Improving emergency departments during COVID-19 pandemic: a simulation and MCDM approach with MARCOS methodology in an uncertain environment

Ali Memarpour Ghiaci · Harish Garg · Saeid Jafarzadeh Ghoushchi

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Abstract

The coronavirus disease (COVID-19) pandemic forced healthcare systems to quickly modify to swapping healthcare essentials. The emergency department (ED) decision-making condition is complex and particularly unstable order for care in a stated period conducts decision-makers to attempt to alter assets to touch the demand. ED managers are generally enforced to discover strategies and improving scenarios for decreasing transfer of patients. For this end, the proposed framework of this study is first developed to integrate the simulation model of the flow process of the COVID-19 patients with the Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) methodology in Spherical fuzzy context to assess and prioritize scenarios based on desired performance measures. As a contribution, the proposed framework determined the importance of the performance measures based on Spherical fuzzy sets. The proposed SF-MARCOS approach takes the performance measures weights from the expert’s team based on spherical fuzzy theory and the performance measures values from the simulation model, and rank the improving scenarios. Finally, a real-life study in a private hospital in Tehran, Iran, illustrates the effectiveness and feasibility of the proposed framework. The analysis of the results shows that the patients’ transfer rate can be reduced by applying new strategies with sensible expenditure.

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✉ Harish Garg
harishg58ittr@gmail.com

Ali Memarpour Ghiaci
ali.memarpour@mut.ac.ir

Saeid Jafarzadeh Ghoushchi
s.jafarzadeh@uut.ac.ir

1 Industrial Engineering Department, Malek Ashtar University of Technology, Tehran 15875-1774, Iran
2 School of Mathematics, Thapar Institute of Engineering and Technology (Deemed University), Patiala, Punjab 147004, India
3 Department of Mathematics, Graphics Era Deemed to be University, Dehradun, Uttarakhand, India
4 Faculty of Industrial Engineering, Urmia University of Technology, Urmia, Iran

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1 Introduction

The appearance of COVID-19 as a universal health threat in early 2020 unexpectedly inter-changed both health essentials and the health services. As of first half of March 2022, over 450 million cases of confirmed coronavirus disease of 2019 (COVID-19) have been reported globally. According to Fig. 1, almost 7 million of these cases have been Iranian (WHO 2022). The high virulence profile of coronavirus conducted to a plurality of emergency departments (EDs) visits in a short period of time. Simulation models allow us to assess various performance measured (e.g., patient waiting time, length of stay, utilization of doctors, nurses and facilities, treatment unit occupancy, etc.) for an ED (Hamza et al. 2021; Oh et al. 2016).

Various ED simulation models have been suggested to uninterrupted enhance ED services, optimize ED resources use, minimize transfer rate of patients, and ultimately certify patient contentment (Ahsan et al. 2019; Wang et al. 2012; Zeinali et al. 2015). The issue of patient transfer in COVID-19 pandemic relates to lack of the resources in ED. Waiting time mentions to the entire time that a patient waited in advance being in the service of the ED (Hamza et al. 2021; Yarmohammadian et al. 2017; Zhao et al. 2015). However, decision-making in EDs is particularly sensitive because of its effect on the quality of treat given and the count of rejected patients that leave ED without being treated (Uriarte et al. 2017). To determine the trade-offs or conflicts between performance measures of simulation model, MCDM methods are needed (Abo-Hamad and Arisha 2013; Gul et al. 2016). MCDM methods have been applied in various fields to solve selection and prioritizing problems, such as logistics (Mešić et al. 2022), healthcare (Vojinović et al. 2022), risk management (Ghoushchi et al. 2021a, b, c; Ghoushchi et al. 2019), renewable energy (Ghoushchi et al. 2022; Goswami et al. 2022) and information technology (Chen and Lin 2022). Integrated simulation and MCDM-based studies are especially utilized to assess alternatives that have been created from the performance measures of a simulation model. Hamza et al. (2021) proposed a novel simulation model of the flow of patient to improve the performance of the ED.
Gündoğdu and Kahraman (2020) introduced the Spherical Fuzzy Set (SFS). SFS is an extension of the Pythagorean fuzzy set (PFS), Intuitionistic fuzzy sets (IFS), and Neutrosophic Sets (NS), especially to manage the uncertainty throughout the quantification of expert. IFS is a two-dimensional that defines both membership and non-membership degrees. In IFS, the addition of membership, non-membership, and hesitancy degree is 1; therefore, the hesitancy degree is calculable from the aforementioned equation (Atanassov 1989; Ghoushchi et al. 2021c; Ranjbarzadeh and Saadi 2020). Hesitant fuzzy sets (HFS) was introduced in 2010 (Torra 2010). HFS elements can adopt more than one value for their membership between [0, 1] interval (Garg et al. 2022a, b). PFS was developed by Yager (2013a). It is an extended form of IFS, in which the relationship between its membership degree (s) and non-membership (d) degree is as follows: $0 \leq s^2 + d^2 \leq 1$ (Garg 2018; Garg et al. 2022a, b; Rahnamay Bonab and Osgooei 2022; Yager 2013b). NS has been established by Smarandache (1999). The term “neutro-sophy” means “knowledge of neutral thought” that the concept of the expression ‘neutral’ shows the major difference between ‘fuzzy’ and ‘IF’ sets (Majumdar and Samanta 2014). The NS considers that all elements have three degrees: truthness, indeterminacy, and falsity (Bolturk and Kahraman 2021). Picture fuzzy set is the extension of IFS. It can properly deal with different points of view in humans (Cuong and Kreinovich 2013).

Finally, the SFS was established by Kutlu Gündoğdu and Kahraman (2019a), which is the generalized form of NSs and PFSs. By all means, it has greater space that gives greater latitudes to decision-makers (DMs). A linguistic evaluation scale based on SF gives the DMs the chance to make more reliable decisions and overcome their hesitancy (Ghoushchi et al. 2021a, b, c, 2022; Gündoğdu and Kahraman 2020; Jafarzadeh Ghoushchi et al. 2022; Kutlu Gündoğdu and Kahraman 2019a).

However, the Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) technique has not been integrated with a simulation model in the SF environment, though SFSs are demonstrated jointly of the precious tools to operate with the uncertainty and vagueness that happen in real life. Thus, the current research emphasizes on SFSs. The emergency department improvement simulation model has been the focus of many authors, but none have studied the emergency department improvement problem in a SF environment. Existing literatures exhibit that there is a necessity to improve emergency departments during COVID-19 pandemic. The emergency department improvement process includes many objective and subjective attributes that have disputing objectives. Consequently, the above-mentioned issue needs a systematic and satisfactory approach to improve emergency departments during coronavirus disease. To address this apprehension, an integrated Simulation-SF-MARCOS approach is advanced. The proposed approach can purpose more feasible and accurate outputs utilizing the advantages of the SFS set, which considers uncertainty in a more appropriate way in the improvement of emergency departments during COVID-19 pandemic.

The related works are reviewed in this Sect. 2. Section 3 details the materials and methods. The proposed methodology of this study is presented in Sect. 4. In Sect. 5, a case study is introduced and the analysis of results from application of the suggested approach is done. In Sect. 6, a sensitivity analysis is made to illustrate advantages of the proposed approach. In the end, the conclusions and evolution suggestions of this study are presented in Sect. 7.
2 Literature review

A number of studies related to our work are reviewed in this section. In the first subsection, the papers are reviewed which have been published about hospital and emergency departments during COVID-19 pandemic. In the second subsection, applied simulation and MCDM methods in hospital and emergency department improvement are investigated.

2.1 Hospitals and emergency departments during COVID-19

The healthcare sectors play a significant role in national politics especially in critical situations because of dangerous diseases such as COVID-19. Katanić and Damjanović (2022) compared human mobility for six categories during the COVID-19 pandemic. Any divergence from the optimal health service places extra influence on experts of healthcare (Ahsan et al. 2019). The main treat considering healthcare services is the overflowing problem in ED (Richardson and Hwang 2001; Trzeciak and Rivers 2003). In developed nations, overflowing orders urgent awareness as fast aging societies escalate the utilization of ED (Forero et al. 2019; Jensen et al. 2020), which exerts an important impact on patient safety and could decrease the possibilities of survival of critical patients in definite situations because of the long waiting time. Consequently, long patient and throughput time adversely results the whole national healthcare system and its capability to prepare minimum service in any country (Searle et al. 2015; Trzeciak and Rivers 2003).

2.2 Simulation and MCDM methods in hospital and emergency department

There are a limited number of papers in the literature that relates to integrated simulation and MCDM methods. Some of these studies are as follows: Eskandari et al. (2011) presented a novel approach that integrates the simulation model with the group analytical hierarchical process (AHP) and TOPSIS methods to more accurately explore the patient flow of the ED in Tehran, Iran. Azimi et al. (2010) suggest the best control strategy utilizing TOPSIS simulation which simulated using enterprise dynamics simulation software. Jlassi et al. (2011) select a physician after presenting a simulation research for an ED unit. Amarantou et al. (2021) presented integrated approach of simulation and AHP to improve the operations of an ED.

2.3 Research gap

In the first part of this section, some papers related to EDs and COVID-19 are surveyed. Even though some papers have been published about hospitals and emergency departments during emergency departments during COVID-19 pandemic, but few of them proposed effective and feasible solutions to improve EDs during this pandemic. Thus, the lack of research to prepare solutions to improve the emergency departments is firmly required.

The second part of this section also displays that most of the related works in this field have developed the emergency department processes in regular situation, and just a few of them have focused on emergency department during COVID-19 pandemic.

As a result, based on the review, it is clear that, most of the studies deal with crisp values to assess the criteria (performance measures) weights for improve scenario analysis. The experts might be impotent to assign crisp values in their points of view. There has been no work reported to improve EDs processes during coronavirus disease in SF context as an
appropriate way to consider uncertainty. Hence, according to the literature review, the major contributions of this research are as follows:

A. Propose an integrated Simulation-Spherical fuzzy-MARCOS (Simulation-SF-MARCOS) framework
B. Consider real case (real information and data) to increase the effectiveness of the research in reality
C. Determine importance of the performance measures in SF context
D. Apply the SFs-based MARCOS method to prioritize scenarios

3 Methodology

3.1 Structure and framework of simulation

Simulation is a potent tool for investigating with a comprehensive model a real system to find out how the system will answer to changes. The actual ability of simulation is fully discovered when utilized to study complex systems such as Healthcare systems.

To simulate an ED system, Arena software and related modules are applied. As the patient arrives to the ED of the hospital, he/she goes by a triage process in triage his/her severity level as in standard ED practice would be determined. If the patients’ disease has been diagnosed, he/she would go directly to have first aid operations and check if he/she needs an oxygen concentrator. At triage, the patient is classified either mild, moderate or critical. Different patient classes will have to go through different trajectories in the ED system. If the patient does not show known COVID-19 symptoms, and the PCR test result assigned negative, he/she will exit the ED, otherwise, he/she will be routed to the evaluation process. Mild patients are having the PCR test and are advised to stay isolated at home. It is assumed in the system that the first aid must be performed for patients in need. Next, the staff will check for available beds patients at the ICU either the CCU or regular floor for further treatment. Treated patients will go home, otherwise go to COVID morgue because of death. Critical patients will be assigned to an ICU or CCU bed if available, otherwise, they will transfer to another hospital and would be counted into the number of critical transferred patients. Moderate patients will be assigned to a corona regular floor bed, if available. Otherwise, the moderate corona will have the PCR test, transferred to another hospital and would be count into the number of moderate transferred patients. Conceptual model of the ED system shown in Fig. 2.

3.2 Prelamination of spherical fuzzy sets

Spherical fuzzy set (SFS) theory is one of the newest fuzzy sets introduced by Kutlu Gündoğdu and Kahraman (2019b). This section presents some of properties, arithmetic operations, and principles of SFSs.

Definition 1 According to the Kutlu Gündoğdu and Kahraman (2019b), SFS $Z$ of the universe of discourse $X$ is given by:

$$Z = [(x \cdot (\mu_z(x), v_z(x), \pi_z(x))) | x \in X]$$

(1)
where $\mu_z : X \rightarrow [0, 1]$, $v_z : X \rightarrow [0, 1]$, and $\pi_z : X \rightarrow [0, 1]$ display the membership, non-membership, and hesitance degree for every $x \in X$ in the SFS $Z$, respectively. Also,

$$0 \leq (\mu_z(x))^2 + (v_z(x))^2 + (\pi_z(x))^2 \leq 1. \quad (2)$$

**Definition 2** (Kutlu Gündoğdu and Kahraman 2019b) Let $Z_1 = [\mu_{z1}, v_{z1}, \pi_{z1}]$ and $Z_2 = [\mu_{z2}, v_{z2}, \pi_{z2}]$ be two spherical fuzzy numbers (SFNs) and $k \geq 0$. The basic mathematical operations of $Z_1$ and $Z_2$ are as follows:
$Z_1 \oplus Z_2 = \left[ \sqrt{\mu_{z_1}^2 + \mu_{z_2}^2 - \mu_{z_1}^2 \mu_{z_2}^2} \right]
\left[ (1 - \mu_{z_1}^2) \pi_{\z_1} + (1 - \mu_{z_2}^2) \pi_{\z_2} - \pi_{\z_1} \pi_{\z_2} \right]$

(3)

$Z_1 \otimes Z_2 = \left[ \mu_{z_1} \mu_{z_2} \right. \left[ 1 + \frac{v_{z_1} v_{z_2}}{\sqrt{v_{z_1}^2 + v_{z_2}^2}} \right] \left[ (1 - \mu_{z_1}^2) \pi_{\z_1} + (1 - \mu_{z_2}^2) \pi_{\z_2} - \pi_{\z_1} \pi_{\z_2} \right]$

(4)

$kZ = \left[ \sqrt{1 - (1 - \mu_{z}^2)^k} \right. \left. v_z^k \left[ (1 - \mu_{z}^2)^k - (1 - \mu_{z}^2 - \pi_{z}^2)^k \right] \right]$

(5)

$Z^k = \mu_{z}^k \sqrt{1 - (1 - \mu_{z}^2)^k} \left[ (1 - \mu_{z}^2)^k - (1 - \mu_{z}^2 - \pi_{z}^2)^k \right]$

(6)

**Definition 3** (Kutlu Gündoğdu and Kahraman 2019b) For these SFS $Z_1 = [\mu_{z_1}, v_{z_1}, \pi_{\z_1}]$ and $Z_2 = [\mu_{z_2}, v_{z_2}, \pi_{\z_2}]$. The following rules under the condition $k, k_1, k_2 > 0$, are valid.

$Z_1 \oplus Z_2 = Z_2 \oplus Z_1$

(7)

$Z_1 \otimes Z_2 = Z_2 \otimes Z_1$

(9)

$k(Z_1 \oplus Z_2) = kZ_1 \oplus kZ_2$

(10)

$k_1 Z_1 + k_2 Z_1 = (k_1 + k_2) Z_1$

(11)

$(Z_1 \otimes Z_2)^k = Z_1^k \otimes Z_2^k$

(12)

$Z_1^{k_1} \otimes Z_1^{k_2} = Z_1^{k_1+k_2}$

(13)

**Definition 4** (Kutlu Gündoğdu and Kahraman 2019b) Let $Z = [\mu_{z}, v_{z}, \pi_{z}]$ display an SFN. The score value (SV) and accuracy function (AF) of the Z is calculated as follows:

Score($Z$) = $(\mu_{z} - \pi_{z})^2 - (v_{z} - \pi_{z})^2$

(13)

Accuracy($Z$) = $\mu_{z}^2 + v_{z}^2 + \pi_{z}^2$

(14)

Note that: $Z_1 < Z_2$ if and only if

1. score ($Z_1$) < score ($Z_2$) or
2. score($Z_1$) = score ($Z_2$) and Accuracy ($Z_1$) < Accuracy ($Z_2$)

(15)

**Definition 5** (Kutlu Gündoğdu and Kahraman 2019b) Single-valued Spherical Weighted Arithmetic Mean (SWAM) with regard to, $w = \ldots$, is computed as follows:

SWAM$_w$ ($Z_1 \cdots Z_n$) = $w_1 Z_1 + w_2 Z_2 + \cdots + w_n Z_n$

$$\left\{ 1 - \prod_{i=1}^{n} (1 - \mu_{z}^2)^{w_i} \right\}^{\frac{1}{2}} \prod_{i=1}^{n} v_{z}^{w_i}, \left\{ \prod_{i=1}^{n} (1 - \mu_{z}^2)^{w_i} \prod_{i=1}^{n} (1 - \mu_{z}^2 - \pi_{z}^2)^{w_i} \right\}^{\frac{1}{2}}$$

(16)
Definition 6 (Kutlu Gündoğdu and Kahraman 2019b) Spherical Weighted Geometric Mean (SWGM) with regard to, \( w = (w_1 \cdot w_2 \ldots \cdot w_n). w_i \in [0, 1]; \sum_{i=1}^{n} w_i = 1 \), is computed as follows.

\[
\text{SWGM}_w (Z_1 \ldots Z_n) = Z_1^{w_1} + Z_2^{w_2} + \cdots + Z_n^{w_n} = \left\{ \prod_{i=1}^{n} \frac{\mu_{w_i}^{1/z}}{z_i^{1}} \left[ 1 - \prod_{i=1}^{n} (1 - v_i^{2/z_i})^{w_i} \right]^{1/2} \right\}
\]

(17)

Definition 7 (Kutlu Gündoğdu and Kahraman 2019b) The distance between two SFNs \( A \) and \( B \) is computed as follows:

\[
\text{dis} (A, B) = \arccos \left\{ 1 - \frac{1}{2} \left[ \left( (\mu_A - \mu_B)^2 + (v_A - v_B)^2 + (\pi_A - \pi_B)^2 \right) \right] \right\}
\]

(18)

This expression can also be utilized to calculate the spherical distance between two SFSs (Kutlu Gündoğdu and Kahraman 2019b).

\[
\text{dis}(A, B) = \frac{2}{\pi} \sum_{i=1}^{n} \arccos \left\{ 1 - \frac{1}{2} \left[ (\mu_A - \mu_B)^2 + (v_A - v_B)^2 + (\pi_A - \pi_B)^2 \right] \right\}
\]

(19)

The normalized spherical distance between \( A \) and \( B \), is explained as (Kutlu Gündoğdu and Kahraman 2019b):

\[
\text{dis}^n (A, B) = \frac{2}{n\pi} \sum_{i=1}^{n} \arccos \left\{ 1 - \frac{1}{2} \left[ \left( (\mu_A - \mu_B)^2 + (v_A - v_B)^2 + (\pi_A - \pi_B)^2 \right) \right] \right\}
\]

(20)

3.3 Proposed SF-MARCOS method

MARCOS method introduced by Stević et al. (2020). This section aims to explain MARCOS for prioritizing improvement scenarios based on SFSs.

Step 1: Formation of the initial decision matrix based on simulation phase results.

Step 2: Determining the ideal and the counter-ideal.

In this section, based on Eqs. (21) and (22), ideal \( \hat{A}_{di} \) and anti-ideal \( \hat{A}_{id} \) values are determined (Stević et al. 2020).

\[
\hat{A}_{di} = \min_{1 \leq i \leq m} x_{ij} \cdot j \in B^{\text{max}}, \ \min_{1 \leq i \leq m} x_{ij} \cdot j \in C^{\text{min}}
\]

(21)

\[
\hat{A}_{id} = \max_{1 \leq i \leq m} x_{ij} \cdot j \in B^{\text{max}}, \ \min_{1 \leq i \leq m} x_{ij} \cdot j \in C^{\text{min}}
\]

(22)

The expression B means the criteria that have a profit aspect and the phrase C means the criteria that have a cost aspect.

Step 3: The normalization of the extended initial matrix.

Normalization is carried out by utilizing the following equations (Stević et al. 2020):

\[
n_{ij} = \frac{x_{ij}}{\hat{A}_{id}} \quad \text{if} \ j \in C
\]

(23)

\[
n_{ij} = \frac{x_{ij}}{\hat{A}_{id}} \quad \text{if} \ j \in B
\]

(24)

Step 4: Conversion of linguistic variables to SFNs.
Table 1 Linguistic Terms and their related SFNs (Kutlu Gündoğdu and Kahraman 2019b)

| Linguistic variables                        | Spherical fuzzy number |
|---------------------------------------------|------------------------|
|                                             | $\mu$ | $\nu$ | $\pi$ |
| Absolutely more importance (AMI)            | 0.9   | 0.1   | 0.1   |
| Very high importance (VHI)                  | 0.8   | 0.2   | 0.2   |
| High importance (HI)                        | 0.7   | 0.3   | 0.3   |
| Slightly more importance (SMI)               | 0.6   | 0.4   | 0.4   |
| Equally importance (EI)                     | 0.5   | 0.5   | 0.5   |
| Slightly low importance (SLI)                | 0.4   | 0.6   | 0.4   |
| Low importance (LI)                         | 0.3   | 0.7   | 0.3   |
| Very low importance (VLI)                   | 0.2   | 0.8   | 0.2   |
| Absolutely low importance (ALI)              | 0.1   | 0.9   | 0.1   |

The weights of performance measures from the expert’s team are transformed to SFNs using Table 1.

Step 5: Weighing decision matrix.

Weighted decision matrix is carried out by multiplying normalized matrix values by corresponding weights.

Step 6: Determine the utility degrees of alternatives.

In this step, the utility degrees of options are computed utilizing the Eqs. (25) and (26) (Kovač et al. 2021).

\[ K_i^+ = \frac{2}{n \cdot \pi} \sum_{j=1}^{n} \arccos \left( \mu_{ij} \cdot \mu_{ij}^* + v_{ij} \cdot \nu_{ij}^* + \pi_{ij} \cdot \pi_{ij}^* \right) \]  
\[ K_i^- = \frac{2}{n \cdot \pi} \sum_{j=1}^{n} \arccos \left( \mu_{ij} \cdot \mu_{ij}^* + v_{ij} \cdot \nu_{ij}^* + \pi_{ij} \cdot \pi_{ij}^* \right) \]  

where $x_{ij} = (\mu_{ij} + v_{ij} + \pi_{ij})$ represents the weighted element of decision matrix.

Step 7: Determine the utility functions of each alternative and ranking.

Finally, the utility function of each alternative is calculated using Eq. (27) (Stević et al. 2020).

\[ F_i = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^-)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^+)}} \]  

where $f(K_i^-)$ and $f(K_i^+)$ represent the utility functions of alternatives, calculated according to (Stević et al. 2020):

\[ f(K_i^-) = \frac{K_i^-}{K_i^+ + K_i^-} \]  
\[ f(K_i^+) = \frac{K_i^+}{K_i^+ + K_i^-} \]  

Step 8: Determine the options ranks.

Rank the options according to the parameter $F_i$ in descending order (Stević et al. 2020).
4 Proposed methodology

This section presents the integrated Simulation-MCDM approach in the SF environment to improve emergency departments during the COVID-19 pandemic by reducing the patients’ transfer rate. According to Fig. 3, the proposed methodology contains three main steps to attain the goal of the current study:

1. Data collecting and forming a databank
2. Developing the simulation model
3. Selecting the top scenario by applying decision-makers preferences in SF context

In the first phase, the ED patients’ data containing arrival rate and distinct service times collected and stored in databank. Statistical distributions constructed by utilizing stored data for the simulation model. Then, in the second phase, the arena simulation software is utilized for discrete event systems and forming the simulation model.

In the last phase, to make sure the proposed model and defining performance measures, we have invited professional experts who have rich experience in the relevant field. In this phase, first, the significance of the performance measures is recognized by experts utilizing Table 1. So that the significance of the performance measures is discovered by linguistic variables of the absolutely more importance (AMI) and the absolutely low importance (ALI) and, respectively. Also, the values of significance are exhibited utilizing a 9-point rating scale from ALI to AMI. These values are transformed to SF numbers based on Table 1. Then, the initial decision matrix is constructed based on the collected data and performance measures.

![Flow of proposed methodology](image)

Fig. 3 The flow of proposed methodology
The weighted SF decision matrix is structured using weights of the criteria (out of the experts’ preference). In the following, scenarios are ranked according to the MARCOS method. High efficiency, simple structuring and optimizing the decision-making process are some advantages of the MARCOS method. According to the results of SF-MARCOS approach, the scenarios with a higher outcome will be ranked higher in the ranking of scenarios based on the proposed approach.

5 Case study

Tehran, the capital city of Islamic Republic of Iran, is the case study of the current study. According to the explanations provided in the proposed approach, the aim of the current research is to identification and evaluation ED system improvement scenarios during COVID-19 pandemic by presenting an integrated Simulation-SF-MARCOS model.

The ED’s patient flow of a private hospital in Tehran have been the case study of this paper. The ED treat COVID-19 patients in three main portions: ICU, CCU that has changed application to treat COVID-19 patients because of critical situation of COVID-19 pandemic, and regular floor. Both of ICU and CCU include 3 beds and regular floor include 5 beds. The ED have totally 5 oxygen concentrator that can be share between portions. Triage has one doctor and one bed. The first aid process implementation by one doctor and one nurse. In this case, according to database, 21.35% of patients are symptomatic. PCR result time is assumed 6 h. Around 80% of critical patients will need an oxygen concentrator. However, moderate patients usually do not need oxygen concentrator. 90% of patients are assumed to need to have a first aid treatment by a doctor and a nurse.

The model was simulated for 100 days with the addition of two initial days that were threw away as warm-up period. The warm-up period is prepared to get rid of any bias at the early stages of the processes. Twelve replications of 24 h were performed for each day.

The scenarios from 1 to 11 have been shown in Table 2. The proposed scenarios and their descriptions were evaluated in the virtual model to choose the best scenario.

| Scenario | Description |
|----------|-------------|
| 1        | Adding one oxygen concentrator |
| 2        | Adding one oxygen concentrator and one ICU bed |
| 3        | Adding one oxygen concentrator and one regular floor bed |
| 4        | Adding one ICU bed and one regular floor bed |
| 5        | Adding one oxygen concentrator and one CCU bed |
| 6        | Adding two oxygen concentrator and one ICU bed |
| 7        | Adding three oxygen concentrators |
| 8        | Adding one doctor to first aid |
| 9        | Adding one doctor and one nurse to first aid |
| 10       | It includes scenarios 2 and 6 |
| 11       | It includes scenarios 6 and 7 |
5.1 Simulation results

In this research, simulation attempts to choose the best scenario and reveal which scenario decreases the transfer rate more than others. The key performance indicators (KPIs) are improvement percentage of patients’ transfer rate, average waiting time, utilization of resources, and expenditure that were procured from the results report. Results of the simulation are inputs for the weighting criteria phase. Finally, Table 3 reveals the results of running scenarios.

5.2 SF-MARCOS results

The SF-MARCOS method ranks the scenarios. Spherical fuzzy weights of criteria are the inputs for SF-MARCOS. According to first step of the MARCOS method, first, initial decision matrix is formed utilizing the results of simulation phase, so the rows of this matrix represent scenarios and the columns of this matrix stand for the evaluation criteria (see Table 3). Next, according to steps of SF-MARCOS method, the normalized decision matrix formed using Eqs. (23) and (24). Then, based on the next step, the normalized decision matrix must be weighted. According to experts’ opinion, the SF linguistic variable (LV) weights of criteria include improvement percentage of patients’ transfer rate, average waiting time, utilization of resources, and expenditure considered as AMI, VLI, SMI, HI, SMI, EI, SMI, LI, and VHI. The LVs converted to SF numbers utilizing Table 1. The weighted decision matrix is established as Table 4.

In the next step, the degrees of utility of ideal $K_i+$ and anti-ideal $K_i−$ of the alternatives are attained using Eqs. (25) and (26). Finally, according to the next step of the SF-MARCOS methodology, the utility functions $F_i$ of alternatives is obtained using Eq. (27). Then, based on the obtained $F_i$, the prioritizing of the options in descending order is done. According to Table 5, it can be seen that scenario 3 and scenario 6 are ranked first and second with 0.388 and 0.387 scores, respectively, and scenario 9 with 0.368 score is ranked 11th. Also, the prioritization of the scenarios can be seen in Fig. 4.

Finally, according to the results of scenario 3 implementation, the critical transfer rate and moderate transfer rate are improved by 10% and 4%, respectively.

5.3 Comparative analysis

A comparative analysis is organized to validate the proposed methodology to assess scenarios. SF-TOPSIS and SF-WASPAS methodologies are utilized to test the efficacy of SF-MARCOS. The weights of the criteria obtained in the SF context are utilized to assess the scenarios for this aim.

Further analysis of Table 6 shows that the results obtained from SF-TOPSIS and SF-WASPAS methods, scenario 3 has the highest score. The alternative with first priority is determined as same as the SF-MARCOS method. In addition, Sc.6 is in the second priority according to both SF-TOPSIS and the proposed approach. Furthermore, compared with SF-WASPAS method, the SF-MARCOS approach has almost similar results, but not as same as SF-TOPSIS; SF-WASPAS results are different from two other methods in some ranks (Fig. 5). On the other hand, the scenarios 6 and 8 are jointly ranked in second priority and its reveals the weakness and limitation of TOPSIS method in spherical fuzzy sets environment. Also, it can confuse the DMs in the process of ED improvement. According to the outputs of this section, it can be obtained that the presented methodology is compatible with other
| Scenarios | Transfer rate (% of improvement) | Average waiting time (Min) | Utilization (%) | Expenditure (cost unit) |
|-----------|----------------------------------|---------------------------|-----------------|------------------------|
|           | Critical  | Moderate |                      | First aid | ICU | CCU | Regular floor bed | Ox. concentrator |                      |                          |
| Sc. 1     | 7         | 0        | 15,555                | 100        | 99  | 99  | 99              | 99                | 14,000                 |
| Sc. 2     | 6         | 0        | 15,475.2              | 100        | 90  | 77  | 99              | 99                | 30,000                 |
| Sc. 3     | 10        | 4        | 15,530.4              | 100        | 99  | 99  | 99              | 99                | 26,000                 |
| Sc. 4     | 9         | 1        | 15,513.6              | 100        | 86.75 | 49 | 99              | 99                | 28,000                 |
| Sc. 5     | 7         | 3        | 15,555.6              | 100        | 88.33 | 81.75 | 99              | 99                | 30,000                 |
| Sc. 6     | 7         | 3        | 15,391.2              | 100        | 99  | 99  | 99              | 99                | 44,000                 |
| Sc. 7     | 7         | 1        | 15,555                | 100        | 99  | 99  | 99              | 74                | 42,000                 |
| Sc. 8     | 5         | 3        | 15,508.2              | 74         | 87  | 77.66 | 99              | 99                | 12,500                 |
| Sc. 9     | 6         | 0        | 13,432.8              | 96         | 89  | 75.33 | 99              | 99                | 17,100                 |
| Sc. 10    | 11        | 2        | 15,438                | 100        | 99  | 99  | 99              | 99                | 74,000                 |
| Sc. 11    | 12        | 2        | 15,391.2              | 100        | 99  | 99  | 99              | 69                | 86,000                 |
| Scenarios | Transfer rate (% of improvement) | Average waiting time (Min) | Utilization (%) | Expenditure (Cost Unit) |
|-----------|---------------------------------|---------------------------|-----------------|------------------------|
|           | Critical                        | Moderate                  | First aid       | ICU                    | CCU                     | Regular floor bed | Ox. concentrator |                   |
| Sc. 1     | (0.787, 0.261, 0.108)           | (0, 1, 0)                 | (0.565, 0.453, 0.387) | (0.7, 0.3, 0.3) | (0.6, 0.4, 0.4) | (0.5, 0.5, 0.5) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.773, 0.237, 0.2) |
| Sc. 2     | (0.751, 0.316, 0.107)           | (0, 1, 0)                 | (0.566, 0.4514, 0.387) | (0.7, 0.3, 0.3) | (0.577, 0.434, 0.391) | (0.447, 0.583, 0.465) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.588, 0.511, 0.176) |
| Sc. 3     | (0.865, 0.146, 0.105)           | (0.2, 0.8, 0.2)           | (0.565, 0.452, 0.387) | (0.7, 0.3, 0.3) | (0.6, 0.4, 0.4) | (0.5, 0.5, 0.5) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.623, 0.461, 0.183) |
| Sc. 4     | (0.843, 0.177, 0.106)           | (0.101, 0.945, 0.102)     | (0.566, 0.452, 0.387) | (0.7, 0.3, 0.3) | (0.56, 0.448, 0.388) | (0.364, 0.709, 0.397) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.605, 0.487, 0.18) |
| Sc. 5     | (0.787, 0.261, 0.108)           | (0.173, 0.845, 0.174)     | (0.565, 0.453, 0.387) | (0.7, 0.3, 0.3) | (0.573, 0.441, 0.389) | (0.459, 0.564, 0.473) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.588, 0.511, 0.176) |
| Sc. 6     | (0.787, 0.261, 0.108)           | (0.173, 0.846, 0.175)     | (0.567, 0.449, 0.387) | (0.7, 0.3, 0.3) | (0.6, 0.4, 0.4) | (0.5, 0.5, 0.5) | (0.6, 0.5, 0.4) | (0.3, 0.7, 0.3) | (0.502, 0.633, 0.157) |
| Sc. 7     | (0.787, 0.261, 0.108)           | (0.1, 0.946, 0.102)       | (0.565, 0.453, 0.387) | (0.7, 0.3, 0.3) | (0.6, 0.4, 0.4) | (0.5, 0.5, 0.5) | (0.6, 0.5, 0.4) | (0.261, 0.766, 0.264) | (0.512, 0.619, 0.159) |
Table 4 (continued)

| Scenarios | Transfer rate (% of improvement) | Average waiting time (Min) | Utilization (%) | Expenditure (Cost Unit) |
|-----------|---------------------------------|---------------------------|-----------------|-------------------------|
|           | Critical | Moderate |                | First aid | ICU | CCU | Regular floor bed | Ox. concentrator |                   |
| Sc. 8     | 0.706, 0.383, 0.105 | 0.173, 0.846, 0.174 | 0.566, 0.452, 0.387 | 0.626, 0.41, 0.285 | 0.569, 0.447, 0.388 | 0.449, 0.58, 0.466 | 0.6, 0.5, 0.4 | 0.3, 0.7, 0.3 | 0.8, 0.2, 0.2 |
| Sc. 9     | 0.751, 0.316, 0.107 | 0, 1, 0 | 0.6, 0.4, 0.4 | 0.69, 0.315, 0.298 | 0.574, 0.439, 0.39 | 0.443, 0.59, 0.461 | 0.6, 0.5, 0.4 | 0.3, 0.7, 0.3 | 0.725, 0.308, 0.198 |
| Sc. 10    | 0.884, 0.121, 0.102 | 0.142, 0.894, 0.143 | 0.567, 0.45, 0.387 | 0.7, 0.3, 0.4 | 0.6, 0.5, 0.4 | 0.3, 0.7, 0.3 | 0.6, 0.5, 0.4 | 0.3, 0.7, 0.3 | 0.398, 0.761, 0.128 |
| Sc. 11    | 0.9, 0.1, 0.1 | 0.142, 0.894, 0.143 | 0.567, 0.449, 0.387 | 0.7, 0.3, 0.4 | 0.6, 0.5, 0.4 | 0.3, 0.7, 0.3 | 0.6, 0.5, 0.4 | 0.252, 0.779, 0.256 | 0.371, 0.791, 0.121 |
| ai        | 0.706, 0.1, 0.1 | 0.0, 0.8, 0 | 0.6, 0.453, 0.4 | 0.626, 0.3, 0.285 | 0.569, 0.4, 0.388 | 0.364, 0.5, 0.397 | 0.6, 0.5, 0.4 | 0.252, 0.7, 0.256 | 0.8, 0.791, 0.201 |
| id        | 0.9, 0.383, 0.109 | 0.2, 1, 0.2 | 0.565, 0.04, 0.386 | 0.7, 0.41, 0.3 | 0.6, 0.448, 0.4 | 0.5, 0.709, 0.5 | 0.6, 0.5, 0.4 | 0.3, 0.779, 0.3 | 0.371, 0.2, 0.12 |
Table 5 The results of proposed approach

| Scenarios | $Ki^+$ | $Ki^-$ | $f(Ki^+)$ | $f(Ki^-)$ | $F_i$ | Rank |
|-----------|--------|--------|-----------|-----------|-------|------|
| Sc. 1     | 0.443  | 0.792  | 0.641     | 0.359     | 0.369 | 9    |
| Sc. 2     | 0.444  | 0.788  | 0.640     | 0.360     | 0.369 | 10   |
| Sc. 3     | 0.476  | 0.792  | 0.625     | 0.375     | 0.388 | 1    |
| Sc. 4     | 0.449  | 0.780  | 0.635     | 0.365     | 0.371 | 8    |
| Sc. 5     | 0.472  | 0.790  | 0.626     | 0.374     | 0.386 | 4    |
| Sc. 6     | 0.474  | 0.793  | 0.626     | 0.374     | 0.387 | 2    |
| Sc. 7     | 0.453  | 0.794  | 0.637     | 0.363     | 0.376 | 7    |
| Sc. 8     | 0.474  | 0.788  | 0.624     | 0.376     | 0.387 | 3    |
| Sc. 9     | 0.442  | 0.787  | 0.640     | 0.360     | 0.368 | 11   |
| Sc. 10    | 0.464  | 0.795  | 0.631     | 0.369     | 0.382 | 5    |
| Sc. 11    | 0.460  | 0.797  | 0.634     | 0.366     | 0.380 | 6    |

Fig. 4 Ranking of scenarios

decision-making methods. The SF-WASPAS method does not examine the distances from the ideal solutions and their relative significance. Concurrently, the compromise solution obtained from the SF-MARCOS method is closest solution to the ideal solution; however, the solution obtained from SF-WASPAS is not the closest to ideal solution all the time.

By comparing the outputs obtained from investigated methods, Fig. 6 shows 0.818 correlation coefficient between SF-WASPAS and SF-MARCOS ranking results. On the other hand, we observe very few rank variations between SF-TOPSIS and SF-MARCOS, the correlation coefficient between both approach ranking results is observed as 0.975. It can be obtained from this results that this proposed approach is valid because not only the detected results of this approach are similar to the results of SF-TOPSIS approach as a reliable method in literature (Kutlu Gündoğdu and Kahraman 2019b; Toker and Görener 2022), but also the
Table 6 Comparison of scenarios prioritization based on the proposed approach and existing methods

| Scenarios | SF-TOPSIS | SF-WASPAS | Proposed approach |
|-----------|-----------|-----------|-------------------|
|           | Closeness ratio | Score | $F_i$ (utility value) | |
|           | Rank | Rank | Rank | |
| Sc. 1     | 0.254  | 9 | 0.388  | 10 | 0.369  | 9 |
| Sc. 2     | 0.258  | 8 | 0.352  | 11 | 0.369  | 10 |
| Sc. 3     | 0.272  | 1 | 0.512  | 1 | 0.388  | 1 |
| Sc. 4     | 0.263  | 7 | 0.418  | 8 | 0.371  | 8 |
| Sc. 5     | 0.269  | 3 | 0.483  | 3 | 0.386  | 4 |
| Sc. 6     | 0.27   | 2 | 0.482  | 4 | 0.387  | 2 |
| Sc. 7     | 0.265  | 6 | 0.403  | 9 | 0.376  | 7 |
| Sc. 8     | 0.27   | 2 | 0.474  | 5 | 0.387  | 3 |
| Sc. 9     | 0.245  | 10 | 0.419  | 7 | 0.368  | 11 |
| Sc. 10    | 0.268  | 5 | 0.49   | 2 | 0.382  | 5 |
| Sc. 11    | 0.269  | 4 | 0.424  | 6 | 0.38   | 6 |

Fig. 5 Comparison of preference order of the scenarios with various approaches

ranking outputs of the SF-MARCOS solved duplicate rank results shortcoming of the SF-TOPSIS approach. As a result, the SF-MARCOS method presented additional valid and feasible results than other existing methodologies.

6 Advantages

In this section, a sensitivity analysis is made to show the advantages of working with SF environment. To this end, the variation in the scenario ranking is analyzed concerning changes in criteria (the performance measures) weight vectors. As there are nine performance measures in the simulation model, in our case study, a total of five weight vectors include SF LVs are created. The constructed weight vectors are given in Table 7.
The ranking orders of 11 scenarios with referral to the five weight vectors are given in Table 8. Table 8 shows that when the weight varies, there are variations in the ranking orders of scenarios. While Sc. 3 is ranked as the most suitable scenario to improve the ED, the rank of other improving scenarios varies depending on the weight values.

All the results display higher than 90% correlation coefficient. That illustrates a high and positive correlation. Hence, it is an advantage of the proposed approach that enables experts to consider their hesitancies in the decision process using SFSs.

### 7 Conclusion

The COVID-19 pandemic has disclosed the deficiency of our health systems that were unprepared to address an awfully sizable number of patients requiring respiratory support medical care during a short timeframe. The main aim of current study was to evaluate ED processes in a private hospital in Iran during COVID-19 pandemic. Simulation was utilized to recognize the ED process bottlenecks and then, to assess various scenarios evolved for vanquish these bottlenecks beneficial to reduce transfer rate of patients in ED. The key contributions of this study are related to the development of the Simulation-SF-MARCOS model. Simulation-SF-MARCOS was proposed with the potential to tackle uncertainty and the hesitancy in DEs’ judgements in the assessment of improvement scenarios. Simulation-SF-MARCOS introduced a novel operational patient flow in ED during Covid-19 pandemic to decrease patients transfer rate base on the presented operational patient flow.

This study has shown that patients’ transfer rate can be reduced by taking new policies with reasonable expenditure. The findings of this study suggest that adding one oxygen concentrator and one regular floor bed can improve the critical transfer rate and moderate transfer rate by 10% and 4%, respectively. It is unfortunate that in our current work, we have assumed that the experts’ opinions weights are equal. We may recommend a novel policy for this to determine different weights for experts according to their experience and knowledge. Also, in determining weights of the criteria, we can use and apply an MCDM methods such as SWA or BWM in spherical fuzzy context. Consequently, we are thinking out to eliminate these limitations in future with regard to development of novel integrated decision-making approaches. A further study could expand by integrating MCDM methods to
| Scenarios          | Weight vector 1 | Weight vector 2 | Weight vector 3 | Weight vector 4 | Weight vector 5 |
|-------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                   | HI ALI HI VHI HI LI EI SLI AMI | VHI VLI VHI HI LI SLI VLI LI AMI | AMI ALI ALI SLI VHI LI SMI LI HI | HI VLI VHI HI LI HI AMI VHI AMI | VHI ALI EI SMI EI SLI EI VLI VHI |
| Average transfer rate (% of improvement) | HI | VHI | HI | HI | HI |
| Average waiting time (Min) | HI | LI | HI | LI | LI |
| Utilization (%) | HI | LI | HI | LI | LI |
| Expenditure (cost unit) | AMI | AMI | HI | AMI | AMI |
Table 8 Rank changes depending on the designed weight vectors

| Scenarios | Current weight | Weight vector 1 | Weight vector 2 | Weight vector 3 | Weight vector 4 | Weight vector 5 |
|-----------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|           | $F_i$  | Rank | $F_i$  | Rank | $F_i$  | Rank | $F_i$  | Rank | $F_i$  | Rank | $F_i$  | Rank |
| Sc. 1     | 0.369  | 9     | 0.321  | 9     | 0.321  | 8     | 0.304  | 6     | 0.321  | 8     | 0.306  | 8     |
| Sc. 2     | 0.369  | 10    | 0.317  | 10    | 0.312  | 10    | 0.297  | 11    | 0.313  | 10    | 0.299  | 10    |
| Sc. 3     | 0.388  | 1     | 0.337  | 1     | 0.336  | 1     | 0.314  | 1     | 0.338  | 1     | 0.319  | 1     |
| Sc. 4     | 0.371  | 8     | 0.322  | 8     | 0.316  | 9     | 0.300  | 9     | 0.318  | 9     | 0.304  | 9     |
| Sc. 5     | 0.386  | 4     | 0.334  | 5     | 0.332  | 3     | 0.313  | 4     | 0.333  | 5     | 0.316  | 3     |
| Sc. 6     | 0.387  | 2     | 0.336  | 2     | 0.335  | 2     | 0.314  | 3     | 0.336  | 2     | 0.318  | 2     |
| Sc. 7     | 0.376  | 7     | 0.327  | 7     | 0.321  | 7     | 0.304  | 8     | 0.325  | 7     | 0.308  | 7     |
| Sc. 8     | 0.387  | 3     | 0.332  | 6     | 0.330  | 5     | 0.314  | 2     | 0.331  | 6     | 0.315  | 4     |
| Sc. 9     | 0.368  | 11    | 0.314  | 11    | 0.309  | 11    | 0.298  | 10    | 0.310  | 11    | 0.299  | 11    |
| Sc. 10    | 0.382  | 5     | 0.335  | 3     | 0.331  | 4     | 0.307  | 5     | 0.333  | 4     | 0.314  | 5     |
| Sc. 11    | 0.38   | 6     | 0.334  | 4     | 0.329  | 6     | 0.304  | 7     | 0.335  | 3     | 0.311  | 6     |
consider performance measures weights within q-rung fuzzy, SFSs and PFSs environments. Besides the simulation model utilized in the proposed approach, this model will be applied in several improvement scenarios.

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