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Concurrent Optimization of Patients' Trust and Integrated Resilience Engineering: A Z-Number Data Envelopment Analysis Approach

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Abstract

Background and Objectives: Emergency departments (EDs) often encounter several risk and health issues which significantly impact on overall healthcare performance. Resilience engineering (RE) enables EDs to confront sudden changes and handling health risk issues. Patient trust (PT) is also one of the most effective factors which improve quality of care along with patient satisfaction.
Methods: This study integrates RE and trust to enhance the overall performance of EDs. A unique algorithm is introduced to demonstrate the superiority of the proposed integrated approach. It is composed of Z-number data envelopment analysis (DEA), fuzzy DEA, and statistical analysis. The required data are collected using standard questionnaires from a real-life ED. The obtained results are verified and validated by FDEA.
Findings: The results indicate that considering RE and trust increases ED efficiency significantly. Also, flexibility, fault-tolerance, reporting culture, and specialty level are the most effective factors. Moreover, trust and resiliency have similar statistical impacts on overall system efficiency.
Conclusions: One of the concerns of medical service providers nowadays is to build an efficient ED capable of providing services to a large number of patients. Therefore, to evaluate the performance of the ED, both concepts of PT and RE which are applicable to enhance the preventive safety and promote the performance, are simultaneously considered for the first time in this study.
Keywords: Emergency department, Resilience engineering, Patient trust, Z-Number data envelopment analysis (ZDEA), Statistical analysis

Background and Objectives

Emergency departments (Eds) greet a large number of patients and outpatients 24/7 and provide them with the first aids and immediate treatments every year. Reports state that the number of entrants into the EDs are being increased all around the world. The huge volume of patients' reception leads to a limitation of the relationship between patients and medical staff as well as the incremental probability of medical and safety errors to a great extent. Trust is one of the recently detected concepts which improve the quality of care and patients' satisfaction significantly. Trust means belief that someone or something is reliable, good, honest, effective, etc. Trust is vital for functioning of a society and it is more a relational concept that generally depends on relations of 2 participants; these participants can be people or organizations.[1] Trust plays an important role in healthcare systems where all arrangements are relational. In healthcare systems, most participants like care providers, patients, and others involved, need to interact properly to underpin the cooperation among participants. Healthcare system needs cooperation between patients and care providers and also among healthcare agents to perform efficiently. In healthcare systems, patients' satisfaction and appropriate service provision for patients are major goals of the system.[2]

Trust is related to many factors in healthcare, like access and quality of service.[3] In healthcare systems, the first objective is to better access and utilization of care, it is extremely related to patients' satisfaction and allegiance to the service provider. On the other hand, a good trust in healthcare leads to low levels of complaints, more stable personal relationships, and more business productivity. Various concepts are considered in the past decade to

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improve patients' safety along with patients' satisfaction.[4] Resilience engineering (RE) is relatively a new approach to enhance proactive safety and promote performance. Numerous researchers have indicated the efficiency and applicability of RE in healthcare systems specifically in EDs in the recent decade. There is still not a completely developed definition of resilience reflecting its applicability, however, Wreathall[5] defined RE as "the ability of a system/organization to stay in or to revert in a lump sum into a stable condition, leaving it operating during and after a main disaster or while consistent considerable stresses exist". The traditional factors of RE introduced by Hollnagel et al[6] to measure and assess the resilience of a system are as follows:

- **Management commitment**: Management commitment is an instrument to assess the resilience of a system. Managers' motivation to invest and allocate resources to safety improvement in a preventive and timely manner, is a key factor in a resilient organization. However, such commitment requires both individual and team levels consideration.[5]
- **Reporting culture**: This increases the staff's willingness to report problems. The absence of a precise reporting culture reduces the staffs' motivation to report the safety issues and results in a limitation on the ability of the organization to learn from foibles in defensive conditions.[5]
- **Awareness**: The awareness in a system is a crucial factor for safety and production assessment. Collecting information at the hospital can help the management understand the quality of human performance.[7]
- **Preparedness**: It predicts the activities relevant to the system and organization, along with the problems pertaining to the human performance in man-machine systems and finally makes readiness to prevail them.[8]
- **Flexibility**: Flexibility means the capability of the company to untangle the difficulty without negative influence on the total functionality.[9]

This approach was firstly concerned for complex systems and hazardous environments such as nuclear sites but in time, its applicability to manufacturing and service industries such as healthcare system, it finally found its way. Azadeh et al[10] suggested the following 3 factors to improve the safety performance.

- **Teamwork**: Teamwork has been taken into account as one of the most important factors to generate a positive and cost-effective outcome in various organizations in recent years. By the way, teamwork causes more productivity and compatibility while enhances the job satisfaction and increments the employee retention. It can reduce individual and organizational stress when there is a high workload of the system and thus reduces human errors and increases the system reliability.[11]
- **Redundancy**: According to Clarke,[12] redundancy has a key role in system/organization design which enables them to meet a high degree of safety standards in their performance.
- **Fault-tolerance**: the fault-tolerance control is a developed method to increase safety and reliability of the system. The main goal of fault-tolerant systems is to make the system resist on an optimal constant performance even in presence of faults.[13,14]

This study proposes an integrated approach for concurrent optimization of RE and trust in EDs.

Performance measurement and management in health care systems have gradually been more complicated, hence the managers of the integrated health systems have to manage the organizational strategies considering the system performance measurement and management and then develop and spread them throughout the whole system.[15-17] According to the importance of this subject, there are some various methods to assess the performance and to increase the efficiency of the organizations. Decision-making methods particularly DEA are from the most applicable methods to system performance assessment. Gonçalves et al,[18] investigated the outpatient clinic of 27 hospitals located in Brazil applying the data envelopment analysis (DEA). Nayar and Ozcan,[19] studied the technical efficiency of 53 hospitals in Virginia using DEA. Cimellaro et al[20] proposed a Meta-model based on the ED performance considering the patients' waiting time index along with the RE and safety indices. Jeffcott et al[21] presented the concept of resilience and the way it applies to the healthcare using clinical handover as an exemplar. Costella et al[22] introduced a procedure for assessing health and safety management systems which contained in 2 innovative characteristics.

Trust is the most important element in patient-physician relationship and has a significant impact on the curing effectiveness as well as the satisfaction of the physician and the patient as 60% to 80% of diagnosis and alike ratio of medical decisions gained based on patient trust (PT), patient/physician interviews and transferring the information.[26-28]

There are a number of indices for PT in a variety of studies, six factors are considered in the present study namely the attention to patients, specialty level, quality of care, high-level policy communication and cooperation quality. Some researchers believe in the importance of the quality of patient/physician relationship due to its impact on the patient satisfactory, positive effects of health care achievements, patient's follow up of the physician's prescriptions, reduction in the required time for justification of patient, reduction in claims about physicians and positive evaluation of the physician's performance.[29] The outcomes of inconsistencies among physicians and patients and their belief or diagnosis about the disease are misunderstanding, patient's refusal to follow up the physician's prescription and undesirable results.[30] Another study was done on 2881 patient visited by 138 family physicians in Ohio. The results showed that the highest level of satisfaction was patient-centered care by a physician and the lowest level referred to the high physician's control of the patient.[31] According to the patient-physician relationship problems and ignorance of templates for such relationship, the present study started modeling and optimization of hospital ED simultaneously based on RE indices and PT. In addition, applied Z-number DEA model to evaluate the performance.

In the following, Table 1 shows the present study features and innovations versus other similar studies.

Methods

Description Model Z-number DEA

Zadeh[41] introduced an assumption of Z-number that could explain experts' information into a linguistic variable. This variable was an ordered pair (C, D) where the first number C was the fuzzy constraint and D was defined as the reliability of C. Such representation by Zadeh, led to introduce type-3 of fuzzy numbers by him.

The proposed model is an integrated model based on Z-number that not only holds the DEA properties but also is capable of considering uncertainties in decision-making units (DMUs) along with their relevant reliabilities.

Input and output values are in shape of Z-numbers in this model. Values $\widetilde{CX}_{sm}$ are related to the S_{th} output for the m_{th} DMU. Where $\widetilde{Dx}_{sm}$ refers to the reliability in shape of triangular fuzzy numbers. Equation (1) shows the CCR DEA model based on Z-numbers, while equation (2) is the dual form of equation (1).

$$\begin{aligned} &\min \varphi_0 \\ &\text{s.t } \sum_{m=1}^{t} \varepsilon_m \widetilde{Zy_{nm}} \le \varphi_0 \widetilde{Zy_{n0}} \qquad n=1 \ldots,q \\ &\sum_{m=1}^{t} \varepsilon_m \widetilde{Zx_{sm}} \ge \widetilde{Zx_{s0}} \qquad s = 1. \ldots. w \\ &\varepsilon_m \ge 0 \qquad i = 1.2 \ldots. t \end{aligned} \tag{1}$$

$$\begin{aligned} &Max\ \varphi_0 = \sum_{s=1}^{w} v_s \widetilde{Zx_{n0}} = 1 \\ &\text{s.t } \sum_{n=1}^{q} v_n \widetilde{Zy}_{no} = 1 \\ &\sum_{s=1}^{w} v_s \widetilde{Zx_{sm}} - \sum_{n=1}^{q} u_n \widetilde{Zy_{nm}} \le 0 \qquad i = 1.2. \ldots. t \\ &u_s. u_n \ge 0. \qquad s = 1.2. \ldots. w \quad . \quad n = 1. \ldots. i \end{aligned} \tag{2}$$

The above models are non-linear, for making them linear, first, a method to defuzzify is used and what will be gained is a set of membership functions of reliability amounts, $\widetilde{D} = (\{y. \lambda_{\widetilde{\beta}}(y) |\ y \in [0.1]\})$, where $\mu_{\widetilde{\beta}}(x)$ is the membership function of the reliability amount Equation (3)

Table 1. The features of this study versus other studies.

	Resilience Engineering							Trust							Case Study	Method
	MC	RC	AW	PR	FL	TW	RD	FT	AP	SL	QC	HLP	CO	CQ		
Schutz et al[32]	*	*				*							*		Ambulatory Care Organizations	Content Validity
Carlucci et al[33]									*		*		*	*	Nursing Homes	ANN
Jeffcott et al[21]	*		*	*	*										Healthcare	Qualitative Analysis
Yaghoubi and Rahmati-Najarkolaei[34]													*		Hospital	Statistical Methods
Vredenburg and Bell[35]					*										Health Care	Statistical Methods
jalilibal et al[36]	*	*	*	*	*	*	*								Hospital	DEA; Simulation
Kim[37]				*											Health Care	Qualitative Analysis
Azadian et al[38]	*		*	*	*			*							Hospital	Statistical Methods
Shirali et al[39]	*		*	*	*										Hospital	Statistical Methods
Misfeldt et al[40]						*									Health Care	Socioecological Model
This study	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Emergency Department	Z-Number DEA, FDEA

MC: management commitment; RC: reporting culture; AW: awareness; PR: preparedness; FL: flexibility; TW: teamwork; RD: redundancy; FT: fault-tolerance; AP: attention to patients; SL: specialty level; QC: quality of care; HLP: high level policy; CO: communication; CQ: cooperation quality

Indices	
m	Indicators of DMUs
n	Indicators of inputs
s	Indicators of outputs
t	Number of DMUs
q	Number of inputs
w	Number of outputs
DMU m	The m th DMU
DMU 0	The target DMU (m=0)
Parameters	
$\widetilde{Zx_{nm}}$	Z-number value of input n related to DMU m
$\widetilde{Cx_{nm}}$	Fuzzy value of input n related to DMU m
$\widetilde{Dx_{nm}}$	Fuzzy reliability value of input n related to DMU m
$\widetilde{Zx_{sm}}$	Z-number value of input r related to DMU_m
Variables	
ε_m	Weight variables in the proposed model for obtaining the efficient
φ_0	Objective value of the (efficiency) DEA model

is applied for using center of gravity (COG) method.

$$\propto = \frac{\int y\lambda_{\tilde{D}}(y)dy}{\int \lambda_{\tilde{D}}(y)dy} \quad (3)$$

Assuming that the reliability amounts of DMUs are in shape of triangular membership functions, Equation (4) is generated from the equation (3).

$$\propto = \frac{k+p+r}{3} \quad (4)$$

Equation (5) transforms the input and output amounts of DMUs into the gravity Z-number with abnormal triangular membership function.

$$E_{\tilde{C}^{\beta}}(y) = \beta E_C(y) \qquad y \in Y$$
$$\text{s.t } \lambda_{\tilde{C}^{\beta}}(y) = \beta\, \mu_{\tilde{A}}(y) \qquad y \in Y \quad (5)$$

Considering the above Equations, the second parts of Z-numbers aggregate to the first parts, so 2 normal fuzzy numbers are transformed into one abnormal crisp number (See Figure 1)

According to the Figure 2, if a gravity Z-number, holds an abnormal triangular distribution function with characteristic of $\tilde{Z}^{\alpha..} \sim$ TFN (k, p, r), its characters will be $\tilde{N} = TFN$ (k´, p´, r´). Hence the middle characteristic of normal distribution function is calculated from the Equation p= p´. To find the character α' of the fuzzy set, the assumption of direct relation between the reliability of numbers and the line slope of gravity Z-number is considered. To find β' value, the left side slope of the gravity Z-number which amount is $\frac{\beta}{p-k}$ is used and using that in the left side Equation of the line relevant to the fuzzy set, the equation (6) is achieved.

$$1 = \frac{\beta}{p-k}p + j \rightarrow j = 1 - \frac{\beta p}{p-k}$$
$$\lambda_{\tilde{T}}(y) = \frac{\beta}{p-k}y + 1 - \frac{\beta p}{p-k}.\, y \le p \quad (6)$$

In equation (6), β' is calculated: Now by putting $\lambda_{\tilde{T}}(y) = 0$

$$0 = \frac{\beta}{P-K}\acute{K} + 1 - \frac{\beta P}{P-K} \rightarrow \frac{\beta}{P-K}\acute{K} = \frac{\beta P - P + K}{P-K}$$
$$\beta' = \frac{\beta p - p + k}{\beta} \quad (7)$$

The same procedure is used to calculate r'.

$$0 = \frac{\beta}{P-K}\acute{K} + 1 - \frac{\beta P}{P-K} \rightarrow \frac{\beta}{P-K}\acute{K} = \frac{\beta P - P + K}{P-K}$$
$$\beta' = \frac{\beta p - p + k}{\beta} \quad (8)$$

$$1 = \frac{\beta}{p-r}p + j \rightarrow j = 1 - \frac{\beta p}{p-r}$$
$$\lambda_{\tilde{T}}(Y) = \frac{\beta}{p-r}y + 1 - \frac{\beta p}{p-r} \quad y \ge p$$
$$\lambda_{\tilde{T}}(y) = 0 \quad (9)$$
$$0 = \frac{\beta}{b-c}\acute{c} + 1 - \frac{\beta p}{p-k} \rightarrow \frac{\beta}{p-k}\acute{r} = \frac{\beta p - p + r}{p-k}$$
$$\acute{r} = \frac{\beta p - p + r}{\beta}$$

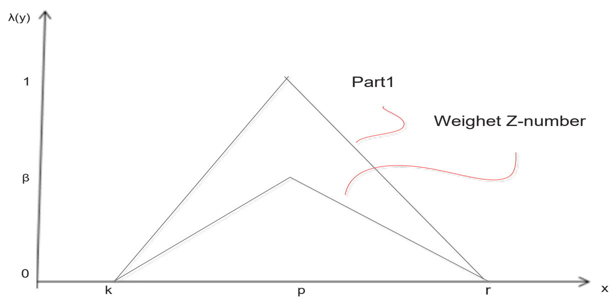

Figure 1. Z-number After Multiplying the Reliability Value.[42]

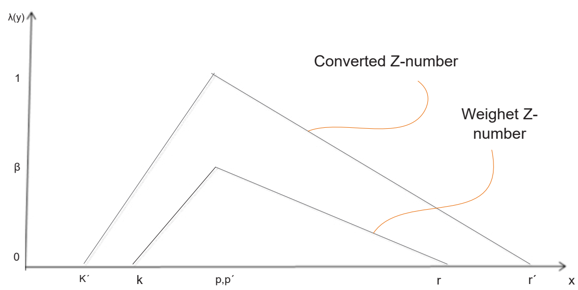

Figure 2. Convert Weighted Z-Numbers to Normal Fuzzy Numbers.[42]

In the proposed Z-DEA model, the expert represents input and output amounts for the *m*th DMU in Z-number values. $\widetilde{DY}_{nm}$ defuzzifies with COG method and calculates the reliability value of. This amount is added to the first pair, $\widetilde{CY}_{nm}$ and then the equations (8) and (9) are exerted to transform the gravity Z- numbers into triangular fuzzy numbers which are shown by $\widetilde{NY}_{nm} \sim TFN(k'.p'.r')$

$$k_{nm} = \frac{i_{nm} + l_{nm} + o_{nm}}{3}$$
$$\acute{p}_{nm} = p_{nm}$$
$$\acute{k}_{nm} = \frac{\beta_{nm} p_{nm} - p_{nm} + k_{nm}}{k_{nm}} \quad (10)$$
$$\acute{r}_{nm} = \frac{\beta_{nm} p_{nm} - p_{nm} + p_{nm}}{\beta_{nm}}$$

Equations (10), are calculation formulas for the characteristics of fuzzy sets $\widetilde{NX}_{ij}$ from the relevant Z-number values.

$$y^l_{nm} = \frac{\alpha x_{nm} \beta y^m_{nm} - \beta y^m_{nm} + \beta y^l_{nm}}{\beta x_{ji}}$$
$$y^u_{nm} = \frac{\alpha y_{nm} \beta y^m_{nm} - \beta y^m_{nm} + \beta y^u_{nm}}{\beta x_{ji}} \quad (11)$$
$$\alpha x_{sm} = \frac{px^l_{sm} + px^m_{sm} + px^u_{sm}}{\alpha y_{nm}}$$
$$x^m_{sm} = \beta x^m_{sm}$$

Using the mentioned transformation model, the fuzzy Z-number is got for DEA. Equations (11) are formulas to transform model inputs into triangular fuzzy numbers.

$$y^l_{nm} = \frac{\alpha x_{nm} \beta y^m_{nm} - \beta y^m_{nm} + \beta y^l_{nm}}{\beta x_{ji}}$$
$$y^u_{nm} = \frac{\alpha y_{nm} \beta y^m_{nm} - \beta y^m_{nm} + \beta y^u_{nm}}{\beta x_{ji}} \quad (12)$$
$$\alpha x_{sm} = \frac{px^l_{sm} + px^m_{sm} + px^u_{sm}}{\alpha y_{nm}}$$
$$x^m_{sm} = \beta x^m_{sm}$$

In addition, Equations (12), show the transformation of output numbers into relevant normal fuzzy numbers.

$$Max\ \varphi_h = \sum_{s=1}^{w} v_s\,(x^l_{sh}.x^m_{sh}.x^u_{sh})$$
St.
$$\sum_{n=1}^{q} v_j\,(y^l_{nh}.y^m_{nh}.y^u_{nh}) = (1^l.1.1^u) \quad (13)$$
$$\sum_{s=1}^{w} v_s\,(x^l_{sm}.y^m_{sm}.y^u_{sm}) - \sum_{n=1}^{q} u_m\,(y^l_{nm}.y^m_{nm}.y^u_{nm}) \le 0 \quad m = 1.\dots.t$$
$$v_s.u_n \ge 0\,.\ r = 1.2.\dots.s \quad n = 1.2.\dots.m$$

$\widetilde{X_{sm}} \sim TFN(x^l_{sh}.x^m_{sh}.x^u_{sh})$ is the normal fuzzy converted number of s^{th} output of DMU_m. Then the fuzzy programming of Z-number CCR model is presented in the Expression (13). Equation (14), is the dual model of Z-number CCR.

$$MAX\ \varphi_h = \textstyle\sum_{s=1}^{w} \bar{x}_{sh}$$
$$\sum_{n=1}^{q} \bar{y}_{nh} = 1$$
$$\textstyle\sum_{s=1}^{w} \bar{x}_{sm} - \sum_{n=1}^{q} \bar{y}_{nm} \le 0 \quad m = 1.2.\dots.t \quad (14)$$
$$u_j(\beta y^m_{nm} + (1-\beta) y^l_{nm}) \le \bar{y}_{nm} \le u_n(\beta y^m_{nm} + (1-\beta) x^u_{nm}) \quad m = 1.\dots.t$$
$$n = 1.\dots.q$$
$$v_s(\beta x^m_{sm} + (1-\beta) x^l_{sm}) \le \bar{x}_{sm} \le u_s(\beta x^m_{sm} + (1-\beta) y^u_{sm}) \quad m = 1.\dots.t$$
$$.n = 1.\dots.w$$
$$v_s.u_n \ge 0\ .r = 1.\dots.s\ .j = 1.\dots.m$$

The schematic view of the proposed approach is demonstrated in Figure 3.

Conceptual Model

Choosing the input/output variables is one of the most important stages in the Z-number DEA model. This paper uses preparedness, reporting culture, learning culture, awareness, management commitment, flexibility, teamwork, redundancy and fault-tolerance variables as the outputs variables in RE_framework. Output variables in trust framework include attention to patients, specialty level, quality of care, high-level policy, communication and cooperation quality. There is no input variable considered. Therefore, a dummy variable is defined as the input variable.

Questionnaire Designation

In this paper, an appropriate questionnaire was applied to evaluate performance by considering the RE and trust effective indices in healthcare. The questionnaire was confirmed and entitled by the experts in terms of content.

Results and Discussion

Case Study

The study is done in a hospital located in Tehran, Iran. The hospital was built incompletely in the 1950s and dedicated to the ministry of health. The hospital started to work as a medical clinic in 1954. The total area is 18500 square meter with 25 000 square meter substructure. The hospital is equipped with 351 bed, among them, 345 are approved. There are subspecialty departments including general surgery, orthopedic, neurosurgery, ENT, internal medicine, gynecology, general ICU, neurosurgery ICU,

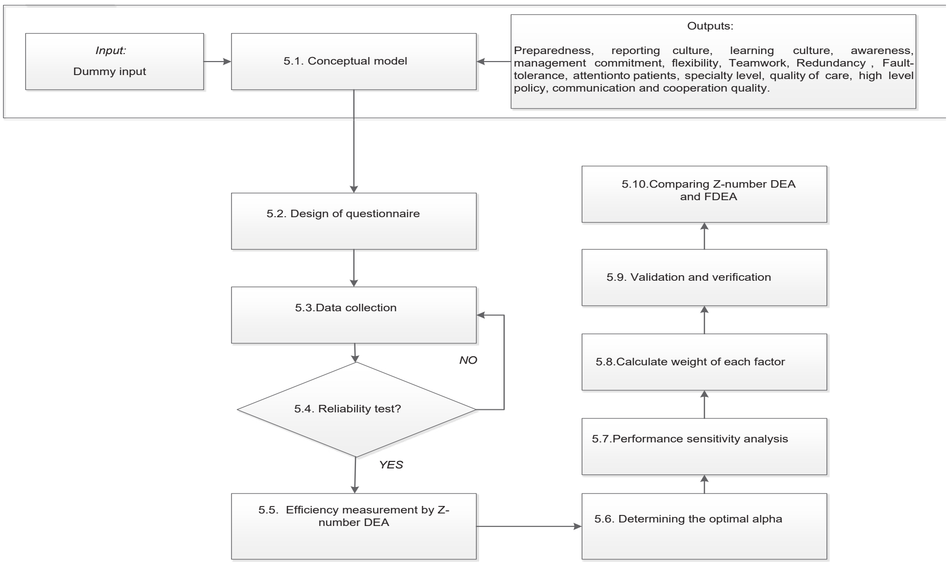

Figure 3. Schematic View of the Proposed Approach.

CCU, POST CCU, dialysis, operating theaters, EDs, ED pharmacy, ED laboratory and para-clinical units including the central laboratory, central pharmacy, radiology, endoscopy, colonoscopy, echocardiography, stress test, bronchoscopy and breath tests, physiotherapy, physical medicine and rehabilitation.

Figure 4 is a flowchart of patients' curing process in ED.

Data Collection

Data has to be collected in this step, therefore the patients of the ED were requested to fill the questionnaire by marking 1 to 20 based on their idea about each question. Among them, 73 patients completely marked questions.

Reliability Test on Questionnaire

A very common method to measure the internal consistency of the questionnaire responses is Cronbach's alpha using SPSS software. Obviously the closer Cronbach's alpha coefficient is to 1, the more internal consistency is between the questions, and consequently the more homogeneous are the questions. If the Cronbach's alpha is greater than 0.6, it shows that the data are valid enough to go to the next step.

The total value of Cronbach's alpha is 71%, hence the collected data are verified. Table 2 shows the Cronbach's alpha of each factor, respectively.

Another performed statistical test is the randomness test. For each factor, 2 samples of 18 data are selected and using Minitab, the *P* value of factors is estimated by 2 sample *t* test which is higher than 0.05, confirming that the data are randomly collected. The respective results are shown in Table 3.

Efficiency Measurement by Z-Number DEA

Firstly, for calculating the efficiency value of each alpha cut, we should specify the reliability values of all input and output variables. Data reliability is described in shape of 3 linguistic variables namely Sure, Usually and Likely. Reliability values are determined by experts according to the Table 4.[42]

Since the Z-number DEA deals with uncertainty using fuzzy approach, we calculate the efficiency considering 14 different α- cuts. In this study; including: 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99 and 1.

Determining the Optimal Alpha

To determine the optimal alpha, a noise analysis is applied. The results are shown in Table 5. The Pearson correlation average of the efficiencies before and after the noise exertion between every alpha is compared and the maximum average correlation is 0.352 which refers to the alpha equal to 0.05 as the optimal alpha.

Sensitivity Analysis

Sensitivity analysis is executed to calculate the weight of factors. In this regard, Z-number DEA model is applied for efficiency score calculation. After calculation of efficiency scores for the existence of all factors, each factor should be eliminated from the model. As the efficiency is estimated in absence of each factor, the performance of each eliminated factor can be investigated by comparing the obtained efficiency scores to calculated efficiency scores in the presence of all factors using paired *t* test. The paired *t* test calculates the differences between each

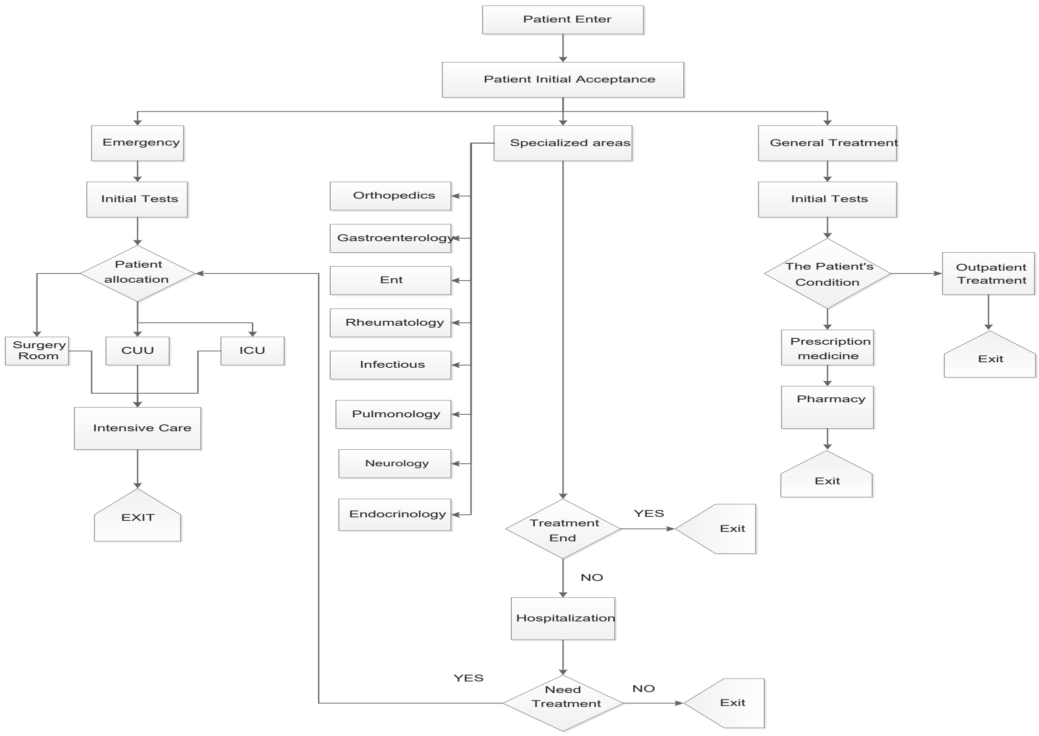

Figure 4. Clinical pathway in considered emergency department

Table 2. Cronbach's Alpha for Each Factor

Factors	Cronbach's Alpha	Factors	Cronbach's Alpha
Management commitment	0.789	Preparedness	0.810
Flexibility	0.768	Attention to Patients	0.73
Teamwork	0.672	Specialty Level	0.773
Redundancy	0.793	Quality of Care	0.801
Fault-tolerance	0.754	High Level Policy	0.71
Reporting culture	0.630	Communication	0.827
Awareness	0.874	Cooperation Quality	0.79

Table 3. Result of 2 Sample t-test

Factors	*P* Value	Factors	*P* Value
Management commitment	0.682	Preparedness	0.705
Flexibility	0.059	Attention to Patients	0.821
Teamwork	0.449	Specialty Level	0.883
Redundancy	0.417	Quality of Care	0.405
Fault-tolerance	0.609	High Level Policy	0.486
Reporting culture	0.366	Communication	0.911
Awareness	0.8692	Cooperation Quality	0.122

Table 4. Classification of Reliability Values Given by Experts

Z=(C,D)	Interval DATA		Membership Functions Parameters
	[15,20]	Sure	[15,17.5,20]
	[11,15]	Usually	[10,12.5,15]
	[1,11]	Likely	[0,5,10]

Table 5. Result of Noise Analysis

α- Cuts	Pearson Correlation Average	α- cuts	Pearson Correlation Average
$\alpha=0.01$	0.165	$\alpha=0.6$	0.148
$\alpha=0.05$	0.352	$\alpha=0.7$	0.141
$\alpha=0.1$	0.177	$\alpha=0.8$	0.220
$\alpha=0.2$	0.189	$\alpha=0.9$	0.146
$\alpha=0.3$	0.190	$\alpha=0.95$	0.177
$\alpha=0.4$	0.191	$\alpha=0.99$	0.119
$\alpha=0.5$	0.213	$\alpha=1$	0.182

pair of efficiency measurements got from before and after the factor's elimination.[43]

The paired *t* test for each factor is performed considering H_0 and H_1 presented in equation (15). The results show that after eliminating each factor, the efficiency decreases which describes the positive impact of the removed factor. Respective results are shown in Table 6.

$$\begin{cases} H_0: \theta_f = \theta_i & \text{f: full efficiency} \\ H_1: \theta_f \neq \theta_i & \text{i: factor i efficiency} \end{cases} \quad (15)$$

Calculation of Weight Factors

To obtain the weight of each factor the average efficiency is calculated using equation (16). The flexibility has the maximum weight of 19% and other factors have almost the same weights. The calculated weights of each factor and total concepts are demonstrated in Figures 5 and 6.

$$W_i = \frac{|\theta - \theta_i|}{\sum|\theta - \theta_i|} \quad (16)$$

θ: *full average efficiency,* θ_i: *average efficiency of the ith factor*

Validation and Verification

For validation and verification of the results, using the Spearman rank-order correlation test in Minitab, the correlation between rank orders obtained from Z-number DEA and FDEA are compared. The correlation coefficient of 0.983 verifies the reasonable reliability of the Z-number DEA method. Table 7 reports the non-parametric Spearman test of relationships between the ranking of FDEA model and Z-number DEA.[44]

Comparing Z-number DEA and FDEA

The average efficiency calculated in Z-number DEA method by considering the optimal alpha equal to 0.05 and the average efficiency calculated in FDEA method

Table 6. Paired *T* Test Results

Factors	Hypothesis	P Value	Analysis	The Impact of Factors
Management commitment	$H_0: \theta_f = \theta_1$ $H_1: \theta_f \neq \theta_1$	0.042	Reject assumption H_0	Positive
Flexibility	$H_0: \theta_f = \theta_2$ $H_1: \theta_f \neq \theta_2$	0.003	Reject assumption H_0	Positive
Teamwork	$H_0: \theta_f = \theta_3$ $H_1: \theta_f \neq \theta_3$	0.001	Reject assumption H_0	Positive
Redundancy	$H_0: \theta_f = \theta_4$ $H_1: \theta_f \neq \theta_4$	0.006	Reject assumption H_0	Positive
Fault-tolerance	$H_0: \theta_f = \theta_5$ $H_1: \theta_f \neq \theta_5$	0.015	Reject assumption H_0	Positive
Reporting culture	$H_0: \theta_f = \theta_6$ $H_1: \theta_f \neq \theta_6$	0.01	Reject assumption H_0	Positive
Awareness	$H_0: \theta_f = \theta_7$ $H_1: \theta_f \neq \theta_7$	0.037	Reject assumption H_0	Positive
Preparedness	$H_0: \theta_f = \theta_8$ $H_1: \theta_f \neq \theta_8$	0.002	Reject assumption H_0	Positive
Attention to Patients	$H_0: \theta_f = \theta_9$ $H_1: \theta_f \neq \theta_9$	0.001	Reject assumption H_0	Positive
Specialty Level	$H_0: \theta_f = \theta_{10}$ $H_1: \theta_f \neq \theta_{10}$	0.012	Reject assumption H_0	Positive
Quality of Care	$H_0: \theta_f = \theta_{11}$ $H_1: \theta_f \neq \theta_{11}$	0.025	Reject Assumption H_0	Positive
High-Level Policy	$H_0: \theta_f = \theta_{12}$ $H_1: \theta_f \neq \theta_{12}$	0.002	Reject assumption H_0	Positive
Communication	$H_0: \theta_f = \theta_{13}$ $H_1: \theta_f \neq \theta_{13}$	0.020	Reject assumption H_0	Positive
Cooperation Quality	$H_0: \theta_f = \theta_{14}$ $H_1: \theta_f \neq \theta_{14}$	0.018	Reject assumption H_0	Positive

Table 7. Correlation Between Rank Efficiency Z-Number DEA and FDEA

DMU No.	Rank FDEA (α=0.99)	Rank Z-DEA (α=0.05)	DMU No.	Rank FDEA (α=0.99)	Rank Z-DEA (α=0.05)	DMU No.	Rank FDEA (α=0.99)	Rank Z-DEA (α=0.05)
1	33	36	26	66	66	51	7	10
2	62	63	27	41	35	52	43	37
3	50	51	28	67	68	53	1	1
4	10	15	29	59	57	54	31	39
5	47	49	30	18	17	55	3	4
6	73	73	31	64	64	56	60	60
7	29	28	32	48	46	57	9	8
8	69	69	33	8	14	58	26	7
9	57	58	34	45	43	59	16	20
10	13	11	35	22	23	60	58	59
11	56	55	36	30	38	61	5	3
12	12	9	37	14	16	62	2	2
13	71	71	38	21	22	63	44	42
14	35	29	39	4	5	64	63	61
15	19	19	40	40	44	65	11	13
16	38	34	41	17	21	66	72	72
17	70	70	42	68	67	67	28	24
18	51	50	43	52	54	68	15	12
19	32	31	44	55	56	69	23	18
20	65	65	45	39	41	70	54	52
21	27	32	46	36	33	71	24	26
22	61	62	47	53	53	72	20	25
23	46	48	48	42	47	73	49	45
24	34	27	49	25	30	Spearman Correlation=0.983		
25	37	40	50	6	6			

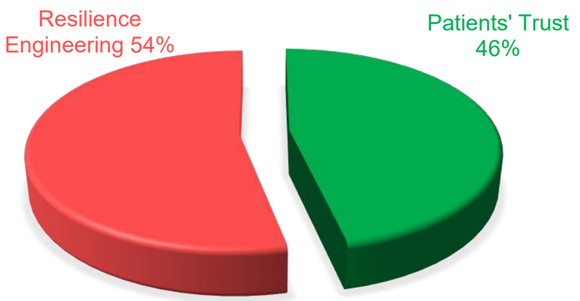

Figure 5. Total Weight of Resilience Engineering and Patients' Trust.

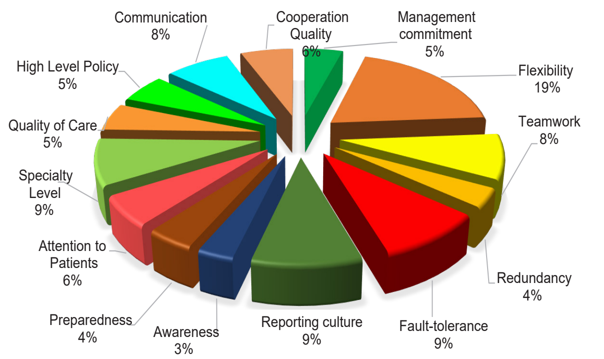

Figure 6. Weight of Resilience Engineering and Patients' Trust Indicators.

by considering the optimal alpha of 0.99 are compared. The average efficiency of Z-number DEA model is 1.003 and the average efficiency of FDEA is 0.992. Since the average efficiency of Z-number DEA is higher, then Z-number DEA is remarked as a better method (Table 8).

In order to indicate the superiority of the proposed algorithm considering RE and patients trust concepts together, the efficiency scores of RE and PT factors are calculated separately, and the results are compared to the combined conceptual model of the presented study. The results are presented in Table 9.

Conclusions

ED as one of the most important and risky departments of hospitals is a bottleneck of confronting with a large number of entrants in unusual times and undertakes not only to look after the critical ills and injured of accidents or disasters but to manage the medical emergencies. One of the concerns of medical service providers nowadays is to build an efficient ED capable of providing services to a large number of patients. Therefore, to evaluate the performance of the ED, both concepts of PT and RE which are applicable to enhance the preventive safety and promote the performance, are simultaneously

Table 8. Comparison Results Between Z-Number DEA and FDEA

DMU No.	Efficiency FDEA ($\alpha=0.99$)	Efficiency Z-number DEA ($\alpha=0.05$)	DMU No.	Efficiency FDEA ($\alpha=0.99$)	Efficiency Z-number DEA ($\alpha=0.05$)	DMU No.	Efficiency FDEA ($\alpha=0.99$)	Efficiency Z-number DEA ($\alpha=0.05$)
1	1.002	1.013	26	0.962	0.972	51	1.003	1.019
2	0.982	0.987	27	1.002	1.013	52	1.002	1.013
3	1.002	1.009	28	0.957	0.965	53	1.005	1.029
4	1.003	1.018	29	0.989	1.001	54	1.002	1.013
5	1.002	1.010	30	1.003	1.016	55	1.004	1.021
6	0.853	0.865	31	0.974	0.981	56	0.986	0.996
7	1.002	1.014	32	1.002	1.011	57	1.003	1.019
8	0.954	0.962	33	1.003	1.018	58	1.002	1.020
9	0.990	0.998	34	1.002	1.011	59	1.003	1.015
10	1.003	1.018	35	1.003	1.015	60	0.990	0.998
11	0.996	1.004	36	1.002	1.013	61	1.004	1.022
12	1.003	1.019	37	1.003	1.016	62	1.005	1.024
13	0.917	0.926	38	1.003	1.015	63	1.002	1.011
14	1.002	1.014	39	1.004	1.021	64	0.981	0.991
15	1.003	1.016	40	1.002	1.011	65	1.003	1.018
16	1.002	1.013	41	1.003	1.015	66	0.905	0.918
17	0.935	0.950	42	0.954	0.969	67	1.002	1.015
18	1.002	1.010	43	1.001	1.006	68	1.003	1.018
19	1.002	1.014	44	0.997	1.003	69	1.003	1.016
20	0.965	0.975	45	1.002	1.013	70	0.999	1.007
21	1.002	1.014	46	1.002	1.014	71	1.003	1.014
22	0.983	0.991	47	1.000	1.007	72	1.003	1.015
23	1.002	1.010	48	1.002	1.011	73	1.002	1.011
24	1.002	1.014	49	1.002	1.014	-	-	-
25	1.002	1.013	50	1.003	1.020	Average	0.992	1.003

Table 9. The superiority of the proposed integrated model versus separate concepts

Factors	Mean of Efficiencies	Superiority Result
Combined RE and PT	$\mu_{Combined}=1.003434$	-
RE	$\mu_{RE}=0.96454$	$\mu_{Combine} > \mu_{R}$
PT	$\mu_{Pateint\ Trust}=0.92467$	$\mu_{Combine} > \mu_{Pateint\ Trust}$

considered for the first time in this study. In addition, due to the uncertain nature of the data in the real world, decision making is done under uncertainty. In this regard, the Z-number DEA model has been used to evaluate the system efficiency as a powerful, efficient and new tool in uncertainty. Managers are suggested to consider the obtained results in improvement planning of the safety and patients' trust to improve the overall efficiency.

Authors' Contributions

MT gathered the required data and other authors contributed to data analysis, drafting the manuscript and finalizing it. All authors read and approved the final manuscript.

Competing Interests

The authors declare no competing interests.

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It is with deep sadness that we announce the loss of our dear colleague, Professor Ali Azadeh. Ali Azadeh was an eminent university professor and founder of Department of Industrial Engineering and co-founder of Research Institute of Energy Management and Planning at the University of Tehran. He was a kind teacher and a caring father. Our hearts go out to his family. May God bless his soul and give courage to the family to bear this loss.

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