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APPLICATION OF FUZZY TOPSIS FOR PRIORITIZATION OF PATIENTS ON ELECTIVE SURGERIES WAITING LIST - A NOVEL MULTI-CRITERIA DECISION-MAKING APPROACH

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Abstract: *Prioritizing patients is a growing concern in healthcare. Once resources are limited, prioritization is considered an effective and viable solution in provision of healthcare treatment to awaiting patients. Prioritization is a preferred approach that helps clinicians to apportion scarce resources fairly and transparently. In this study, a novel methodology of prioritizing the patient is formulated using fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The objective is based on actual hospital conditions in Pakistan. The proposed methodology has two contributions: objective scoring mechanism that translates the patient's condition given in human linguistic terms; and second methodology to prioritize patients according to corresponding scores. To validate the proposed methodology, simulation was carried out on actual data collected in real-time by surgeons, while providing consultations to their patients. The proposed methodology outperforms the traditional methodology by reducing average waiting time by 34% (from 4.246 to 2.810 days), minimize wait time and delays by 46.7% (from 15 to 8 days), and number of surgery days by 18%. The majority of the previously presented researched methodologies prioritize the patients subjectively. This study presents an objective methodology to prioritize the patients and decrease wait-times while ensuring transparency and equity.*

Key words*: Elective surgery prioritization, TOPSIS, modified MeNTS scoring system, multi-criteria decision-making, surgical decision-support system, wait-list management.*

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1. Introduction

Resources handicap the healthcare organizations from providing simultaneous treatment to the patients. Under such circumstances, some studies (Déry et al., 2019; Rahimi et al., 2017) consider prioritization to be an effective, viable and a preferred approach in the identification, provisioning and apportion scarce resources in a fair and transparent manner, to patients in need, awaiting (Lauerer & Nagel, 2016). In healthcare, prioritization is applied while prioritization the patients for healthcare services, usage of medical equipment (such as dialysis) and technologies (CT scans, PET scan, MRI), etc (Rahimi et al., 2017).

Patients' prioritization is a process of ranking patients based on the important or significant factors (Déry et al., 2020; Rathnayake et al., 2021). After referral, a specialist examines and evaluates the patients' health condition and decides the priority to perform the relevant procedure. Such decision-making is based on certain criteria, such as the "severity of the patient's disease, mobility, pain, discomfort, moral, necessity of the procedure to be performed, and other socioeconomic factors" (Rahimi et al., 2017, 2016; Li et al., 2019; Prachand et al., 2020; Valente et al., 2020; Silva-Aravena et al., 2021; Hassan et al., 2021; Rana et al., 2022), and is the result of "hypothetical rational thinking" of both the physician and the patient, clinical judgment of the physician, patients' pathological reports, and other facts reported by the patient. The outcome of the arrived decision is subjective and is condemned of missing transparency and equity and may result in denial of required treatment to the deserving and delayed treatment, physician's assessment judgmental errors, emotional & moral burden on the physician, increased workload, and poor resource management at the hospital (Prachand et al., 2020). Literature (Law et al., 2022; McIntyre & Chow, 2020; OECD, 2020; Rana et al., 2022) indicated that prolonged patients' waiting periods and improper prioritization result in poorer medical care, reduced treatment effectiveness, increase in anxiety of patient, higher risk probability of negative outcomes that can lead to aggravation of the patient's health condition and, in extreme cases, death.

Ascertaining the priorities of patients is considered as a complex multicriteria decision-making (MCDM) problem, in which patients are ranked based on multiple criteria (Rahimi et al., 2017; Rana et al., 2022; De Nardo et al., 2020). Prioritization has been carried out in other domains using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a popular MCDM technique (De Nardo et al., 2020; Rahimi et al., 2017) which was developed in 1981 by Hwang and Yoon (Hwang & Yoon, 1981). The core concept of TOPSIS is based on choosing an alternative that is having "shortest geometric distance from positive ideal solution and longest geometric distance from negative ideal solution" (Hwang & Yoon, 1981). Widianta et al. (2018) reported that TOPSIS give 95% accuracy once compared with other MCDM techniques such as Analytic Hierarchy Process (50%), Weighted Sum Method (81.67%), and Preference Ranking Organization Method for Enrichment Evaluation (93.34%). The advantages of using TOPSIS resides in its ease in use, logical approach that gives clarity, and its effective computational ability (Alaoui et al., 2019). Moreover, TOPSIS evaluates all the alternatives, while considering each weighted criterion during the ranking process (Kore et al., 2018). TOPSIS was extended to fuzzy domain by Chu and Lin (2003).

In the recent literature, TOPSIS and Fuzzy TOPSIS have been used in numerous fields such as assessment of energy systems (Taylan et al., 2020), maintenance management (Olugu et al., 2021), occupational accident (Abbasinia & Mohammadfam, 2022), petrochemical industry (Abbassinia et al., 2020), noise control (Mousavi et al., 2019), outsourcing (Kiani et al., 2022), reverse logistics (Naseem et al., 2021), manufacturing systems (Mathew et al., 2020) and renewable energy (Solangi et al., 2019). Usage of TOPSIS can be found in healthcare literature for analysis of dose planning (Malekpoor et al., 2022), hospital waste management (Baghapour et al., 2018), medical device risk factors (Kirkire et al., 2018), triage in intensive care unit (Davodabadi et al., 2021), human errors factors in the emergency departments (Hsieh et al., 2018), mobile health (Rajak & Shaw, 2019), medical diagnosis (Baccour, 2018), and nano material selection (K. Zhang et al., 2019).

Recently, fuzzy sets have been used extensively in healthcare MCDM for material and technique selection of best alternative (Mishra et al., 2020; Chakraborty & Saha, 2022b; Chaurasiya & Jain, 2022; Krishankumar et al., 2022; Salimian & Mousavi, 2022; Liu et al., 2022; Chakraborty & Saha, 2023; Quasim et al., 2023; Ghorbani et al., 2023). In the field of medicine, diagnosis of the disease is always accompanied by uncertainties and ambiguities (De Silva, 2018; Uzun Ozsahin et al., 2020). Behavior and symptoms of a disease vary from patient to patient. Similarly, the same symptoms can be seen due to different diseases thus presenting a difficult treatment regime. Such uncertainties resulted in inclusion of fuzzy logic into the field of medicine (Uzun Ozsahin et al., 2020). Fuzzy logic has been used in disease diagnosis, medical treatment selection, and monitoring of data of patients in real-time (Uzun Ozsahin et al., 2020). Instead of rating the health condition of a patient in a numerical value, it is easy for a surgeon to assign a value from a set of linguistic variables (Gürsel, 2016). For example, severity of disease can be gauged on a scale of 1 to 5 (five being severe), however, it will be much easier for the physician to describe the severity of disease as 'low', 'very mild', 'mild', 'moderate' or 'severe'. As the clinical evaluation of patients involve linguistic variable, Fuzzy TOPSIS was selected for prioritization of patients over generic TOPSIS. Moreover, regardless of the number of decision criteria and alternative, TOPSIS is a straightforward technique that has the same solution procedure (Malik et al., 2021).

Mardani et al. (2019) reviewed the literature from 1989 to 2019 and identified 179 papers on application of decision making and fuzzy sets theory to evaluate the problems related to healthcare. It was found that only 9 (5.0%) papers were related to Fuzzy TOPSIS that contained decision-making on account of medical waste, devices, patient safety, human error, medical software, and use of anesthesia methods in surgical procedure. Furthermore, Palczewski & Salabun (2019)reviewed scholarly papers published between 2009 till 2018 on the application of fuzzy TOPSIS. Out of 25 shortlisted papers, only two papers (Büyüközkan & Çifçi, 2012; Chen, 2015) indicated the application of Fuzzy TOPSIS in the domain of healthcare (electronic service quality in healthcare industry and medical decision-making on treatment methods concerning basilar artery occlusion and acute cerebrovascular disease). The reviewed literature indicates a scarce application of Fuzzy TOPSIS in the domain of healthcare.

Using Weighted Sum Method (WSM), a commonly used MCDM technique, seminal work (Rana et al., 2022) confirmed that the MCDM methodologies have a potential to objectively reduce the patients' waiting-times placed on the surgical wait-lists while ensuring transparency and equity. In contrast, a novel MCDM approach based on Fuzzy-TOPSIS has been introduced in this study that effectively used selected criteria, wait time and maximum time before treatment to rank the patients. Since the clinical evaluation of patients involves fuzzy linguistic variable, Fuzzy TOPSIS was selected for prioritization of patients over generic TOPSIS owing to its efficient computation, ease in use, thoroughness of mathematical concept.

1.1 Research Gap

The application of Fuzzy TOPSIS has been used numerous times in other domains. However, its application in healthcare has remained low as indicated by Mardani et al. (2019) and Palczewski & Salabun, (2019). Moreover, AHP (Rahimi et al., 2017) and WSM (Silva-Aravena et al., 2021; Rana et al., 2022) are the only MCDM methods that have been used for prioritization of patients and the researched literature indicate that fuzzy TOPSIS method has not been used for the prioritization of patients.

1.2 Motivation of the Research

This research has been motivated by the fact that prioritization of patients' access to healthcare services is a pressing concern which has been further exacerbated by the global pandemic. Resources prevent healthcare organizations from providing simultaneous treatment to the patients. Under such circumstances, prioritization is considered to be an effective, viable and a preferred approach in the identification, provisioning and apportion of scarce resources in a fair and transparent manner, to patients in need, awaiting treatment.

1.3 Novelty of the Research

In this paper, a novel methodology where prioritizing the patient is formulated using fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). To validate the proposed methodology, simulation was conducted on actual data collected in real-time by surgeons, while providing consultations to their patients. The proposed methodology outperforms the traditional methodology by reducing average waiting time, minimizing wait time, delays, and number of surgery days.

1.4 Contribution

The proposed methodology is modelled keeping two major contributions: first is the development of objective scoring mechanism that translates the patient's condition given in human linguistic terms; and second is the creation of methodology to prioritize patients according to corresponding scores.

This paper is organized in six sections: after introduction in section 1, preliminaries giving background information are given in the second section. The proceeding section summarizes the methodology that is proposed which is followed by the results section. Analysis of results is given in the discussion section. The last section concludes the present work and outlines research area for the future.

2. PRELIMINARIES

2.1 Related Research

A methodology of prioritization of patients on waiting for elective surgery was introduced in seminal work (Rana et al., 2022) using 17 criteria (Table 1) derived from MeNTS scoring system (Prachand et al., 2020). It was based on WSM, a commonly used MCDM technique. Criterion weights were calculated based on the input of 8 qualified surgeons having a mean experience of 23.3 (SD 1.2) years.

Due to differences in thinking and training of the physicians, there is always a difference in the outcome of clinical examinations of patients. This reliability issue was overcome through "inter-rate agreement" measurement. Given by Fleiss' kappa κ, it is calculated to determine the level of agreement within the surgeons (Silveira, 2022). Through a pilot study, ten patients (selected randomly and meeting the exclusion/ inclusion criteria) were examined by eight random surgeons. The calculated Fleiss' kappa was found to be "Almost Perfect Agreement", κ=0.835 (95% CI, 0.757 to 0.914, p<0.0005).

In a period of three weeks (from 14 Sep - 8 Oct 2021), data of 114 adult willing patients (meeting the inclusion/exclusion criteria) was recorded in real-time by qualified surgeons during clinical examination in surgical out-patient department of a local hospital using non-probability convenience sampling. Using WSM, priority scores of the patients were calculated using weighted criteria. The applied methodology outperformed the traditional "first-come-first serve" methodology by reducing the average wait-time in surgical waitlists by 30% (from 4.246 to 2.956 days) together with ensuring transparency and equity.

Table 1. Criteria used with Weights (Rana et al., 2022)

Serial #	**Criteria or Factors**	**Criteria Weights**
1.	OR Time	0.047
2.	Estimated length of stay	0.023
3.	Post-Op ICU need	0.070
4.	Estimated blood loss	0.072
5.	Surgical team size	0.049
6.	Intubation needed to perform procedure (probability)	0.069
7.	Surgical Site	0.043
8.	Impact of delay in DISEASE outcome (2 weeks)	0.070
9.	Impact of delay in SURGICAL difficulty/risk (2 weeks)	0.072
10.	Impact of delay in DISEASE outcome (6 weeks)	0.070
11.	Impact of delay in SURGICAL difficulty/risk (6 weeks)	0.072
12.	Pain & Discomfort	0.040
13.	Lung disease (asthma, COPD, CF)	0.072
14.	Obstructive Sleep Apnoea	0.043
15.	CV disease (HTN, CHF, CAD)	0.067
16.	Diabetes	0.059
17.	Immunocompromised	0.064

As the work presented in this paper is the extension of research (Rana et al., 2022) using the same 17 criteria (Table I), it was necessary that the proposed methodology is applied on already published dataset of 114 patients to compare the results.

2.2 Fuzzy Method

Logic is a science dealing with reasoning, its modelling and validation, using correct methodology. Fuzzy logic is an approach for modelling logical reasoning wherein the statement's truth is neither a binary true nor binary false. Instead, it is that point of truth that hovers between 'absolutely false or 0' and 'absolutely true or 1' as in case of classical Boolean logic. Although the idea of fuzziness date back to Aristotle, however, it was formally put up by Lotfi Zadeh in 1965 while working on computers to understand the natural language (Zadeh, 1965).. Fuzzy logic leads to the designing of a fuzzy inference system, the purpose of which is to map a collection of inputs into outputs while using human understandable rules instead of using theoretical mathematics and it can be effectively use in the decision-making processes (El Alaoui, 2021).

Situations in real-life do not fall in the crisp 'true' or 'false' state, vagueness and ambiguity in the natural language is always present (De Silva, 2018). A variable with values represented in words in natural language is called linguistic variable (Uzun Ozsahin et al., 2020). After the introduction of Fuzzy logic by Lotfi Zadeh (Zadeh, 1965)., the linguistic vagueness can be described crisply. Fuzzy logic is a mathematical tool which is used for modeling of systems with uncertainty (Reyes-García & Torres-García, 2022; Uzun Ozsahin et al., 2020).

In the field of medicine, diagnosis of the disease is always accompanied by uncertainties and ambiguities (De Silva, 2018; Uzun Ozsahin et al., 2020). Behavior and symptoms of a disease vary from patient to patient. Similarly, the same symptoms can be seen due to different diseases thus presenting a difficult treatment regime. Such uncertainties resulted in inclusion of fuzzy logic into the field of medicine (Uzun Ozsahin et al., 2020). Fuzzy logic has been used in disease diagnosis, medical treatment selection, and monitoring of data of patients in real-time (Uzun Ozsahin et al., 2020). Instead of rating the health condition of a patient in a numerical value, it is easy for a surgeon to assign a value from a set of linguistic variables (Omoregbe et al., 2020). For example, severity of disease can be gauged on a scale of 1 to 5 (five being severe), however, it will be much easier for the physician to describe the severity of disease as 'low', 'very mild', 'mild', 'moderate' or 'severe'. As the clinical evaluation of patients involves linguistic variables, Fuzzy TOPSIS was selected for prioritization of patients over generic TOPSIS. Moreover, regardless of the number of decision criteria and alternative, it is a straightforward technique that has the same solution procedure (Malik et al., 2021).

A fuzzy number (FN) is a fuzzy set in $\mathbb{R}$, such that $x: \mathbb{R} \to [0,1]$ with properties: 1) $x(t) \geq \min\{x(s), x(r)\}, for\ s \leq t \leq r$, that is x convex; 2) $(\exists)t_o \in \mathbb{R}: x(t_o) = 1$, that is x is normal; and 3) $(\forall)t \in \mathbb{R}, (\forall)t \in [0,1]: x(t) < \alpha, (\exists)\delta > 0$ such that $|s - t| < \delta \Rightarrow x(s) < a$, that is x is upper semicontinuous (El Alaoui, 2021).

The fuzziness in Fuzzy logic is described by its membership function (Zadeh, 1965). Different fuzzy numbers can be used as fuzzy membership functions such as Gaussian fuzzy number, trapezoidal fuzzy number, and triangular fuzzy number (TFN). These have been effectively used in the fields of business, management, humanities, physical science and engineering. This study utilized the triangular membership functions for prioritization of patients on the wait list owing to its simple modelling, ease in interpreting the results, and its capability to represent the 5-level fuzzy linguistic variables more adequately (Uzun Ozsahin et al., 2020).

The analysis of data starts by obtaining TFN once 'm_1', 'm_2' and 'm_3' are arranged such that 'm_1' represents minimum value, 'm_2' represents a promising value and 'm_3' represents the maximum value that describe the event. A TFN is denoted as $\mu_{\widetilde{M}} = (m_1, m_2, m_3)$ and is defined by its membership function as:

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0\ if\ x < m_1 \\ \frac{x-m_1}{m_2-m_1}\ if\ m_1 \leq x < m_2 \\ \frac{m_3-x}{m_3-m_2}\ if\ m_2 \leq x < m_3 \\ 0\ if\ \mathrm{x} > m_3 \end{cases} \tag{1}$$

A fuzzy triangular number is depicted in Figure 1.

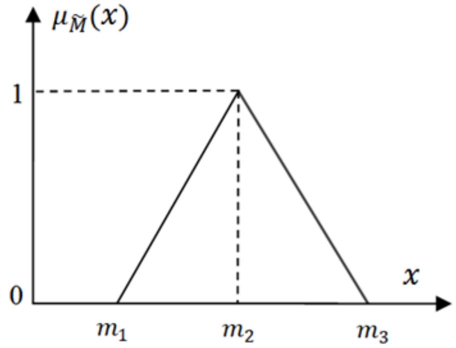

Figure 1. Triangular Fuzzy Number

TFN is used to generate Fuzzy scale that can translate "fuzzy linguistic variables" into Fuzzy number. A 1-5 scale has been applied to rate the alternatives and criteria. Table 2 is a representation of linguistic variables and respective TFN membership functions for the alternates for evaluation against the criteria (Ab Kadir et al., 2019). The fuzzy ratings given in this table are defined in accordance with (Ismail et al., 2019; Ayub et al., 2020; Yaakob et al., 2020; Gupta et al., 2021). The consent level of fuzzy scale is odd number (3, 5, 7, or 9) (Ismail et al., 2019; Ayub et al., 2020).

Table 2. Linguistic variables and respective TFN membership functions (five-levels) for alternates

Linguistic Terms (examples)			Score	TFN Membership Function (m_1, m_2, m_3)
No Impact	None	Not present	1	(0, 0, 0.25)
Slight	Very mild	Off & on	2	(0, 0.25, 0.5)
Mild	Mild	Mild	3	(0.25, 0.5, 0.75)
Moderate	Moderate	Moderate	4	(0.5, 0.75, 1.0)
Significant	Significant	Intense	5	(0.75, 1.0, 1.0)

Criteria weights $\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n]$, where $\widetilde{w}_j$, $j = 1, 2, \dots, n$ is linguistic variables that are explained by TFN, $\widetilde{w}_j = (w_{1_j}, w_{2_j}, w_{3_j})$, and are given in Table 3.

Table 3. Criteria used with Fuzzy Weights

Criteria or Factors	**Fuzzified Criteria Weights**		
	w_1	w_2	w_3
OR Time	0.00	0.47	0.75
Estimated length of stay	0.00	0.09	0.50
Post-Op ICU need	0.50	0.81	1.00
Estimated blood loss	0.50	0.88	1.00
Surgical team size	0.25	0.50	0.75
Intubation needed to perform procedure (probability)	0.50	0.81	1.00
Surgical Site	0.00	0.41	0.75
Impact of delay in DISEASE outcome (2 weeks)	0.50	0.88	1.00
Impact of delay in SURGICAL difficulty/risk (2 weeks)	0.50	0.88	1.00

Criteria or Factors	Fuzzified Criteria Weights		
	w_1	w_2	w_3
Impact of delay in DISEASE outcome (6 weeks)	0.50	0.88	1.00
Impact of delay in SURGICAL difficulty/risk (6 weeks)	0.50	0.88	1.00
Pain & Discomfort	0.00	0.38	0.75
Lung disease (asthma, COPD, CF)	0.50	0.88	1.00
Obstructive Sleep Apnoea	0.00	0.38	0.75
CV disease (HTN, CHF, CAD)	0.50	0.78	1.00
Diabetes	0.25	0.69	1.00
Immunocompromised	0.50	0.75	1.00

2.3 Problem Formulation of Fuzzy MCDM

A MCDM problem decision matrix with $m\ alternative\ \{A_1, A_2, \dots, A_m\}$ that are to assessed by application of $n\ criteria\ \{C_1, C_2, \dots, C_n\}$ is expressed as (El Alaoui, 2021; El Alaoui et al., 2019):

$$D = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ \\ \end{matrix} \begin{pmatrix} C_1 & C_2 & \dots & C_n \\ x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \\ w_1 & w_2 & \dots & w_n \end{pmatrix} \tag{2}$$

where x_{ij} is a numerical data and represent the value of i^{th} alternative where $i: (1 \leq i \leq m)$ with respect to the j^{th} criterion where $j: (1 \leq j \leq n)$. The importance (or weight) of the C_j criterion to the decision is denoted by $\widetilde{W}_j$ which is given by $\widetilde{W}_j = \{\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n\}$.

2.4 Fuzzy TOPSIS

The basic steps in Fuzzy TOPSIS method can be describe as follows (El Alaoui, 2021):

(1) Evaluation of each alternative with respect to n^{th} criteria.

(2) Evaluation of criteria weight using linguistic variables:

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \tag{3}$$

where $\widetilde{w}_j,\ j = 1, 2, \dots, n$ is linguistic variables which can be explained by TFN, $\widetilde{w}_j = (w_{1_j}, w_{2_j}, w_{3_j})$

(3) Formulation of decision matrix in which values are assigned to the alternatives as per each criterion:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m1} & \dots & \tilde{x}_{mn} \end{bmatrix} \tag{4}$$

where $\tilde{x}_{ij}, \forall i, j$ is linguistic variables which can be explained by TFN, $\tilde{x}_{ij} = (m_{1_{ij}}, m_{2_{ij}}, m_{3_{ij}})$

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \quad (3)$$

where $\widetilde{w}_j$, $j = 1, 2, \dots, n$ is linguistic variables which can be explained by TFN, $\widetilde{w}_j = (w_{1_j}, w_{2_j}, w_{3_j})$

(4) Formulation of decision matrix in which values are assigned to the alternatives as per each criterion:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m1} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (5)$$

where $\tilde{x}_{ij}, \forall i, j$ is linguistic variables which can be explained by TFN, $\tilde{x}_{ij} = (m_{1_{ij}}, m_{2_{ij}}, m_{3_{ij}})$

(5) Formulating a normalize the decision matrix using:
For Benefit Criteria (maximization)

$$\tilde{r}_{ij} = (\frac{m_{1_{ij}}}{x^*_{ij}}, \frac{m_{2_{ij}}}{x^*_{ij}}, \frac{m_{3_{ij}}}{x^*_{ij}}) \quad (6)$$

with $x^*_{ij} = max_i\{x^3_{ij}\}$
For Cost Criteria (minimization)

$$\tilde{r}_{ij} = (\frac{x^-_{ij}}{m_{3_{ij}}}, \frac{x^-_{ij}}{m_{2_{ij}}}, \frac{x^-_{ij}}{m_{1_{ij}}},) \quad (7)$$

with $x^-_{ij} = min_i\{x^1_{ij}\}$

(6) Formulation of Weighted Normalized Fuzzy Decision Matrix $\tilde{V} = [\tilde{v}_{ij}]_{m \times n}$:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \widetilde{w}_{ij} \quad (8)$$

(7) Calculation of Fuzzy Positive Ideal Solution (FPIS)

$$A^* = \{\tilde{v}^*_1, \tilde{v}^*_2, \dots, \tilde{v}^*_n\} \quad (9)$$

$with\ \tilde{v}^*_j = (1, 1, 1)$

(8) Calculation of Fuzzy Negative Ideal Solution (FNIS)

$$A^- = \{\tilde{v}^-_1, \tilde{v}^-_2, \dots, \tilde{v}^-_n\} \quad (10)$$

$with\ \tilde{v}^-_j = (0, 0, 0)$

(9) Calculation of Fuzzy Distance from each alternative to FPIS

$$d^+_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^*_j),\ i = 1, 2, \dots, m \quad (11)$$

with $d(\tilde{v}_{ij}, \tilde{v}^*_j) = \sqrt{\frac{1}{3}\left[(v^1_{ij} - 1)^2 + (v^2_{ij} - 1)^2 + (v^3_{ij} - 1)^2\right]}$

(10) Calculation of Fuzzy Distance from each alternative to FNIS

$$d^-_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^-_j),\ i = 1, 2, \dots, m \quad (12)$$

with $d(\tilde{v}_{ij}, \tilde{v}^-_j) = \sqrt{\frac{1}{3}\left[(v^1_{ij})^2 + (v^2_{ij})^2 + (v^3_{ij})^2\right]}$

(11) Calculation of Fuzzy Closeness Coefficient

$$CC_i = \frac{d^-_i}{(d^-_i + d^+_i)},\ i = 1, 2, \dots, m \quad (13)$$

(12) The value of fuzzy closeness coefficients (CC_i), when sorted (larger to smaller), gives the ranking within the set of alternatives based on the given criteria.

3. METHODOLOGY

Understanding the limitations of the prioritization of patients given in research (De Nardo et al., 2020; Rana et al., 2022), a new technique is, therefore, proposed in this study as an effective way forward to address the shortcomings. The overall application of the proposed methodology is described in Figure 2 whereas actual prioritization of patients using Fuzzy TOPSIS is depicted in Figure 3. Except for clinical examination of patient and filling of evaluation form, all the other steps are automated in Surgical Decision Support Tool especially designed for the purpose.

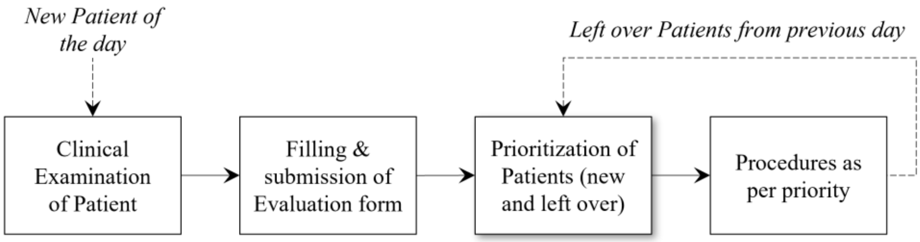

Figure 2. Proposed Methodology

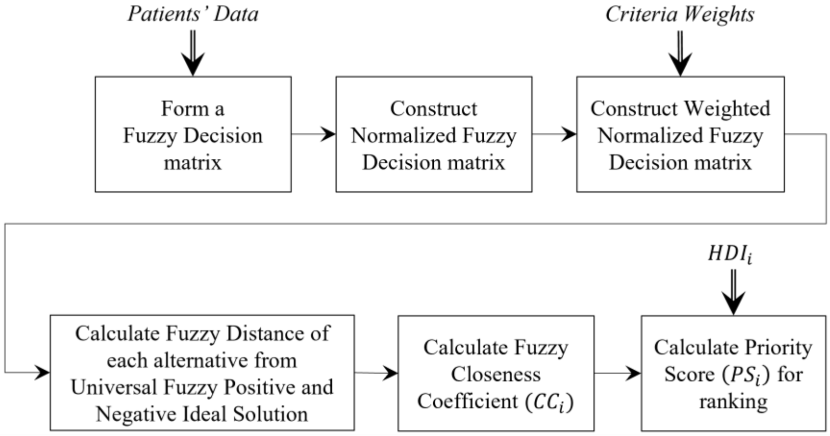

Figure 3. Prioritization of Patients using Fuzzy TOPSIS

3.1 Health Deterioration Index

Health Deterioration Index (HDI) is an index which is a numerical measure of health outcome and risk factors over time while being on the waitlist. It is a relation between wait-time of patient on waitlist to maximum time before treatment (MTBT - assigned by the physician at the time of examination) which changes linearly with the passage of time.

Considering i^{th} patient $\{i \in \mathbb{N} \mid 1, 2, 3, \ldots\}$ on the waitlist with chronological waiting time WT_i $(WT_i = t_p - t_e)$, Maximum Time Before Treatment $MTBT_i = \{MTBT \in \mathbb{Z} \mid 4, 8, 12, 26, 52\}$ weeks, health deterioration index HDI_i is given by:

$$HDI_i = \frac{WT_i}{MTBT_i} \quad (14)$$

where for i^{th} patient, t_e is date of clinical examination, t_p is date of prioritization. $MTBT_i$ is assigned to a patient by the physician after clinical examination and is given in weeks.

The longer a patient waits, it is more probable that patients' health deteriorates. An HDI < 1 indicates that patient has low probability of health deterioration and has waited less than MTBT; an HDI = 1 means that patient has spent same amount of time as determined MTBT and probability of health deterioration is moderate; and if HDI > 1, it implies that the patient has waited more than determined MTBT and is probability of health deterioration is high. It is, therefore, reasonable to assign higher priority to patients with more waiting time.

In research (Rana et al., 2022), although prioritization of the patients was dynamic in nature as it prioritizes the patients that are being introduced at different time frame, however, seventeen considered criteria did not included the wait-time of patients on waitlist. The wait-time starts once the examining surgeon places the patient on the waitlist. After the examination, 'maximum-time before treatment' is assigned to the patients based on the probability of deterioration of condition after which the presented condition changes.

To validate its efficacy and compare the results, the proposed methodology is applied on the data used in research (Rana et al., 2022). At the date of prioritization t_p, the priority score PS_i of i^{th} patient $\{i \in \mathbb{N} \mid 1, 2, 3, \ldots\}$ on the waitlist, is given by:

$$PS_i(t_p) = HDI_i \times CC_i \quad (15)$$

where HDI_i is health deterioration index obtained from (13) and $CC_i = \{CC \in \mathbb{R} \mid 0 \leq CC \leq 1\}$ is Fuzzy Closeness Coefficient of i^{th} patient obtained through Fuzzy TOPSIS method, obtained from (12).

3.2 Simulated Unprioritized and Prioritized Surgical Waitlists

Computer simulations are used to prepare unprioritized and prioritized waitlists. The 'Unprioritized Waitlist' is built on the traditional prioritization method of 'first-come-first-serve' in which name of patient arriving early is added before the subsequent patient in a sequential and chronological order as per arrival of the patients. Patients are entertained as per the waitlist (Rana et al., 2022). 'Prioritized Waitlist' is formulated at the end of 'outpatient' day and before the subsequent operation day. The list includes the leftover patients from previous surgeries and those who have been recently examined on 'outpatient' day. The priority score of each patient on the list is calculated considering the 'patient's wait-time' on the list and allotted 'maximum time before treatment' using (16). Patients having priority scores are placed before the patients with priority score.

3.3 Average Wait-Time on Waitlist

Average wait-time is defined as the “average number of days a patient remains on the waitlist before undergoing surgical procedure.” Average wait time is a vital quantitative measure utilized for waitlist performance evaluation (Rana et al., 2022). It is calculated on after the completion of simulation and is given by following equation:

$$\boldsymbol{a_{eswl}} = \frac{1}{n}\sum_{p=1}^{n}(\boldsymbol{t_{s_p}} - \boldsymbol{t_{e_p}}) \quad (16)$$

where a_{eswl} is average wait time of all patients on waitlist, t_{s_p} is surgery date of the patient *‘p’*, and t_{e_p} is date once the patient *‘p’* is put on waitlist after examination by surgeon. Time (t_e) remains the same in unprioritized waitlist as well as prioritized waitlist; however, the time of surgery (t_s) will be different and affect a_{eswl} before and after the prioritization.

3.4 Sensitivity Analysis

As the weight assigned to the criteria significantly impact the outcome of the adopted MCDM method, a sensitivity analysis was required to be performed (Chakraborty & Saha, 2022a). Sensitivity analysis determines the impact of input variables on the target variables. In this way, the decision outcome can be studied by changing the values of the input variables. In this study, sensitive analysis will be carried out by changing the weights of criteria to check their effects on the prioritization (Mukhametzyanov et al., 2018). Owing to the considerable number of alternates (patients) with analysis spread over various days, it was difficult to perform sensitivity test on the complete dataset. However, a random sample data of ten patients was taken and sensitivity test was performed considering five case scenarios (Mukhametzyanov et al., 2018). Table 4 shows different cases used in sensitivity analysis.

Table 4. Comparison Summary - Previous research vs Proposed technique

Case	Variation in Weights
1.	Weights assigned by Experts
2.	Equal weights to all the criteria
3.	50% weightage is given to procedure criteria while disease and patient criteria are given 25% weightage
4.	50% weightage is given to disease criteria while procedure and patient criteria are given 25% weightage
5.	50% weightage is given to patient criteria while procedure and disease criteria are given 25% weightage

3.5 Considerations

The data collected in research (Rana et al., 2022) was considered for application of proposed technique and its analysis to see the comparison of the results. The actual surgical workflow was not disturbed in this work and all the surgeries were simulated. Same assumptions of previous research were taken while simulating these daily surgeries, that is, adults (male and female) of age 15 years and above were considered; pregnant women, patients refusing the surgeries, cancer patients (malignant/ premalignant), and day surgeries/minor OT patients were excluded; availability of all the patients that have been earmarked for the surgery; availability of OT staff, equipment and other OT resources; performance of daily surgeries as assumed procedure time of (30, 60, 120, 180 and 240 minutes); maximum procedure time allowed for a day will not exceed 540±30 minutes; and usage of commercial tools for statistical analysis (*IBM SPSS Statistics for Windows, Version 28.0*, 2021) and simulations (*PyCharm*, 2021). Moreover, in this paper, it is also assumed that the condition of patient has not changed during the period under consideration.

3.6 Ethical Review and Verbal Consent

"Ethical Review Board, Department of Management Sciences, Sir Syed CASE Institute of Technology, Islamabad, Pakistan" was formally obtain. Prior to data recording, "verbal informed consent of patients" was also obtained.

4. Results

As already stated, the data collected in research (Rana et al., 2022) was considered for application of proposed technique to compare results and determine its efficacy. Comparison summary between the simulations of previous results with proposed technique are appended in Table 5. The wait-time count of unprioritized waitlist and prioritized waitlist is given in Table 6. A comparison between the surgeries delayed or performed earlier of previous results and proposed technique are given in Table 7. Details of Delayed Surgeries are appended in Table 8.

Table 5. Comparison Summary - Previous research vs Proposed technique

Attributes	Previous research (Rana et al., 2022)		Present Research
MCDM Technique	None (First-come first-serve)	Weighted-Sum Method	Fuzzy TOPSIS
Criteria Weight Calculation method		Linear scale	Fuzzy Scales
Wait-Time incorporated		No	Yes
Number of patients	114	114	114
Average wait-time (a_{swl})	4.246 days (SD: 3.483)	2.956 days (SD: 5.387)	2.810 days (SD: 2.139)
• Improvement		30.4%	33.8%
Minimum wait-time	1 day	1 day	1 day
Maximum wait-time	15 days	34 days	8 days
• Improvement		- 126.7%	46.7%
Total number of OPD days	12	12	12
Total number of surgery days	39	37	32
• Improvement		5.1%	17.9%
Delayed Surgeries		11	8
• Maximum delays in Surgeries		30	8
• Actual Maximum delay		30	5
• Average actual delay in surgeries		12.546 (SD: 12.546)	3.000 (SD: 1.069)

Table 6. Comparison of Wait Times - Previous research vs Proposed technique

Wait-time (days)	Unprioritized wait time $t_s - t_e$ (unprioritized)		Prioritized wait time $t_s - t_e$ (Prioritized with WSM)		Prioritized wait time $t_s - t_e$ (Prioritized with Fuzzy TOPSIS)	
	Count	Percent	Count	Percent	Count	Percent
1	37	32.5%	94	82.5%	56	49.1%
3	23	20.2%	1	0.9%	23	20.2%
4	17	14.9%	1	0.9%	15 (3 delayed)	13.2%
5	8	7.0%	1	0.9%	3 (3 delayed)	2.6%
6	6	5.3%	4	3.5%	6 (2 delayed)	5.3%
8	10	8.8%	2 (1 delayed)	1.8%	8	7.0%
10	3	2.6%	-	-		
11	4	3.5%	2 (1 delayed)	1.8%		
12	-	-	1 (1 delayed)	0.9%		
13	5	4.4%	2 (2 delayed)	1.8%		
15	1	0.9%	2 (1 delayed)	1.8%		
20			2 (2 delayed)	1.8%		
27			1 (2 delayed)	0.9%		
34			1 (1 delayed)	0.9%		

Table 7. Comparison of number of surgeries - Previous research vs Proposed technique

Surgeries performed earlier or delayed once compared to 'First-come first-serve' technique	Weighted-Sum Method (Rana et al., 2022)	Fuzzy TOPSIS (Present Research)
Neither delayed nor performed earlier	36	52
Performed earlier	67	54
Delayed	11	8

Table 8. Details of Delayed Surgeries - Proposed Technique

Patient ID	Examination Date	Surgery Date (First-come first-serve)	Surgical Date (F-TOPSIS)	Wait-Time (Days)	Difference in Surgical Dates (Days)
	T_e	T_{SF}	T_{ST}	$WT = T_{ST} - T_e$	$T_{ST} - T_{SF}$
P003-01	17-Sep-2021	18-Sep-2021	23-Sep-2021	6	5
P003-03	17-Sep-2021	18-Sep-2021	21-Sep-2021	4	3
P004-01	20-Sep-2021	21-Sep-2021	25-Sep-2021	5	4
P004-04	20-Sep-2021	23-Sep-2021	25-Sep-2021	5	2
P006-01	24-Sep-2021	25-Sep-2021	28-Sep-2021	4	3
P006-03	24-Sep-2021	25-Sep-2021	28-Sep-2021	4	3
P009-06	01-Oct-2021	05-Oct-2021	07-Oct-2021	6	2
P010-03	04-Oct-2021	07-Oct-2021	09-Oct-2021	5	2
Average				4.875 days	3.000 days
Standard Deviation				0.835 days	1.069 days

Figure 4 shows the sensitivity analysis of weight variation of the criteria.

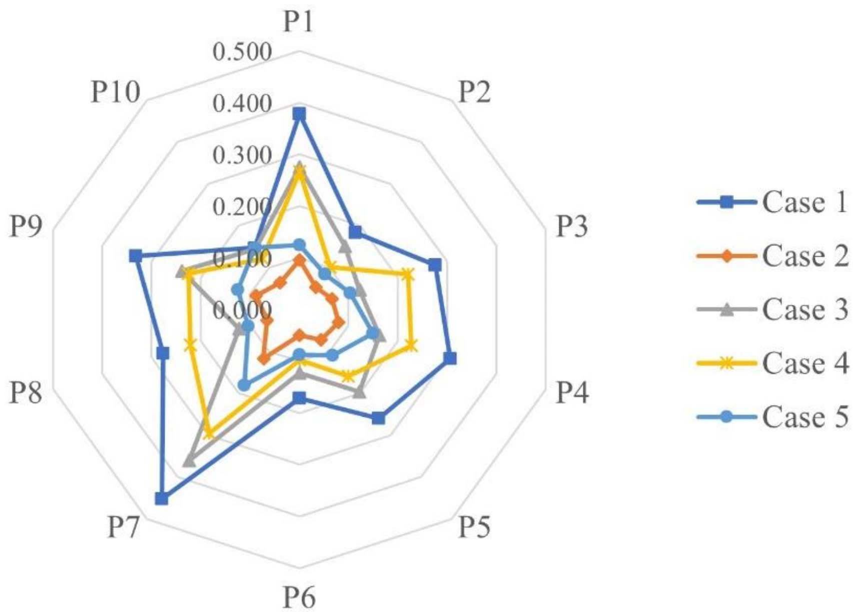

Figure 4. Sensitivity Analysis of Criteria Weights

Different cases of weight variation are given in Table 9 whereas Table 10 shows the position of patients on the priority list from which it can be seen that Patient #7 stands on as top priority in all the cases.

Table 9. Patient-wise Sensitivity Analysis of Criteria Weights

Patients	Case 1	Case 2	Case 3	Case 4	Case 5
P1	0.378	0.096	0.275	0.266	0.124
P2	0.184	0.054	0.150	0.102	0.084
P3	0.276	0.066	0.123	0.221	0.103
P4	0.306	0.080	0.162	0.228	0.150
P5	0.261	0.072	0.196	0.160	0.109
P6	0.171	0.050	0.123	0.098	0.088
P7	0.452	0.118	0.362	0.296	0.181
P8	0.276	0.066	0.123	0.221	0.103
P9	0.332	0.088	0.239	0.225	0.125
P10	0.147	0.064	0.145	0.122	0.147

Table 10. Priority-wise Sensitivity Analysis of Criteria Weights

Patient's Priority	Case 1	Case 2	Case 3	Case 4	Case 5
1st	7	7	7	7	7
2nd	1	1	1	1	4
3rd	9	9	9	4	10
4th	4	4	5	9	9
5th	3	5	4	3	1
6th	8	3	2	8	5
7th	5	8	10	5	3
8th	2	10	6	10	8
9th	6	2	3	2	6
10th	10	6	8	6	2

5. Discussion

Patients' prioritization is a rising concern within the medical domain particularly where healthcare systems have meagre resources being publicly funded. Such healthcare systems are usual focus of criticism such as missing transparency, delayed and/or denied treatment to the deserving, errors in judgment during assessment, increased load of work, emotional and ethical burden on the physician, and unmanaged hospital resources. Such issues have partially been addressed (Rana et al., 2022) in which prioritization of patients was carried out objectively and the average wait-time for the patients on the waitlist was effectively reduced. The present research is focused on improving the methodology through application of established multi-criteria decision making (MCDM) techniques.

Gebre et al. (2021) classified MCDM into discreate or continuous. Within discreate classification, it was further bifurcated into 1) Value function MCDM such as Weighted Sum Model (WSM) or Simple Additive Weighting (SAW), weighted product model (WPM), and combination of both, that is, Weighted Aggregated Sum Product Assessment (WASPAS) methods. These are the simplest MCDM methods that are used in simple multicriteria decision-making where all the data are in the same units (Perwira & Apriani, 2020). Utility function MCDM such as Multi Attribute Value Theory (MAVT), Multi Attribute Utility Theory (MAUT), etc. Such methods are used for decision making under risk (Martino Neto et al., 2022); 2) Pairwise comparison which compares different alternates in accordance with the set of criteria (Badi & Abdulshahed, 2019). These techniques include Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Best-Worst Method (BWM), Full Consistency Method (FUCOM), etc. 3) Out Ranking methods such as Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Elimination and Choice Expressing Reality (ELECTRE), Geometrical Analysis for Interactive Aid (GAIA) etc (Gebre et al., 2021). In ranking MCDM methods, decision-makers carry out pairwise ranking of all the alternatives with respect to each other against every criterion so as to assess which alternative is preferred over the other. The objective is to get support measures to judge each alternative until the overall top-ranked alternative is obtained. As compared to other methodologies, ranking methods are considered to be a complex methodology having non-intuitive inputs (Marqués et al., 2020); and lastly 4) Distance based MCDM methods that rank the alternates according to "shortest distance from the positive ideal solution and the longest distance from the negative ideal solution" (Hwang & Yoon, 1981), (Yuan et al., 2022). These methods include Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIšekriterijumsko KOmpromisno Rangiranje or multi-criteria optimization and compromise solution (VIKOR), Multi-Objective Optimization based on Ratio Analysis (MOORA), Multi-Attributive Border Approximation area (MABAC), etc.

Value function MCDM methods (WSM, WPM, WASPAS, etc) are used when the relationship between criteria and the alternates are simple. WSM has been used in prioritization of patients (Silva-Aravena et al., 2021; Rana et al., 2022), although the results were quite promising but some of the patients had to wait for more than the normal. From this it can be implied that the value function MCDM methods are not that efficient. Utility function MCDM methods are used when the decisions are to be made in situations involving risk where the outcomes are based on unknown probabilities. As the prioritization of patients is not carried out on unknown probabilities rather it is based on the physical and clinical condition of the patient judged by the surgeon, utility function MCDM methods (MAVT and MAUT) are not applicable.

While carrying out AHP and ANP methods, considering n number of criteria, it requires $n(n-1)/_2$ pairwise comparisons against each alternate (Sofuoğlu, 2019). Accordingly, an MCDM problem with 17 criteria will require 127 pairwise comparisons. A normal physical examination of patients varies from 15 to 20 minutes. After examination of 15 minutes, if a surgeon takes on average 30 seconds for a pairwise comparison, then a surgeon will require a continuous 39.25 hours (7.5 hours physical examination time plus 31.75 hours of pairwise comparison) to evaluate only 30 patients. Similarly, BWM requires or $2n-3$ pairwise comparisons (Pamučar et al., 2020; Moslem, 2023) meaning that 31 pairwise comparisons against each patient are still required which translates into approximately 15.5 hours of continuous examination of 30 patients. As this is humanly not possible for the surgeon, such pairwise comparison MCDM methods are, therefore, practically not possible to implement in case of prioritization of patients. The number of pairwise comparison have drastically reduced in case of FUCOM only requires $(n-1)$ pairwise comparisons (Sofuoğlu, 2019). FUCOM is a new subjective MCDM method mostly used in finding the criteria weights in the literature (Sofuoğlu, 2019). In order to address the high number of pairwise comparisons in AHP and BWM, these methods have been augmented with parsimonious models. These are one of the simplest models that has good explanatory predictive power as they can explain the data with a least possible parameter (Zhang et al., 2020). Only $(n-1)$ pairwise comparison required are required in parsimonious AHP (Abastante et al., 2019) and parsimonious BWM (Moslem, 2023) models. Parsimonious AHP and parsimonious BWM are new techniques with only few application thus the question on applicability remains open in terms of limitation and application conditions (Ammirato et al., 2022; Moslem, 2023). Considering 17 criteria, 16 pairwise comparisons will take 4 hours or continuous 13.5 hours (including 7.5 hours physical examination) to evaluate 30 patients a day. Similar is the case with ranking MCDM method which are also based on pairwise comparison and required evaluators time and cognition.

Distance based MCDM methods selects an alternate with shortest distances to positive and farthest distance negative ideal solution and rely on assignment of values to a different criterion against a particular alternative (Mudashiru et al., 2021). After the physical examination of patient, surgeon's input of approximately 3 minutes is required only once while assigning value to different criterion against a particular patient (assuming that a surgeon takes average of 10 seconds to judge and assign a value). It will take approximately 18 minutes to complete the complete evaluation of a patient or about continuous 9 hours for thirty patients which is four and half hours saving in case of other MCDM methods. Except for clinical examination of patient and filling of evaluation form, all the other steps are automated in Surgical Decision Support Tool especially designed for the purpose. Widianta et al. (2018) reported that TOPSIS give 95% accuracy once compared with other MCDM techniques such as Analytic Hierarchy Process (50%), Weighted Sum Method (81.67%), and Preference Ranking Organization Method for Enrichment Evaluation (93.34%).

To conclude the above discussion, we can comment that there is difference between selection and prioritization of alternatives, both rank the alternatives, but the former selects the best alternative and discard the rest of the alternatives, whereas in prioritization, no alternate is discarded as they are just arranging in an order based on the given criteria. As indicated earlier, in literature, AHP (Rahimi et al., 2017) and WSM (Silva-Aravena et al., 2021; Rana et al., 2022) are the only MCDM methods that have been used for prioritization of patients and the researched literature indicate that this may be one the first study that uses fuzzy TOPSIS method for the prioritization of patients.

Average wait-time is a key measure to gauge the performance of prioritization of waitlist (Rahimi et al., 2017; Rana et al., 2022; Rathnayake et al., 2021; Silva-Aravena et al., 2021). It can be seen that MCDM techniques reduce the average waiting time and as compared to WSM, Fuzzy TOPSIS technique (proposed in this research) has not only reduced it further but also substantially reduce maximum wait-time and number of delayed surgeries. The reduction in average and maximum wait-time, average delay time, and reduced surgery days can be clarified by two reasons: firstly, the use of fuzzy sets in determination of the priority scores of the patients including the calculation of weights; and secondly, the introduction of health deterioration index which assigns higher priority to patients who has waited more on the waitlist.

The clinical examination of patients is a subjective evaluation (Prachand et al., 2020; Rana et al., 2022; Silva-Aravena et al., 2021), the outcome of which cannot be precise as it involves approximation which are given in linguistic variables whose values are words or sentences in a natural or artificial language (e.g., mild, moderate, severe). Such vagueness in language is termed as "linguistic variables" and is quantified through Fuzzy Logic (Reyes-García & Torres-García, 2022). In this paper, using fuzzy logic, the linguistic variables are converted into crisp values which depicts a better health state and priority of the patients.

Literature (Rahimi et al., 2017; Prachand et al., 2020; Valente et al., 2020; Silva-Aravena et al., 2021; Hassan et al., 2021; Rana et al., 2022; Globerman et al., 2013;

Oudhoff et al., 2007; Prentice & Pizer, 2007; De Nardo et al., 2020; Testi et al., 2008) indicated that prioritization of patients is a complex process that is carried out once a patient is evaluated against multiple criteria. The traditional methodology based on "first-come-first-served" approach (Rahimi et al., 2017) do not use explicit criteria to rank the patient within the waitlist and use chronological time in deciding the rank of the patient in the list. Wait-time is a leading factor towards patients' dissatisfaction and discomfort. Beside other factors such as the health condition of patients, if the wait-time is also included as a contributing factor towards deciding the priority of the patient, it effectively eliminates the concerns of the patients. Ratio of wait-time to clinical urgency assessment has directly been used to ascertain the priority of the patients research (Valente et al., 2020). In research (Rahimi et al., 2016; Silva-Aravena et al., 2021), authors grouped the patients in four urgency categories based on their priority score vis-à-vis their health deterioration index (defined in this paper) for prioritization of patients through grouping of patients. Research (Silva-Aravena et al., 2021) also used maximum treatment time as a factor in accessing the priority score of the patient. In this paper, like authors (Rahimi et al., 2016; Valente et al., 2020; Silva-Aravena et al., 2021), overall priority score of the patient is obtained by directly multiplying the health deterioration index with health score, thus, giving it more weightage.

As the weight assigned to the criteria significantly impact the outcome of the adopted MCDM method, a sensitivity analysis is required to be performed (Chakraborty & Saha, 2022a). Its purpose is to see the effect of on entity on the overall outcome results (Saltelli et al., 2019). In this study, sensitive analysis was carried out by changing the weights of criteria to check their effects on the prioritization (Mukhametzyanov et al., 2018). It was concluded from the analysis that the prioritization is sensitive to the weights of the criteria that are used for the prioritization as changing the weights between the criteria alter the rank of the patients.

Some similarities and differences can be highlighted once compared with previous related researches on the prioritization of patients (Rahimi et al., 2016; Li et al., 2019; Silva-Aravena et al., 2021; Testi et al., 2008; Almeida et al., 2020; Rahimi et al., 2022); all the techniques are based on different criteria against which a patients are evaluated and scored. Moreover, like some of these studies, the proposed technique catered for the wait-time of the patient for prioritization. The proposed technique uses fuzzy sets to assign the weights to the criteria and then evaluate the examining surgeons' linguistic answers to each criterion. In contrast, the previously referred studies (Rahimi et al., 2016; Li et al., 2019; Silva-Aravena et al., 2021; Testi et al., 2008; Almeida et al., 2020; Rahimi et al., 2022) and research (Rana et al., 2022), used either linear or Likert scales while assigning the weights and score to different criteria. Another difference was found in the number of patients being evaluated, except for (Silva-Aravena et al., 2021; Testi et al., 2008), the number of patient is very small (less than a dozen).

A consideration that can be included in future studies to further improve the methodology pertains to deteriorating condition of the patient. The clinical condition of the patients may change because of ailment or deterioration which may change the priority score. Such a change in the priority score alters the surgery schedule of the patient and effects the overall sequencing of surgeries. Secondly, the linear relationship of health deterioration index may be changed to have more aggressive input once it approaches value of 1. In this way, it will create an alarming situation that the patient is waiting for more time and the health may get affected by delays. Lastly, machine learning techniques can be incorporated into prioritization of patients as demonstrated in papers (Silva-Aravena et al., 2022; Silva-Aravena & Morales, 2022).

6. Conclusion and future work

In this study, for the first time, a decision support system (DSS) for the prioritization of patients is proposed using TOPSIS, integrated a numerical measure of probable depreciated health state of patients on waitlist using modified MeNTS scoring system (having factors based on surgical procedures, effect of disease, and comorbidities of patient). The proposed methodology (Fuzzy TOPSIS - MeNTS DSS) considerably reduced the average and maximum wait-time, average delay time, and reduced surgery days. The proposed methodology has also been validated through simulations with assumptions that were based on existing data.

Besides reduction in time, the proposed priority scores system has other advantages as well: the physicians exactly know the clinical situation of the patients in real-time with their probable health deterioration state; hospital management can plan the capacities more efficiently; fast and fair selection of patients without favoritism of hospital staff including doctors thus satisfying the transparency and equity concerns of the patients; lastly, the automation of the system can help the surgeons to concentrate on their surgical tasks which increase the overall performance of the hospital.

During the waiting time, the clinical condition of the patients may change because of ailment or deterioration of the disease. In this study, it was assumed that the condition of a patient will not change during the period under consideration and is considered as a limitation of this study. Moreover, the actual hospital surgical workflow was not disturbed, and surgeries were simulated, the limitation warrant execution of proposed technique on the actual hospital setup. The availability of all the patients, OT staff, equipment and other OT resources was assumed to be present, however, the effect of non-availability of the same needs further deliberation. Lastly, the simulation of the surgeries was based on fixed surgical time which may vary in actual environment and needs to be studied.

In future research, the proposed methodology can further be modified to cater for the deteriorating clinical conditions of the patients on waitlists as the clinical condition of the patients may change because of ailment or deterioration which may change the priority score. A methodology can also be developed for prioritization of patients, while considering the scares resources such as limited capacities of Intensive Care Unit (ICU), Post-Anesthesia Care Unit (PACU) and surgical wards, availability of tools, equipment, and gasses in operating room, etc.

List of Abbreviations

Abbreviation	**Description**
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BWM	Best-Worst Method
CAD	Coronary Artery Disease
CC	Closeness Coefficient
CF	Cystic Fibrosis
CHF	Congestive Heart Failure
COPD	Chronic Obstructive Pulmonary Disease

CT Scan	Computed Tomography Scan
ELECTRE	Elimination and Choice Expressing Reality
FUCOM	Full Consistency Method
GAIA	Geometrical Analysis for Interactive Aid
HDI	Health Deterioration Index
HTN	Hypertensive
ICU	Intensive Care Unit
MABAC	Multi-Attributive Border Approximation area
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MCDM	Multicriteria Decision-Making
MeNTS	Medically Necessary Time Sensitive
MOORA	Multi-Objective Optimization based on Ratio Analysis
MRI	Magnetic Resonance Imaging
MTBT	Maximum Time Before Treatment
OPD	Outpatient Department
PACU	Post-Anesthesia Care Unit
PET Scan	Positron Emission Tomography Scan
Post-Op	Post Operative
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PS	Priority Score
SAW	Simple Additive Weighting
TFN	Triangular Fuzzy Number
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VIšekriterijumsko KOmpromisno Rangiranje or multicriteria optimization and compromise solution
WASPAS	Weighted Aggregated Sum Product Assessment
WPM	Weighted Product Model
WSM	Weighted Sum Method
WT	Waiting Time

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