This work provides an effective framework for investigating and improving the relationship between managers and staff.

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