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A Personnel Selection Problem in Healthcare System Using Fuzzy-TOPSIS Approach

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Abstract The methods of multiple criteria decision-making (MCDM) are increasingly becoming the most desired tools for making daily decisions in various fields of human endeavors. Staff employment in any sector requires a thorough evaluation of the applicant before selection to ensure effective and efficient service delivery. Besides, healthcare is one of the most complicated organizations dealing with human lives. This paper has developed a staff selection model considering a fuzzy environment by using the technique for order preference similar to the ideal solution (TOPSIS) method. For the delivery and promotion of quality healthcare systems, medical staff selection is crucial to the system. Therefore, the study evaluates medical staff by using the expert's linguistic judgement under the criteria of skill, experience and ability to respond to a problem. The expert's vagueness in judgments has been represented by using fuzzy triangular numbers. The study determines the closeness coefficient, the measures of separation and the ideal solutions of the TOPSIS method. The most appropriate medical staff are ranked and selected based on the available criteria. The Fuzzy-TOPSIS method is simple and can help other organizations achieve proper ranking, evaluation and selection of qualified candidates, as it takes imprecise information into account.

Keywords Fuzzy-TOPSIS, triangular fuzzy number, separation measure, closeness coefficient, ideal solution

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1. Introduction

Nowadays, MCDM methods are increasingly becoming the most desired tools for making daily decisions in various fields of human endeavors. Staff employment in any sector needs a thorough evaluation of the applicant before selecting them for

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effective and efficient service delivery. Besides, healthcare is one of the most complicated organizations dealing with human lives. Determining acceptable alternative measures and ranking prioritized needs in a medical unit/department are undoubtedly very demanding and challenging tasks that are necessary concerning various factors.

There are various multi-criteria techniques that help top managers select the right personnel from many qualified candidates to handle patients with reasonable care and services [25]. An optimum staff selection has a substantial positive impact on the effectiveness and efficiency of healthcare delivery process. Because of strategy diversity and disease characteristics among various patients, it would not be possible to consider all the criteria upon which decisions are made. Hence, a careful selection of qualified individuals in expression is needed. Medical personnel are more attracted to the recent advancement in technology, while the complexity of the system depends on an expertise selection. The healthcare industry is increasing day by day due to the exponentially growing population and the demand intensity for their global services. The need for optimal expert selection by decision-makers (DMs) is cardinal to achieving high-quality healthcare service delivery [29]. The decision to select a substantive medical expert or technologies involves evaluation on different criteria to ascertain their efficacy before selection. The challenging task before management is to adopt the evaluation technique, as the methods become increasingly important. This, in the literature, is known as a selection problem. This article presents a model for evaluating the medical staff under a fuzzy environment.

This article is organized as follows. Section 1 provides the introduction and overview of the study. The related literature on MCDM is reviewed in Section 2. Section 3 discusses the methodology of the study. Section 4 discusses preliminary fuzzy sets and TOPSIS under fuzziness. Section 5 presents the application of the methods discussed in a healthcare staff evaluation and selection. Finally, the article is concluded in Section 6.

2. Literature review

Over a decade, researchers have been using different techniques to evaluate and select criteria, suppliers and the quality of individuals. Some authors addressed the problem by using a single objective function, while others employed multiple objectives under different conditions and constraints. For instance, the requirements for selecting effective security in an engineering approach were studied by using Fuzzy logic, TOPSIS and analytic network process (ANP) [5, 6]. Fuzzy ANP has been applied in determining an organizational sectoral competition level based on "Poter's five forces analysis" [16]. Service quality, the impact of healthcare Web applications, environmental sustainability and RFID system suppliers have been evaluated in the healthcare industry by using Fuzzy TOPSIS, analytic hierarchy process (AHP) and ANP [2, 10, 11, 33, 34]. Recently, Khambhati, Patel and Kumar [20] have evaluated service quality performance and compared models of the urban public healthcare system. A hospital classification based on service quality has been studied by using AHP as an MCDM tool [4]. Similarly, an integrated approach for the TOPSIS has been studied recently in selection of pharmaceutical suppliers [23]. The performance of an operating room in a hospital has been evaluated with the help of a balanced scorecard and fuzzy linguistics to measure the service [22]. The VIKOR method, TOPSIS and fuzzy MCDM have been carried out to obtain the weight importance of criteria in hospitals [3, 12, 22, 26, 32]. The TOPSIS approach has been hybridized alongside fuzzy sets considering the Pythagorean approach and applied in assessing the risk associated with a natural gas pipeline clearing and grading, and the objective is to prioritize the hazards [27]. Recently, Gardas, Ghongade and Jagta [17] have studied the interconnectivity among the dependence causative factors of non-union fracture and prioritised the factors by using MCDM. Hosseini et al. [18] applied a hybrid multiple-attribute decision-making analysis to assessing the tourism risk for improving the urban heritage in Tehran. The data play a vital role in decision-making process, and the COVID-19 pandemic has demonstrated that several authors conducted comparative studies by using existing models and made decisions based on the data availability. Some such works include the comparison of trigonometric model distributions for practical data set analysis as conducted by Chesneau and Artault [15]. Sun et al., [31] have analyzed the dynamics of SIS epidemic model considering the effects of awareness.

In the existing literature, limited studies were reported in consideration of the fuzzy sets, MCDM techniques and healthcare staff evaluation and selection. Therefore, this study presents an approach using the fuzzy TOPSIS concept to provide a truthful process for healthcare staff evaluation and selection decisions. An MCDM is a crucial perspective of operations research, and by extension, it reflects a multiple criterion in the decision-making environment.

3. Methodology

3.1. TOPSIS method

TOPSIS had been initially developed for solving MADM problems [19], and was extended to solve MODM problems [21]. The principle underlying this method is choosing the alternative having the longest possible distance from its solutions known as negative ideal solutions (NIS) and the shortest reasonable distance known as positive ideal solutions (PIS).

Assume that there exists a decision matrix D, having m as the number of alternatives and each having n as the number of criteria (see equation (3.1), the cost or benefit of the criteria may be attributed and measured in various units. Hence, there is a conflicting nature. The problem a decision-maker faces is the selection of the best alternative considering the available information

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ldots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}. \tag{3.1}$$

The stepwise algorithms for TOPSIS computations are given below.

Step 1. Formulate and normalize the decision matrix. Since the attributes of the criteria have different units of measurement, they are first normalized to bear the same unit, and various methods exist for doing that. Using the vector method, we have

$$r_{ij} = \frac{x_{ij}}{\left(\sum_{i=1}^{m} x_{ij}\right)^{1/2}}, \tag{3.2}$$

where x_{ij} are resulting consequences of the decision matrix D.

Step 2. Construct the weighted matrix as follows

$$\upsilon_{ij} = w_j r_{ij}, \quad i = 1, 2 \cdots m, \quad j = 1, 2, \cdots n, \tag{3.3}$$

where w_j represents the criteria weights and $\sum_j w_j = 1$.

Step 3. Determine the PIS and NIS as follows

$$\left.\begin{aligned} &PIS^+ = \{\upsilon_1^+, \upsilon_2^+ \cdots \upsilon_n^+\} \\ &\upsilon_j^+ = \{\max_i \upsilon_{ij} \quad if \quad j \in B, \quad \min_i \upsilon_{ij} \quad if \quad j \in C\} \\ &NIS^- = \{\upsilon_1^-, \upsilon_2^- \cdots \upsilon_n^-\} \\ &\upsilon_j^- = \{\min_i \ \upsilon_{ij} \quad if \quad j \in B, \quad \max_i \ \upsilon_{ij} \quad if \quad j \in C\} \end{aligned}\right\}. \tag{3.4}$$

Step 4. Calculate the separation measure as follows

$$\begin{aligned} S_i^+ &= \sqrt{\textstyle\sum_{j=1}^n \left(\upsilon_{ij} - \upsilon_j^+\right)^2}, \quad \forall i = 1, 2, \cdots, m, \\ S_i^- &= \sqrt{\textstyle\sum_{j=1}^n \left(\upsilon_{ij} - \upsilon_j^-\right)^2}, \quad \forall i = 1, 2, \cdots, m. \end{aligned} \tag{3.5}$$

Step 5. Calculate the relativeness to ideal solution as

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \quad i = 1, 2, \cdots, m, \tag{3.6}$$

if $A_i = PIS^+$, *then* $C_i = 1$, *and if* $A_i = NIS^-$, *then* $C_i = 0$, i.e., $C_i \in [0, 1]$. The best alternative is selected based on the value of C_i.

The pictorial representation of the steps involved in the process is given in Figure 1.

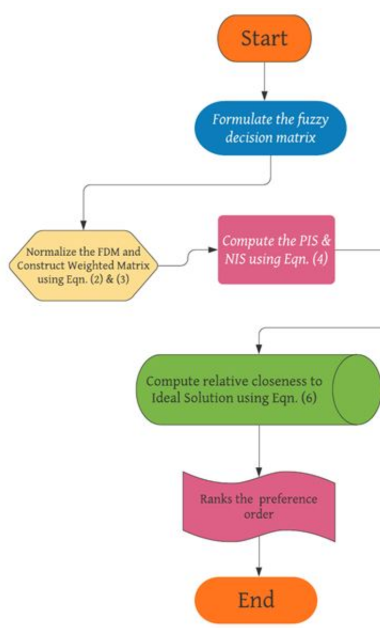

Figure 1. Model framework for FTOPSIS

4. Decision making under a fuzzy environment (DMUFE)

The DMUFE has been reported in different contexts [7] since the 1970s. TOPSIS and AHP are similarly applied without considering the fuzziness in the system [13, 14, 24, 26, 40]. In this section, decision making using TOPSIS under a fuzzy environment is discussed. The usefulness of a fuzzy set concept is discussed first with basic definitions and concepts, and after that the fuzzy-TOPSIS is presented.

4.1. Fuzzy set preliminaries

In this section, some concepts, definitions and notations of the fuzzy set are introduced. Several basic definitions of this topic and their different types are outlined briefly. For more details, we refer the readers to [9, 14, 28, 30, 35–38].

Definition 4.1. Fuzzy set: Let X be considered a set known as the universal of discourse. A mapping $\mu : X \to [0,1]$ can be a membership function, if $\mu(x) \in [0,1]$. A fuzzy set can be denoted by $\widetilde{A}$ and defined as the pair (X, μ) given by the relation in (4.1),

$$\widetilde{A} = \{(x, \mu_x(x))|x \in X\}. \tag{4.1}$$

Definition 4.2. Triangular fuzzy number: A triangular fuzzy number $\widetilde{A}$ can be defined in terms of a triplet (a_1, a_2, a_3) shown in Figure 2.

The membership function $\mu_{\widetilde{A}}(x)$ of $\tilde{\mathbf{A}}$ is given as

$$\mu\widetilde{A}(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}, \; a_1 \leq x \leq a_2, \\ \\ \frac{a_3-x}{a_3-a_2}, \; a_2 \leq x \leq a_3, \\ \\ 0. \qquad Otherwise, \end{cases}$$

where $a_1, a_2, a_3 \in \mathbb{R}$ with $a_1 \leq a_2 \leq a_3$.

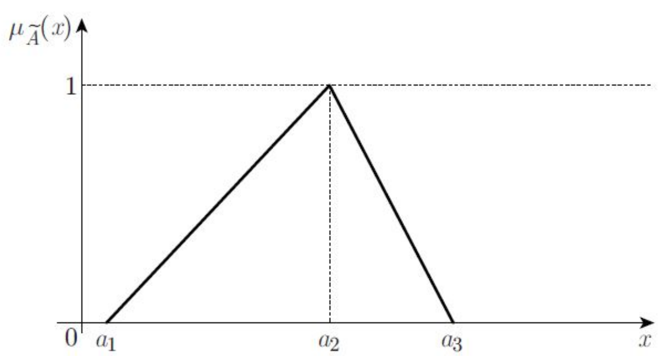

Figure 2. Triangular fuzzy number

Definition 4.3. Fuzzy matrix: Let $\widetilde{\mathbf{D}}$ be a fuzzy matrix such that at least an entry of its element is a fuzzy number [13].

Definition 4.4. Linguistic variable: A variable is said to be linguistic, if and only if its values are expressed in linguistic term [37].

The linguistic variable concepts can be useful in describing a complex decision-making situation in which the precision in the judgement values is neither available nor quantifiable [37]. For example, "speed" is a linguistic variable whose values can be very "high", "moderate", "low", "very low", etc (see Tables 1 and 2). These values are represented as fuzzy numbers.

Table 1. Linguistic variables for importance weight of each criteria

Very poor	(VP)	(0.1,0.1,0.3)
Poor	(P)	(0.1,0.3,0.5)
Medium good	(MG)	(0.3,0.5,0.7)
Good	(G)	(0.5,0.7,0.9)
Very good	(VG)	(0.7,0.9,0.9)

Table 2. Linguistic variables for all alternative ratings

Very low	(VL)	(1,1,3)
Low	(L)	(1,3,5)
Average	(AV)	(3,5,7)
High	(H)	(5,7,9)
Very high	(VH)	(7,9,9)

4.2. Fuzzy-TOPSIS (FTOPSIS)

In the TOPSIS method, the criteria importance information is deterministic. Whereas, in FTOPSIS, they are considered fuzzy because of the vagueness of the information. Hence, they are represented by fuzzy numbers (FNs). Different types of FNs exist. However, this study considers the triangular fuzzy number (TFNs). It is a simple representation of the information in terms of minimum, average and maximum value. Tables 1 and 2 present some examples of such information and their alternative ratings according to Chen [13].

4.3. Fuzzy decision matrix

Here, it is assumed that a group of decision-makers exist. They involve N number of persons (say k), and the criteria importance of individuals and their alternatives can be calculated through a fuzzy decision matrix $\widetilde{D}$ and fuzzy weighted matrices $\widetilde{W}$. According to Modibbo et al., [23], fuzzy decision matrix $\widetilde{D}$ (equation (4.2)) is obtained in light of equations (3.1) and (3.3) as follows.

$$\widetilde{D} = \begin{pmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{pmatrix}, \tag{4.2}$$

$$\widetilde{W} = \left(\widetilde{w}_1 \ \widetilde{w}_2 \ \cdots \ \widetilde{w}_n \right), \tag{4.3}$$

where $\tilde{x}_{ij}$ *and* $\tilde{w}_{ij}$ are the linguistic variables representation for rating and importance weight of the k^{th} DM. They can be expressed by a triangular fuzzy number

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \ \ \forall i, j, \ \ \tilde{w}_{ij} = (w_{ji}, w_{j2}, w_{j3}), \ \ \forall j = 1, 2, \cdots, n.$$

Thus,

$$\left\{ \begin{array}{l} \tilde{x}_{ij} = \frac{1}{K} \left\{ \tilde{x}_{ij}^1 \oplus \tilde{x}_{ij}^2 \oplus \cdots \oplus \tilde{x}_{ij}^k \right\} \\ \tilde{w}_{ij} = \frac{1}{K} \left\{ \tilde{w}_{ij}^1 \oplus \tilde{w}_{ij}^2 \oplus \cdots \oplus \tilde{w}_{ij}^k \right\} \end{array} \right\}. \tag{4.4}$$

A linear transformation is used to normalize the fuzzy decision matrix and different scales compared within the interval [0,1]. Next, a fuzzy decision matrix $\tilde{\mathbf{R}}$ is constructed in light of equation (3.3) as given below.

$$\widetilde{\mathbf{R}} = \left[\tilde{r}_{ij}\right]_{m \times n}. \tag{4.5}$$

The sets of criteria for benefit (B) and cost (C) are constructed from the fuzzy decision matrix $\widetilde{\mathbf{R}}$ as follows.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \ j \in B; \qquad \tilde{r}_{ij} = \left(\frac{a_j^-}{c_i j}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), \ j \in C; \tag{4.6}$$

where $c_j^* = \max_i c_{ij}, \quad if \quad j \in B; a_j^- = \min_i a_{ij}, \quad if \quad j \in C.$

Similarly, we can normalize the fuzzy weighted matrix using equation (3.2) as follows.

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m \times n} \qquad i = 1, 2, \cdots, m; \quad and \quad j = 1, 2, \cdots, n, \tag{4.7}$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_j$.

The elements of $\tilde{v}_{ij}$ are normalize positive triangular FNs on interval [0,1] for all i, j. Therefore, the fuzzy positive ideal solution (PIS^*) and fuzzy negative ideal solution (NIS^-) can be defined from the normalized fuzzy weighted elements $\tilde{v}_{ij}$ as follows.

$$PIS^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \cdots, \tilde{v}_n^*\right), \qquad NIS^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \cdots, \tilde{v}_n^-\right), \tag{4.8}$$

where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$ for $j = 1, 2, \cdots, n$.

Next, the euclidian distance (D_i^* & D_i^-) can be calculated for each alternative from PIS^* and NIS^- as follows.

$$\begin{array}{l} D_i^* = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2, \cdots, m, \\ D_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \cdots, m, \end{array} \tag{4.9}$$

where $d(.,.)$ measures the distance between two fuzzy numbers. The closeness coefficient (CC_i) is used to determine the ranking of the individual alternatives and is given below.

$$CC_i = \frac{D_i^-}{D_i^* + D_i^-}, \quad i = 1, 2, \cdots, m. \tag{4.10}$$

As CC_i tends to unity, A_i becomes closer to PIS^* and the furthest from NIS^-. Finally, the alternatives of ranking order are determined and selected based on the closeness coefficient function.

5. Application of the methods in healthcare staff selection

Considering Department of Community Medicine (say), we would like to select healthcare personnel according to their performance during an interview. Suppose that there is a set of interviewers $E = \{E_1, E_2, E_3\}$ who will rate the candidates objectively based on a certain set of criteria $C = \{C_1, C_2, C_3\} = \{$ Skills, Experience, Response$\}$. Also, suppose that there is a set of candidates A, B, C, D who must undergo a rigorous interview before finally selected. Now, the problem is who should be selected among the candidates based on the interview results.

Table 3 presents the linguistic ratings of the first interviewer for all the candidates.

Table 3. Linguistic rating of candidates for the interviewer E_1

Candidate	Skills	Experience	Response
A	Average	Very high	High
B	High	Very high	Average
C	Very high	Average	Low
D	Low	Average	Very low

Table 4 presents the linguistic ratings of the second interviewer for all the candidates.

Table 4. Linguistic rating of candidates for the interviewer E_2

Candidate	Skills	Experience	Response
A	High	Very high	High
B	High	High	Average
C	Very high	Average	Very low
D	Low	Average	Very low

Table 5 presents the linguistic ratings of the third interviewer for all the candidates.

Table 5. Linguistic rating of candidates for the interviewer E_3

Candidate	Skills	Experience	Response
A	Average	High	High
B	High	Average	Average
C	High	Average	Low
D	Very Low	Low	Very low

Using the concept of triangular fuzzy number and the linguistic variables defined in Table 2, the first interviewer's alternative ratings for all candidates are given in Table 6.

Table 6. Alternative ratings for the interviewer E_1

Candidate	Skills			Experience			Response		
A	3	5	7	7	9	9	5	7	9
B	5	7	9	7	9	9	3	5	7
C	7	9	9	3	5	7	1	3	5
D	1	3	5	3	5	7	1	1	3

Similarly, the second interviewer's alternative ratings for all candidates are given in Table 7.

Table 7. Alternative ratings for the interviewer E_2

Candidate	Skills			Experience			Response		
A	5	7	9	7	9	9	5	7	9
B	5	7	9	5	7	9	3	5	7
C	7	9	9	3	5	7	1	1	3
D	1	3	5	3	5	7	1	1	3

Finally, the third interviewer's alternative ratings for all candidates are given in Table 8.

Table 8. Alternative ratings for the interviewerE_3

Candidate	Skills			Experience			Response		
A	3	5	7	5	7	9	5	7	9
B	5	7	9	3	5	7	3	5	7
C	5	7	9	3	5	7	1	3	5
D	1	1	3	1	3	5	1	1	3

The combined fuzzy decision matrix of the three interviewers for all the candidates is given in Table 9.

Table 9. Combined fuzzy decision matrix

Candidate	Skills			Experience			Response		
A	3	5.666666667	9	5	8.333333333	9	5	7	9
B	5	7	9	3	7	9	3	5	7
C	5	8.333333333	9	3	5	7	1	2.3333333	5
D	1	2.333333	5	1	4.33333	7	1	1	3

Table 10 presents the fuzzy normalized decision matrix of Table 9.

Table 10. Normalized fuzzy decision matrix

Candidate	Skills			Experience			Response		
A	0.333	0.630	1	0.556	0.926	1	0.111	0.143	0.200
B	0.556	0.778	1	0.333	0.778	1	0.143	0.200	0.333
C	0.556	0.926	1	0.333	0.556	0.778	0.200	0.429	1
D	0.111	0.259	0.556	0.111	0.481	0.778	0.333	1	1

Now, the weighted normalized fuzzy decision matrix is constructed by using equation (4.3) and presented in Table 11.

Table 11. Weighted normalized fuzzy decision matrix

Candidate	Skills			Experience			Response		
A	1.667	4.407	9	3.889	8.333	9	0.333	0.714	1.400
B	2.778	5.444	9	2.333	7	9	0.429	1	2.333
C	2.778	6.481	9	2.333	5	7	0.600	2.143	7
D	0.556	1.815	5	0.778	4.333	7	1	5	7
A*	2.778	6.481	9	3.889	8.333	9	1	5	7
A-	0.556	1.815	5.000	0.778	4.333	7	0.333	0.714	1.400

Now, by using equation (4.8), the distances from the fuzzy positive and negative ideal solutions are computed and presented in Tables 12 and 13 respectively.

Table 12. Distance from FPIS

Candidate				d^*
A	1.358	0.000	4.089	5.448
B	0.599	1.183	3.564	5.346
C	0.000	2.417	1.666	4.083
D	3.773	3.145	0.000	6.919

Table 13. Distance from FNIS

Candidate				d^-
A	2.826	3.145	0.000	5.971
B	3.372	2.124	0.566	6.062
C	3.773	0.977	3.340	8.091
D	0.000	0.000	4.089	4.089

Finally, equation (4.10) is used to compute the relative closeness coefficient to ideal solutions and the results presented in Table 14.

Table 14. Closeness Coefficient

Candidate	CC_i value	Rank
A	0.522908521	3
B	0.531405555	2
C	0.664606015	1
D	0.371494137	4

From Table 14, it is clear that the best coefficient of closeness is candidate C with a value of 0.66461 followed by candidate B with CC_i value of 0.53141. Then, the closeness values of candidates A and B are 0.52291 and 0.37150 respectively. Therefore, if only one candidate is needed, then candidate C will be selected, and if two candidates are needed, C and B will be selected. Similarly, if three candidates are required for the job, candidates C, B, A are qualified and so on. Also, the selection could be based on remuneration. That is to say, everyone can be selected with varying salaries based on the candidates' performance during the interview.

6. Conclusion

Multiple decision-making is a challenging task confronted by managers in any organizations. Selecting the best person capable of fully satisfying the requirement of decision-makers in respect of predetermined criteria and the needs of organizations is also a challenging decision. The present paper discusses an MCDM method in solving a staff selection problem by considering a fuzzy situation in a healthcare system. The study considers a multi-expert's judgment in interviewing and assessing the candidates for the healthcare staff selection. The triangular fuzzy number represents the vagueness in the assessment information of the experts based on the criteria for skills, experience and ability to respond to issues by the candidates quickly. We aggregated the experts' rating alternatives, and employed the TOPSIS method in addressing decision-making under a fuzzy environment. The separation measures and the positive and negative ideal solutions are then computed. Finally, the candidates are ranked considering the values of the closeness coefficient.

This approach is flexible, systematic and devoid of bias. The method is applicable in organizations other than healthcare such as faculty selection in universities and supplier selection in supply chain networks. The limitation of the technique is that different experts or interviewers may have different ratings of candidates. However, it is bias-free, if adopted. Many crises and partitions arising from job interviews will be minimum, if a scientific approach is employed. Selected staff based on these methods are very likely to work hard because of subsequent evaluations for promotions. Hence, the quality of service will improve in particular, thereby improving the system generally. A further limitation is that the study has not considered the membership and non-membership functions of the fuzzy number. These limitations will be incorporated and explored in future researches. The fuzzy TOPSIS method is simple, and it can help other organizations rank and select qualified personnel or equipment types properly.

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