



HAL
open science

Measuring Performance, Estimating Most Productive Scale Size, and Benchmarking of Hospitals Using DEA Approach: A Case Study in Iran

Pejman Peykani, Emran Mohammadi, Fatemeh Sadat Seyed Esmaeili

► To cite this version:

Pejman Peykani, Emran Mohammadi, Fatemeh Sadat Seyed Esmaeili. Measuring Performance, Estimating Most Productive Scale Size, and Benchmarking of Hospitals Using DEA Approach: A Case Study in Iran. *International Journal of Hospital Research*, 2018. hal-02274529

HAL Id: hal-02274529

<https://hal.science/hal-02274529v1>

Submitted on 30 Aug 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Measuring Performance, Estimating Most Productive Scale Size, and Benchmarking of Hospitals Using DEA Approach: A Case Study in Iran

Pejman Peykani¹, Emran Mohammadi^{1,*}, Fatemeh Sadat Seyed Esmaeili²

¹ School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

² Faculty of Mathematics, Science and Research Branch, Islamic Azad University, Tehran, Iran

Abstract

Background and Objectives: The goal of current study is to evaluate the performance of hospitals and their departments. This manuscript aimed at estimation of the most productive scale size (MPSS), returns to scale (RTS), and benchmarking for inefficient hospitals and their departments.

Methods: The radial and non-radial data envelopment analysis (DEA) approaches under variable returns to scale (VRS) assumption are applied for performance assessment of hospitals. Also, the MPSS model in DEA is employed to identify hospital with optimal scale size. Furthermore, the benchmarking for inefficient decision making units (DMUs) is introduced using the slack based measure (SBM) model.

Results: In this manuscript, the DEA approaches are implemented at macro and micro levels in health care. At macro level, the performance of 15 Iranian hospitals is assessed and at micro level, the performance of 15 departments of one hospital is evaluated. It should be noted that the number of staff, the number of beds, location & infrastructures, and equipment & facilities were considered as the input variables and number of patients and number of surgeries were selected as output variables. According to the results, six hospitals at macro level and seven hospital departments at micro level were efficient. As a result, these hospitals and departments can be considered as a benchmark for other DMUs. Notably, only four hospitals at macro level and four hospital departments at micro level have the most productive scale size.

Conclusions: The current study presents a functional pattern to managers at macro and micro levels in health care systems to better planning for capacity development and resource saving.

Keywords: Hospital Performance Evaluation, Data Envelopment Analysis (DEA), Health Care, Most Productive Scale Size (MPSS), Returns to Scale (RTS).

1. Introduction

Hospital is one of the most important parts in the health care network and the major share of health care from gross domestic product (GDP) is spent in hospitals. In other words, hospitals as one of the most important and largest providers of health care services, play a crucial role in health economics. Therefore, measuring the performance and productivity of hospitals is mandatory.

Data envelopment analysis (DEA) is one of the applicable tools that can be applied to evaluate the performance of hospitals.¹⁻³ DEA is one of the most effective and powerful methods widely used in many real-world applications.⁴⁻⁹ The initial idea of DEA approach was raised by Farrell¹⁰ and then developed by Charnes et al.¹¹ and Banker et al.¹² under constant returns to scale (CRS) and variable returns to scale (VRS) assumptions, respectively.¹³ It should be noted that so far, DEA has been applied in many studies to assess the performance of Iranian hospitals.¹⁴⁻¹⁶ Table 1 summarizes the studies that applied DEA approach for performance assessment of hospitals and health care centers in Iran:

Table 1: The Application of DEA in Iranian Hospitals and Health Care Centers: A Literature Review

| Year | Research | DEA Approach | | | | | | | | | | | | | | | Application | | | | | | |
|------|------------------------------------|--------------|-----|-----|------|-----|-----|------|------------|-------|-------|--------|-------|-------|-------|-------|-------------|------|-------|-----------|---------------------|-----------------------|-----------------------|
| | | CCR | BCC | SBM | MPSS | RTS | MPI | WDEA | Congestion | SEDEA | CEDEA | CSWDEA | MGDEA | CDDEA | CGDEA | CCDEA | FDEA | RDEA | Other | Hospitals | Health Care Centers | Identical Departments | Different Departments |
| 2007 | Hajialiafzali et al. ¹⁷ | | • | | | | | | | • | | | | | | | | | | • | | | |
| 2008 | Hatam ¹⁸ | • | | | | | | | | | | | | | | | | | | • | | | |
| 2010 | Hatam et al. ¹⁹ | • | • | | | • | • | | | | | | | | | | | | | • | | | |
| 2010 | Jandaghi et al. ²⁰ | • | • | | | | | | | | | | | | | | | | | • | | | |
| 2011 | Ketabi ²¹ | • | | | | | | | • | | | | | | | | | | | | | • | |
| 2011 | Shahhoseini et al. ²² | • | • | | | | | | | | | | | | | | | | | • | | | |
| 2012 | Ebrahimnejad ²³ | | | | | | | | | | | | | | | | • | | | • | | | |
| 2012 | Ghotbuee et al. ²⁴ | • | | | | | | | | | | | | | | | | | | | • | | |
| 2012 | Khani et al. ²⁵ | • | | | | | | | | | | | | | | | | | | • | | | |
| 2012 | Mamani et al. ²⁶ | | • | | | | | | | | | | | | | | | | | • | | | |

| Year | Research | DEA Approach | | | | | | | | | | | | | | | | Application | | | | | |
|------|----------------------------------------------|--------------|-----|-----|------|-----|-----|------|------------|-------|-------|--------|-------|-------|-------|-------|------|-------------|----------|-----------|---------------------|-----------------------|-----------------------|
| | | CCR | BCC | SBM | MPSS | RTS | MPI | WDEA | Congestion | SEDEA | CEDEA | CSWDEA | MGDEA | CDDEA | CGDEA | CCDEA | FDEA | RDEA | Hybrid A | Hospitals | Health Care Centers | Identical Departments | Different Departments |
| 2012 | Sheikhzadeh et al. ²⁷ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2013 | Yusefzadeh et al. ²⁸ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2014 | Kalantary & Azar ²⁹ | | | | | | | | | | | | | | | | • | | | • | | | |
| 2014 | Lotfi et al. ³⁰ | • | • | | | • | • | | | | | | | | | | | | | • | | | |
| 2014 | Mehrtak et al. ³¹ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2014 | Torabipour et al. ³² | • | • | | | • | • | | | | | | | | | | | | | • | | | |
| 2015 | Haji Sami et al. ³³ | | | | | | | | | | | | | | | | • | | | | | • | |
| 2015 | Jahangoshai Rezaee & Karimdadi ³⁴ | | | | | | | | | | | • | | | | | | | | • | | | |
| 2015 | Kheirollahi et al. ³⁵ | | | | | | | • | | | | | | | • | | | | | • | | | |
| 2015 | Rezapour et al. ³⁶ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2016 | Kakeman et al. ³⁷ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2016 | Kalhor et al. ³⁸ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2016 | Nabilou et al. ³⁹ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2016 | Rabbani et al. ⁴⁰ | | | | | | | | | | | | | | | | | • | | • | | | |
| 2016 | Rezaei et al. ⁴¹ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2017 | Abadi et al. ⁴² | | | | | | | | | | | • | | | | | | | | • | | | |
| 2017 | Ameryoun et al. ⁴³ | | | | | | | | | | | • | | | | | | | | • | | | |
| 2017 | Farzianpour et al. ⁴⁴ | • | • | | | • | | | | | | | | | | | | | | • | | | |
| 2017 | Kakemam et al. ⁴⁵ | | • | | | | | | | | | | | | | | | | | • | | | |
| 2017 | Kheirollahi et al. ⁴⁶ | | | | | | | • | | | | | | | | • | | | | • | | | |
| 2017 | Mirmozaffari & Alinezhad ⁴⁷ | • | • | | | | | | | | • | | | | | | | | | • | | | |
| 2017 | Mirmozaffari & Alinezhad ⁴⁸ | • | • | | | | • | | | | | | | | | | | | | • | | | |
| 2017 | Raei et al. ⁴⁹ | | | | | | • | | | | | | | | | | | | | • | | | |
| 2017 | Shafaghat et al. ⁵⁰ | • | | | | | | | • | | | | | | | | | | | • | | | |
| 2018 | Alinezhad & Mirmozaffari ⁵¹ | | | | | • | | | | | | | | | | | | | | • | | | |

| Year | Research | DEA Approach | | | | | | | | | | | | | | Application | | | | | | | | | |
|------|-----------------------------------------|--------------|-----|-----|------|-----|-----|------|------------|-------|-------|--------|-------|-------|-------|-------------|------|------|------------|-----------|---------------------|-----------------------|-----------------------|---|--|
| | | CCR | BCC | SBM | MPSS | RTS | MPI | WDEA | Congestion | SEDEA | CEDEA | CSWDEA | MGDEA | CDDEA | CGDEA | CCDEA | FDEA | RDEA | Non-radial | Hospitals | Health Care Centers | Identical Departments | Different Departments | | |
| 2018 | Bahrami et al. ⁵² | • | • | | • | | | | | | | | | | | | | | | | | • | | | |
| 2018 | Hadipour et al. ⁵³ | • | | | | | | | • | | | | | | | | | | | | | • | | | |
| 2018 | Jahangoshai Rezaee et al. ⁵⁴ | | | | | | | | | | | • | | | | | | | | | | • | | | |
| 2018 | Ketabi et al. ⁵⁵ | • | | | | | | | • | | | | | | | | | | | | | | • | | |
| 2018 | Kiani et al. ⁵⁶ | • | • | | | • | | | | | | | | | | | | | | | | • | | | |
| 2018 | Omrani et al. ⁵⁷ | | | | | | | | | | | | | • | | | | | | | | • | | | |
| 2018 | Pirani et al. ⁵⁸ | • | • | | | • | | | | | | | | | | | | | | | | • | | | |
| 2019 | Hatefi & Haeri ⁵⁹ | | | | | | | | | | | | | | | • | | | | | | • | | | |
| 2019 | Jahangoshai Rezaee et al. ⁶⁰ | | | | | | | | | | | • | | | | | | | | | | • | | | |
| 2019 | Our Work | • | • | • | • | | | | | | | | | | | | | | | | | • | | • | |

As it can be seen in Table 1, in the current research, the radial and non-radial DEA methods as well as the most productive scale size (MPSS) model are applied in Iranian health care system for performance assessment of hospital and their departments. Moreover, the input and output-oriented slack based measure (SBM) models are employed for identifying input-excess, output-shortfall, and reference-set for inefficient decision making units (DMUs). In other words, the main purpose of this research is to explore causes of inefficiency of hospital and their departments by applying different DEA models. In fact, this study is an applied research in Iran's health care systems that can be used to provide more services or to improve the quality of hospital services by managing the available resources.

The rest of this paper is organized as follows: The background of radial and non-radial DEA models under both input and output orientations are explained in Section 2. The approach for estimation of MPSS is proposed in Section 3. Then, the proposed DEA approaches of the current study are implemented for a real case study of Iranian hospitals and the results are evaluated in Section 4. Finally, managerial insights and conclusions of study as well as some directions for future research are given in Section 5.

2. Data Envelopment Analysis (DEA)

In this section, the background of DEA models based on radial and non-radial approaches are introduced. Assume that there are n homogenous DMUs that each $DMU_j (j=1, \dots, n)$ uses m inputs $x_{ij} (i=1, \dots, m)$ to produce s outputs $y_{rj} (r=1, \dots, s)$ and k is the index of DMU under evaluation.

2.1. Radial Approach

In radial approach, DEA calculates the maximum proportional reduction in all inputs under input orientation (increment in all outputs under output orientation) to increase the efficiency of DMU under evaluation. It should be noted that the BCC model is a popular radial DEA model under variable returns to scale.¹² The input and output-oriented BCC models are presented as Models (1) and (2), respectively:

$$\begin{aligned} & \text{Min } \theta & (1) \\ \text{s.t. } & \sum_{j=1}^n \theta_j x_{ij} \leq \theta x_{ik}, \quad i=1, \dots, m \\ & \sum_{j=1}^n \theta_j y_{rj} \geq y_{rk}, \quad r=1, \dots, s \\ & \sum_{j=1}^n \theta_j = 1 \\ & \theta_j \geq 0, \quad j=1, \dots, n \end{aligned}$$

$$\begin{aligned} & \text{Max } \theta & (2) \\ \text{s.t. } & \sum_{j=1}^n \theta_j x_{ij} \leq x_{ik}, \quad i=1, \dots, m \\ & \sum_{j=1}^n \theta_j y_{rj} \geq \theta y_{rk}, \quad r=1, \dots, s \\ & \sum_{j=1}^n \theta_j = 1 \\ & \theta_j \geq 0, \quad j=1, \dots, n \end{aligned}$$

Note that in output-oriented BCC model presented in Model (2), the efficiency of DMU under investigation is calculated by $1/\theta^*$.

2.2. Non-Radial Approach

In non-radial approach in contrast with radial approach, DEA model reduces inputs under input orientation (increases outputs under output orientation) non-proportionally. In other words, non-radial DEA model consider the input excesses and the output shortfalls using slack variables.⁶¹ The input and output-oriented SBM models are introduced as Models (3) and (4), respectively:

$$\text{Min } \theta = 1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i}{x_{ik}} \quad (3)$$

$$\text{s.t. } \sum_{j=1}^n \theta_j x_{ij} + s_i = x_{ik}, \quad i = 1, \dots, m$$

$$\sum_{j=1}^n \theta_j y_{rj} \geq y_{rk}, \quad r = 1, \dots, s$$

$$\sum_{j=1}^n \theta_j = 1$$

$$s_i \geq 0, \quad i = 1, \dots, m$$

$$\theta_j \geq 0, \quad j = 1, \dots, n$$

$$\text{Max } \theta = 1 + \frac{1}{s} \sum_{r=1}^s \frac{t_r}{y_{rk}} \quad (4)$$

$$\text{s.t. } \sum_{j=1}^n \theta_j x_{ij} \leq x_{ik}, \quad i = 1, \dots, m$$

$$\sum_{j=1}^n \theta_j y_{rj} - t_r = y_{rk}, \quad r = 1, \dots, s$$

$$\sum_{j=1}^n \theta_j = 1$$

$$t_r \geq 0, \quad r = 1, \dots, s$$

$$\theta_j \geq 0, \quad j = 1, \dots, n$$

It should be noted that the s_i and the t_r , respectively, represent the amount of i^{th} input surplus and r^{th} output shortages. Also, the efficiency of DMU under evaluation based on output-oriented SBM model that presented in Model (4), is calculated by $1/\theta^*$.

3. Estimating Most Productive Scale Size (MPSS)

The type of returns to scale for each DMUs under VRS production possibility set (PPS) is a very important issue.⁶² Because, the type of RTS presents the direction of rescaling needed for improving the efficiency.

If the RTS of DMU is an increasing returns to scale (IRS), the expansion of the DMU under investigation will be suggested. And if the RTS of DMU is a decreasing returns to scale (DRS), contraction of DMU will be suggested. Finally, if the RTS of DMU is CRS, it is believed that the DMU under investigation operates as the most productive scale size (MPSS). The concept of MPSS has been introduced by Banker⁶³ for the first time. Cooper et al.⁶⁴ presented Model (5) for estimating MPSS:

$$\begin{aligned}
 & \text{Max } \Delta = \frac{\Phi}{\Theta} \tag{5} \\
 & \text{s.t. } \sum_{j=1}^n \lambda_j x_{ij} - \Theta x_{ik} \leq 0, \quad i = 1, \dots, m \\
 & \quad \sum_{j=1}^n \lambda_j y_{rj} - \Phi y_{rk} \geq 0, \quad r = 1, \dots, s \\
 & \quad \sum_{j=1}^n \lambda_j = 1 \\
 & \quad \Theta, \Phi \geq 0 \\
 & \quad \lambda_j \geq 0, \quad j = 1, \dots, n
 \end{aligned}$$

It should be stated that the DMU under evaluation is the MPSS, if and only if in the fractional objective function $\Delta^* = 1$.⁶⁵

4. Real Case Studies and Numerical Results

In this section, the implementation of DEA approach using real-world data at macro level (hospitals) and micro level (departments of hospital) from Iranian health care system are presented. Based on literature review⁶⁶, and expert opinions, inputs and outputs of DEA approach are selected. The input variables include the number of staff (doctors, nurses, and ancillary personnels), the number of beds, location & infrastructures, and equipment & facilities. Also, the output variables include number of patients and number of surgeries.

4.1. The Macro Level: Hospital

As previously discussed, the goal at macro level is to assess the performance of hospitals. To reach this goal, 15 Iranian hospitals are selected and data from these hospitals are gathered. Summary of real-world data for inputs and outputs variables of these hospitals are presented in Table 2.

Table 2: Data Set for 15 Hospitals in Iran

| Hospital Code | Inputs | | | | Outputs | |
|---------------|-----------------|----------------|-------------------------------------|---------------------------------|--------------------|---------------------|
| | Number of Staff | Number of Beds | Score of Location & Infrastructures | Score of Equipment & Facilities | Number of Patients | Number of Surgeries |
| H01 | 356 | 120 | 72 | 56 | 58734 | 1867 |
| H02 | 878 | 452 | 94 | 92 | 420434 | 19321 |
| H03 | 333 | 141 | 66 | 60 | 76489 | 3218 |
| H04 | 399 | 285 | 68 | 75 | 146468 | 3080 |
| H05 | 362 | 122 | 62 | 58 | 142352 | 555 |
| H06 | 186 | 76 | 45 | 52 | 48854 | 1800 |
| H07 | 315 | 125 | 59 | 47 | 78278 | 4223 |
| H08 | 175 | 94 | 35 | 53 | 97932 | 1155 |
| H09 | 223 | 89 | 66 | 47 | 108205 | 1752 |
| H10 | 76 | 20 | 35 | 24 | 60628 | 85 |
| H11 | 100 | 24 | 45 | 34 | 78954 | 432 |
| H12 | 212 | 78 | 46 | 39 | 96451 | 2185 |
| H13 | 95 | 30 | 33 | 35 | 46196 | 630 |
| H14 | 320 | 175 | 58 | 78 | 136582 | 5837 |
| H15 | 107 | 73 | 43 | 37 | 85139 | 2062 |

Then, after collecting data, the radial and non-radial models under input and output orientation are run and MPSS and RTS for each hospital are estimated. The results of performance appraisal of hospitals are illustrated in Table 3.

Table 3: The Results of Hospitals Evaluation

| Hospital Code | MPSS | | | RTS | | | Radial | | Non-Radial | |
|---------------|------------|-----|----|-----|-----|-----|------------|----------------------|------------|----------------------|
| | Δ^* | Yes | No | DRS | CRS | IRS | θ^* | $\frac{1}{\theta^*}$ | θ^* | $\frac{1}{\theta^*}$ |
| H01 | 2.54 | | ● | | | ● | 0.56 | 0.40 | 0.51 | 0.39 |
| H02 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| H03 | 1.84 | | ● | | | ● | 0.65 | 0.57 | 0.63 | 0.50 |
| H04 | 1.49 | | ● | | | ● | 0.68 | 0.69 | 0.59 | 0.47 |
| H05 | 1.16 | | ● | | ● | | 0.86 | 0.91 | 0.79 | 0.21 |
| H06 | 1.73 | | ● | | | ● | 0.82 | 0.67 | 0.76 | 0.54 |
| H07 | 1.27 | | ● | | ● | | 0.89 | 0.87 | 0.83 | 0.63 |
| H08 | 1.03 | | ● | | | ● | 1.00 | 1.00 | 1.00 | 1.00 |
| H09 | 1.32 | | ● | | ● | | 0.78 | 0.83 | 0.75 | 0.65 |
| H10 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| H11 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| H12 | 1.19 | | ● | | | ● | 0.88 | 0.85 | 0.83 | 0.82 |
| H13 | 1.41 | | ● | | | ● | 1.00 | 1.00 | 1.00 | 1.00 |
| H14 | 1.19 | | ● | | | ● | 0.91 | 0.86 | 0.83 | 0.81 |
| H15 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |

As seen in Table 3, 4 hospitals including H02, H10, H11, and H15 are the MPSS. In addition to these hospitals, H08 and H13 are also efficient. Finally, by applying input and output-oriented SBM models, input-excess, output-shortfall, and reference-set for 9 inefficient hospitals are proposed in Table 4:

Table 4: The Benchmarking for Hospitals

| Hospital Code | Input-Oriented | | | | Reference-Set | Output-Oriented | | Reference-Set |
|---------------|----------------|--------|-------|-------|---------------|------------------|---------|---------------|
| | Input-Excess | | | | | Output-Shortfall | | |
| | s_1 | s_2 | s_3 | s_4 | | t_1 | t_2 | |
| H01 | 205.70 | 59.98 | 31.53 | 25.70 | H02, H10 | 96813.64 | 2801.79 | H02, H11 |
| H02 | 0.00 | 0.00 | 0.00 | 0.00 | H02 | 0.00 | 0.00 | H02 |
| H03 | 126.38 | 50.64 | 21.39 | 24.92 | H02, H10 | 95813.50 | 2377.58 | H02, H11 |
| H04 | 131.66 | 161.94 | 18.92 | 34.78 | H02, H10 | 65656.91 | 5518.48 | H02, H15 |
| H05 | 103.84 | 3.88 | 13.60 | 18.55 | H02, H10 | 14791.35 | 4202.05 | H02, H11 |
| H06 | 83.11 | 10.02 | 3.06 | 16.72 | H10, H15 | 62145.78 | 820.57 | H02, H10, H11 |
| H07 | 66.48 | 12.07 | 11.31 | 8.37 | H02, H10 | 80159.69 | 654.07 | H02, H10, H11 |
| H08 | 0.00 | 0.00 | 0.00 | 0.00 | H08 | 0.00 | 0.00 | H08 |
| H09 | 56.36 | 28.34 | 16.80 | 8.03 | H02, H11 | 22609.28 | 1548.66 | H02, H11 |
| H10 | 0.00 | 0.00 | 0.00 | 0.00 | H10 | 0.00 | 0.00 | H10 |
| H11 | 0.00 | 0.00 | 0.00 | 0.00 | H11 | 0.00 | 0.00 | H11 |
| H12 | 48.45 | 10.84 | 4.56 | 7.58 | H02, H10 | 17367.40 | 537.61 | H02, H10, H11 |
| H13 | 0.00 | 0.00 | 0.00 | 0.00 | H13 | 0.00 | 0.00 | H13 |
| H14 | 44.36 | 19.10 | 3.84 | 28.97 | H02, H15 | 41000.70 | 905.60 | H02, H11, H15 |
| H15 | 0.00 | 0.00 | 0.00 | 0.00 | H15 | 0.00 | 0.00 | H15 |

It is worth mentioning that the type of input and output variables is integer and the values that presented in Table 4, should be approximated to the nearest integer value.

4.2. The Micro Level: Hospital Departments

In this subsection, the performance of hospital departments as a micro level is evaluated. For this purpose, 15 departments of hospitals including intensive care unit (ICU), intensive care unit-open heart (ICU-OH), neonatal intensive care unit (NICU), coronary care unit (CCU), post coronary care unit (Post CCU), very important person (VIP), kidney transplant, head and neck surgery, neurology and physical medicine, internal, orthopedics and urology, general surgery, heart, pregnancy and maternity, and pediatric, are considered.

Then, data from these departments were gathered and the summary of real-world data are introduced in Table 5:

Table 5: Data Set for 15 Departments of a Hospital in Iran

| Department Code | Inputs | | | | Output : | |
|-----------------|-----------------|----------------|-------------------------------------|---------------------------------|--------------------|---------------------|
| | Number of Staff | Number of Beds | Score of Location & Infrastructures | Score of Equipment & Facilities | Number of Patients | Number of Surgeries |
| D01 | 31 | 26 | 82 | 63 | 2128 | 207 |
| D02 | 21 | 11 | 67 | 48 | 656 | 138 |
| D03 | 19 | 18 | 58 | 52 | 1024 | 12 |
| D04 | 22 | 26 | 67 | 69 | 2714 | 472 |
| D05 | 11 | 12 | 48 | 58 | 771 | 161 |
| D06 | 14 | 29 | 63 | 39 | 1208 | 725 |
| D07 | 15 | 27 | 64 | 48 | 725 | 518 |
| D08 | 25 | 50 | 88 | 93 | 4313 | 3255 |
| D09 | 30 | 38 | 70 | 59 | 1955 | 46 |
| D10 | 25 | 34 | 64 | 73 | 1771 | 92 |
| D11 | 54 | 78 | 88 | 96 | 5486 | 2921 |
| D12 | 30 | 62 | 84 | 47 | 4669 | 1967 |
| D13 | 37 | 60 | 93 | 94 | 4439 | 1794 |
| D14 | 15 | 16 | 34 | 29 | 2887 | 92 |
| D15 | 18 | 18 | 39 | 59 | 1116 | 115 |

Now, by employing the DEA models that were proposed in Models (1) to (4), the efficiency score for each department are calculated. Additionally, type of RTS for each department as well as MPSS are estimated. The results of performance assessment of hospitals are shown in Table 6:

Table 6: The Results of Evaluating the Hospital Departments

| Department Code | MPSS | | | RTS | | | Radial | | Non-Radial | |
|-----------------|------------|-----|----|-----|-----|-----|------------|----------------------|------------|----------------------|
| | Δ^* | Yes | No | DRS | CRS | IRS | θ^* | $\frac{1}{\theta^*}$ | θ^* | $\frac{1}{\theta^*}$ |
| D01 | 2.01 | | ● | | | ● | 0.59 | 0.65 | 0.52 | 0.27 |
| D02 | 2.38 | | ● | | | ● | 1.00 | 1.00 | 1.00 | 1.00 |
| D03 | 3.17 | | ● | | | ● | 0.78 | 0.34 | 0.71 | 0.04 |
| D04 | 1.42 | | ● | | | ● | 0.74 | 0.82 | 0.66 | 0.57 |
| D05 | 2.22 | | ● | | | ● | 1.00 | 1.00 | 1.00 | 1.00 |
| D06 | 1.93 | | ● | | | ● | 1.00 | 1.00 | 1.00 | 1.00 |
| D07 | 3.23 | | ● | | | ● | 0.89 | 0.60 | 0.85 | 0.46 |
| D08 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| D09 | 2.95 | | ● | | | ● | 0.50 | 0.51 | 0.47 | 0.05 |
| D10 | 2.71 | | ● | | | ● | 0.57 | 0.49 | 0.50 | 0.09 |
| D11 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| D12 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| D13 | 1.32 | | ● | | ● | | 0.88 | 0.93 | 0.76 | 0.71 |
| D14 | 1.00 | ● | | | ● | | 1.00 | 1.00 | 1.00 | 1.00 |
| D15 | 2.63 | | ● | | | ● | 0.89 | 0.39 | 0.78 | 0.38 |

According to Table 6, 4 departments including D08, D10, D11, and D14 are the MPSS. In addition to these departments, D02, D05, and D06 are also efficient. Like the previous subsection, using input and output-oriented SBM models, input-excess, output-shortfall, and reference-set for 8 inefficient departments are measured. The results of benchmarking for inefficient departments are shown in Table 7:

Table 7: The Benchmarking for a Hospital Departments

| Department Code | Input-Oriented | | | | Reference-Set | Output-Oriented | | Reference-Set |
|-----------------|----------------|-------|-------|-------|---------------|------------------|---------|---------------|
| | Input-Excess | | | | | Output-Shortfall | | |
| | s_1 | s_2 | s_3 | s_4 | | t_1 | t_2 | |
| D01 | 15.64 | 8.76 | 46.04 | 31.67 | D08, D14 | 98.71 | 1088.33 | D02, D08, D14 |
| D02 | 0.00 | 0.00 | 0.00 | 0.00 | D02 | 0.00 | 0.00 | D02 |
| D03 | 4.00 | 2.00 | 24.00 | 23.00 | D14 | 717.35 | 565.97 | D02, D05, D08 |
| D04 | 5.80 | 5.92 | 26.51 | 32.31 | D08, D14 | 0.00 | 700.10 | D02, D08, D14 |
| D05 | 0.00 | 0.00 | 0.00 | 0.00 | D05 | 0.00 | 0.00 | D05 |
| D06 | 0.00 | 0.00 | 0.00 | 0.00 | D06 | 0.00 | 0.00 | D06 |
| D07 | 0.00 | 7.93 | 18.63 | 1.57 | D05, D08, D14 | 1624.15 | 38.28 | D05, D08, D14 |
| D08 | 0.00 | 0.00 | 0.00 | 0.00 | D08 | 0.00 | 0.00 | D08 |
| D09 | 15.00 | 22.00 | 36.00 | 30.00 | D14 | 1830.20 | 1692.61 | D08, D12, D14 |
| D10 | 10.00 | 18.00 | 30.00 | 44.00 | D14 | 1735.80 | 1705.13 | D05, D08, D14 |
| D11 | 0.00 | 0.00 | 0.00 | 0.00 | D11 | 0.00 | 0.00 | D11 |
| D12 | 0.00 | 0.00 | 0.00 | 0.00 | D12 | 0.00 | 0.00 | D12 |
| D13 | 9.02 | 4.05 | 14.87 | 47.26 | D08, D12, D14 | 292.71 | 1339.98 | D08, D11, D12 |
| D14 | 0.00 | 0.00 | 0.00 | 0.00 | D14 | 0.00 | 0.00 | D14 |
| D15 | 2.93 | 1.75 | 4.61 | 29.53 | D08, D14 | 1680.33 | 202.58 | D05, D08, D14 |

As seen in Table 7, the results introduce a functional pattern for managers in health care systems to better planning for capacity development and resource saving. Since in most cases, it is easier for hospital managers to reduce inputs such as the number of staff than to increase outputs such as the number of patients. Consequently, the input-oriented model is recommended.

5. Managerial Insights, Conclusions, and Future Research Directions

Performance appraisal of hospitals is one of the major concerns of managers. The reason for this is the identification of hospitals with a desirable performance as a benchmark for inefficient hospitals. Undoubtedly, DEA is one of the most powerful approaches that can be applied to performance assessment, ranking and benchmarking in health care. In this research, the radial and non-radial DEA models including BCC and SBM are implemented for a real case study in Iran to assess the performance of hospitals and their departments. Also, the most productive scale size and returns to scale are estimated for hospitals and their departments. Finally, input-excess, output-shortfall, and reference-set for each of inefficient DMUs are proposed. For the future studies, hybrid and novel multiple criteria decision making (MCDM) approaches can be employed for performance appraisal of hospitals.⁶⁷⁻⁶⁹ Also, in cases where the number of hospitals is considerable, clustering or grouping approach can be applied to categorize hospitals in different groups so that in each group, there are at least one benchmark hospital and other related hospitals. Moreover, uncertain DEA models such as fuzzy DEA, stochastic DEA, and robust DEA can be applied for performance measurement of hospitals in the presence of data uncertainty and ambiguity.⁷⁰⁻⁷⁴

Abbreviations

DEA: data envelopment analysis, **DMU:** decision making unit, **MPSS:** most productive scale size, **SBM:** slack based measure, **RTS:** returns to scale, **CRS:** constant returns to scale, **VRS:** variable returns to scale, **IRS:** increasing returns to scale, **DRS:** decreasing returns to scale, **GDP:** gross domestic product, **ICU:** intensive care unit, **ICU-OH:** intensive care unit-open heart, **NICU:** neonatal intensive care unit, **CCU:** coronary care unit, **Post CCU:** post coronary care unit, **VIP:** very important person, **MPI:** Malmquist productivity index, **PPS:** production possibility set. **CCR:** Charnes Cooper Rhodes, **BCC:** Banker Charnes Cooper, **WDEA:** window data envelopment analysis, **SEDEA:** super efficiency data envelopment analysis, **CEDEA:** cross

efficiency data envelopment analysis, **CSWDEA**: common set of weights data envelopment analysis, **MGDEA**: multi group data envelopment analysis, **CDDEA**: context dependent data envelopment analysis, **CGDEA**: cooperative game data envelopment analysis, **CCDEA**: chance constrained data envelopment analysis, **FDEA**: fuzzy data envelopment analysis, **RDEA**: robust data envelopment analysis, **BIRDEA**: bootstrap interval robust data envelopment analysis, **MCDM**: multiple criteria decision making.

Competing Interests

The authors declare no competing interests.

Authors' Contributions

Pejman Peykani: Investigation, Conceptualization, Methodology, Literature Review, Data Curation, Software, Validation, Writing - Original Draft. **Emran Mohammadi**: Supervision, Formal Analysis, Investigation, Methodology, Validation, Writing - Review & Editing. **Fatemeh Sadat Seyed Esmaeili**: Investigation, Methodology, Literature Review, Writing - Review & Editing.

References

1. Aldalbahi AG, Juni MH, Rosliza AM, Ying LP, Ibrahim F. Methodological approach and theoretical concept for measuring hospital technical efficiency. *International Journal of Public Health and Clinical Sciences*. 2019;6(1):237-49.
2. Kohl S, Schoenfelder J, Fügener A, Brunner JO. The use of data envelopment analysis (DEA) in healthcare with a focus on hospitals. *Health Care Management Science*. 2019;22(2):245-86.
3. Peykani P, Mohammadi E, Emrouznejad A, Pishvae MS, Rostamy-Malkhalifeh M. Fuzzy Data Envelopment Analysis: An Adjustable Approach. *Expert Systems with Applications*. 2019;136:439-452.
4. Peykani P, Mohammadi E. Interval network data envelopment analysis model for classification of investment companies in the presence of uncertain data. *Journal of Industrial and Systems Engineering*. 2018;11(Special issue: 14th International Industrial Engineering Conference):63-72.

5. Peykani P, Mohammadi E. Window network data envelopment analysis: an application to investment companies. *International Journal of Industrial Mathematics*. 2019.
6. Peykani P, Mohammadi E, Seyed Esmaeili FS. Stock evaluation under mixed uncertainties using robust DEA model. *Journal of Quality Engineering and Production Optimization*. 2019.
7. Peykani P, Mohammadi E, Jabbarzadeh A, Jandaghian A. Utilizing robust data envelopment analysis model for measuring efficiency of stock, a case study: Tehran Stock Exchange. *Journal of New Research in Mathematics*. 2016;1(4):15-24.
8. Peykani P, Mohammadi E, Pishvae MS, Rostamy-Malkhalifeh M, Jabbarzadeh A. A novel fuzzy data envelopment analysis based on robust possibilistic programming: possibility, necessity and credibility-based approaches. *RAIRO-Operations Research*. 2018;52(4):1445-63.
9. Peykani P, Mohammadi E, Rostamy-Malkhalifeh M, Hosseinzadeh Lotfi F. Fuzzy data envelopment analysis approach for ranking of stocks with an application to Tehran stock exchange. *Advances in Mathematical Finance and Applications*. 2019;4(1):31-43.
10. Farrell MJ. The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*. 1957;120(3):253-290.
11. Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. *European Journal of Operational Research*. 1978;2(6):429-44.
12. Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*. 1984;30(9):1078-92.
13. Emrouznejad A, Yang GL. A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. *Socio-Economic Planning Sciences*. 2018;61:4-8.
14. Bahadori M, Izadi AR, Ghardashi F, Ravangard R, Hosseini SM. The evaluation of hospital performance in Iran: a systematic review article. *Iranian Journal of Public Health*. 2016;45(7):855.
15. Mahdian S, Dehghani A, Tafti AD, Pakdaman M, Askari R. Hospitals' efficiency in Iran: A systematic review and meta-analysis. *Journal of Education and Health Promotion*. 2019;8(1):126.
16. Rezaei S, Hajizadeh M, Nouri B, Ahmadi S, Rezaeian S, Salimi Y, Karyani AK. Iranian hospital efficiency: a systematic review and meta-analysis. *International Journal of Health Care Quality Assurance*. 2019;32(2):385-97.

17. Hajialiafzali H, Moss JR, Mahmood MA. Efficiency measurement for hospitals owned by the Iranian social security organisation. *Journal of Medical Systems*. 2007;31(3):166-72.
18. Hatam N. The role of data envelopment analysis (DEA) pattern in the efficiency of social security hospitals in Iran. *Iranian Red Crescent Medical Journal*. 2008;10(3):208.
19. Hatam N, Moslehi S, Askarian M, Shokrpour N, Keshtkaran A, Abbasi M. The efficiency of general public hospitals in Fars Province, Southern Iran. *Iranian Red Crescent Medical Journal*. 2010;12(2):138.
20. Jandaghi G, Matin HZ, Doremami M, Aghaziyarati M. Efficiency evaluation of Qom public and private hospitals using data envelopment analysis. *European Journal of Economics, Finance and Administrative Sciences*. 2010;22(2):83-91.
21. Ketabi S. Efficiency measurement of cardiac care units of Isfahan hospitals in Iran. *Journal of Medical Systems*. 2011;35(2):143-50.
22. Shahhoseini R, Tofighi S, Jaafaripooyan E, Safiaryan R. Efficiency measurement in developing countries: application of data envelopment analysis for Iranian hospitals. *Health Services Management Research*. 2011;24(2):75-80.
23. Ebrahimnejad A. Cost efficiency measures with trapezoidal fuzzy numbers in data envelopment analysis based on ranking functions: application in insurance organization and hospital. *International Journal of Fuzzy System Applications*. 2012;2(3):51-68.
24. Ghotbuee A, Hemati M, Fateminezhad R. An empirical study based on BSC-DEA to measure the relative efficiencies of different health care centers in province of Semnan, Iran. *Management Science Letters*. 2012;2(7):2643-50.
25. Khani F, Naderi H, Zangeneh M, Fazeli E. Measuring the relative efficiency of Ilam hospitals using data envelopment analysis. *Management Science Letters*. 2012;2(4):1189-94.
26. Marnani AB, Sadeghifar J, Pourmohammadi K, Mostafaie D, Abolhalaj M, Bastani P. Performance assessment indicators: how DEA and Pabon Lasso describe Iranian hospitals' performance. *Health Med*. 2012;6(3):791-6.
27. Sheikhzadeh Y, Roudsari AV, Vahidi RG, Emrouznejad A, Dastgiri S. Public and private hospital services reform using data envelopment analysis to measure technical, scale, allocative, and cost efficiencies. *Health Promotion Perspectives*. 2012;2(1):28.
28. Yusefzadeh H, Ghaderi H, Bagherzade R, Barouni M. The efficiency and budgeting of public hospitals: Case study of Iran. *Iranian Red Crescent Medical Journal*. 2013;15(5):393.

29. Kalantary Z, Azar A. A robust data envelopment analysis model for ranking: A case of hospitals of Tehran. *Data Envelopment Analysis and Performance Measurement*. 2014;Proceedings of the 11th International Conference of DEA:21-28.
30. Lotfi F, Kalhor R, Bastani P, Zadeh NS, Eslamian M, Dehghani MR, Kiaee MZ. Various indicators for the assessment of hospitals' performance status: differences and similarities. *Iranian Red Crescent Medical Journal*. 2014;16(4).
31. Mehrtak M, Yusefzadeh H, Jaafari-pooyan E. Pabon Lasso and Data Envelopment Analysis: a complementary approach to hospital performance measurement. *Global Journal of Health Science*. 2014;6(4):107.
32. Torabipour A, Najarzadeh M, Mohammad AR, Farzianpour F, Ghasemzadeh R. Hospitals productivity measurement using data envelopment analysis technique. *Iranian Journal of Public Health*. 2014;43(11):1576.
33. Haji-Sami E, Ebrahimi Khameneh M, Rezaeisaray M, Esmaeili S. Robust DEA under discrete uncertain data: An application for Iranian hospital emergency. *8th International Conference of Iranian Operations Research Society, Iran*. 2015.
34. Jahangoshai Rezaee M, Karimdad A. Do geographical locations affect in hospitals performance? A multi-group data envelopment analysis. *Journal of Medical Systems*. 2015;39(9):85.
35. Kheirollahi H, Matin BK, Mahboubi M, Alavijeh MM. Chance constrained input relaxation to congestion in stochastic DEA. An application to Iranian hospitals. *Global Journal of Health Science*. 2015;7(4):151.
36. Rezapour A, Azar FE, Zadeh NY, Roumiani Y, Faradonbeh SB. Technical efficiency and resources allocation in university hospitals in Tehran, 2009-2012. *Medical journal of the Islamic Republic of Iran*. 2015;29:266.
37. Kakeman E, Forushani AR, Dargahi H. Technical efficiency of hospitals in Tehran, Iran. *Iranian Journal of Public Health*. 2016;45(4):494.
38. Kalhor R, Amini S, Sokhanvar M, Lotfi F, Sharifi M, Kakemam E. Factors affecting the technical efficiency of general hospitals in Iran: data envelopment analysis. *Journal of the Egyptian Public Health Association*. 2016;91(1):20-5.

39. Nabilou B, Yusefzadeh H, Rezapour A, Azar FE, Safi PS, Asiabar AS, Ahmadzadeh N. The productivity and its barriers in public hospitals: case study of Iran. *Medical journal of the Islamic Republic of Iran*. 2016;30:316.
40. Rabbani M, Heidari N, Farrokhi Asl H. A bootstrap interval robust data envelopment analysis for estimate efficiency and ranking hospitals. *Journal of Industrial Engineering and Management Studies*. 2016;3(2):107-22.
41. Rezaei S, Dopeykar N, Barouni M, Jafari M, Gharibi F. Do Hospitals Affiliated With the Kurdistan University of Medical Sciences Perform Efficiently? Non-parametric Data Envelopment Analysis. *Hospital Practices and Research*. 2016;1(4):135-40.
42. Abadi NY, Noori S, Haeri A. The use of resource allocation approach for hospitals based on the initial efficiency by using data envelopment analysis. *Journal of Health Management and Informatics*. 2017;4(4):101-6.
43. Ameryoun A, Najafi S, Nejati-Zarnaqi B, Khalilifar SO, Ajam M, Ansarimoghadam A. Factor selection for service quality evaluation: a hospital case study. *International Journal of Health Care Quality Assurance*. 2017;30(1):58-66.
44. Farzianpour F, Emami AH, Foroushani AR, Ghiasi A. Determining the technical efficiency of hospitals in tabriz city using data envelopment analysis for 2013-2014. *Global Journal of Health Science*. 2016;9(5):42.
45. Kakemam E, Dargahi H, Rahimi Foroushani A. Association between managers' competency and technical efficiency in general hospitals in Iran. *Journal of Patient Safety & Quality Improvement*. 2017;5(3):567-71.
46. Kheirollahi H, Hessari P, Charles V, Chawshini R. An input relaxation model for evaluating congestion in fuzzy DEA. *Croatian Operational Research Review*. 2017;8(2):391-408.
47. Mirmozaffari M, Alinezhad A. Ranking of heart hospitals using cross-efficiency and two-stage DEA. *7th International Conference on Computer and Knowledge Engineering*. 2017;217-222.
48. Mirmozaffari M, Alinezhad A. Window analysis using two-stage DEA in heart hospitals. *International Conference on Innovation in Science, Engineering Computer and Technology, UAE*. 2017.
49. Raei B, Yousefi M, Rahmani K, Afshari S, Ameri H. Patterns of productivity changes in hospitals by using Malmquist-DEA Index: a panel data analysis (2011-2016). *Australasian Medical Journal*. 2017;10(10):856-64.

50. Shafaghat T, Hatam N, Rahimi Zarchi MK, Kavosi Z, Bayati M. Efficiency determination of hospitals of Shiraz university of medical sciences using simple and super efficiency DEA Models. *International Journal of Hospital Research*. 2017;6(3):55-68.
51. Alinezhad A, Mirmozaffari M. Malmquist productivity index using two-stage DEA model in heart hospitals. *Iranian Journal of Optimization*. 2018;10(2):81-92.
52. Bahrami MA, Rafiei S, Abedi M, Askari R. Data envelopment analysis for estimating efficiency of intensive care units: a case study in Iran. *International Journal of Health Care Quality Assurance*. 2018;31(4):276-82.
53. Hadipour H, Kavooosi-Kalashami M, Salari A, Motamed MK. How efficient rural healthcare centres work in Iran?. *International Journal of Collaborative Research on Internal Medicine & Public Health*. 2018;10(1):747-59.
54. Jahangoshai Rezaee M, Yousefi S, Hayati J. A decision system using fuzzy cognitive map and multi-group data envelopment analysis to estimate hospitals' outputs level. *Neural Computing and Applications*. 2018;29(3):761-77.
55. Ketabi S, Teymouri E, Ketabi M. Efficiency measurement of emergency departments in Isfahan, Iran. *International Journal of Process Management and Benchmarking*. 2018;8(2):142-55.
56. Kiani MM, Mosavi Rigi SA, Karami H, Sepaseh F, Naghdi B, Shiravani M. Efficiency evaluation of university hospitals in Bushehr province before and after the implementation of the health system development plan. *Evidence Based Health Policy, Management and Economics*. 2018;2(1):1-1.
57. Omrani H, Shafaat K, Emrouznejad A. An integrated fuzzy clustering cooperative game data envelopment analysis model with application in hospital efficiency. *Expert Systems with Applications*. 2018;114:615-28.
58. Pirani N, Zahiri M, Engali KA, Torabipour A. Hospital efficiency measurement before and after health sector evolution plan in southwest of Iran: a DEA-Panel Data Study. *Acta Informatica Medica*. 2018;26(2):106.
59. Hatefi SM, Haeri A. Evaluating hospital performance using an integrated balanced scorecard and fuzzy data envelopment analysis. *Journal of Health Management and Informatics*. 2019;6(2):66-76.

60. Jahangoshai Rezaee M, Karimdadi A, Izadbakhsh H. Road map for progress and attractiveness of Iranian hospitals by integrating self-organizing map and context-dependent DEA. *Health Care Management Science*. 2019;1-27.
61. Tone K. A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*. 2001;130(3):498-509.
62. Banker RD, Thrall RM. Estimation of returns to scale using data envelopment analysis. *European Journal of Operational Research*. 1992;62(1):74-84.
63. Banker RD. Estimating most productive scale size using data envelopment analysis. *European Journal of Operational Research*. 1984;17(1):35-44.
64. Cooper WW, Thompson RG, Thrall RM. Extensions and new developments in DEA. *Annals of Operations Research*. 1996;66(1):1-45.
65. Jahanshahloo GR, Khodabakhshi M. Using input–output orientation model for determining most productive scale size in DEA. *Applied Mathematics and Computation*. 2003;146(2-3):849-55.
66. Azreena E, Juni MH, Rosliza AM. A systematic review of hospital inputs and outputs in measuring technical efficiency using data envelopment analysis. *International Journal of Public Health and Clinical Sciences*. 2018;5(1):17-35.
67. Torkzad A, Beheshtinia MA. Evaluating and prioritizing hospital service quality. *International Journal of Health Care Quality Assurance*. 2019;32(2):332-46.
68. Sedady F, Beheshtinia MA. A novel MCDM model for prioritizing the renewable power plants' construction. *Management of Environmental Quality: An International Journal*. 2019;30(2):383-99.
69. Beheshtinia MA, Omidi S. A hybrid MCDM approach for performance evaluation in the banking industry. *Kybernetes*. 2017;46(8):1386-407.
70. Cheraghi S, Hosseini-Motlagh SM, Ghatreh Samani M. Integrated planning for blood platelet production: a robust optimization approach. *Journal of Industrial and Systems Engineering*. 2017;10(special issue on healthcare):55-80.
71. Ghatreh Samani MR, Hosseini-Motlagh SM, Ghannadpour SF. A multilateral perspective towards blood network design in an uncertain environment: Methodology and implementation. *Computers & Industrial Engineering*. 2019;130:450-71.

72. Ghatreh Samani M, Hosseini-Motlagh SM. A hybrid algorithm for a two-echelon location-routing problem with simultaneous pickup and delivery under fuzzy demand. *International Journal of Transportation Engineering*. 2017;5(1):59-85.
73. Hosseini-Motlagh SM, Ghatreh Samani MR, Cheraghi S. Robust and stable flexible blood supply chain network design under motivational initiatives. *Socio-Economic Planning Sciences*. 2019.
74. Hosseini-Motlagh SM, Ghatreh Samani MR, Homaei S. Blood supply chain management: robust optimization, disruption risk, and blood group compatibility (a real-life case). *Journal of Ambient Intelligence and Humanized Computing*. 2019:1-20.