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A New Extension of the VIKORSort-Based Method for Fuzzy Classification: An Application for Prioritizing Patients in the ICU Unit Queue

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Abstract

Due to the importance of the field of health in people's lives, the use of different sciences in order to improve this field for the comfort of people has expanded significantly in recent years. Considering that the ranking field can have many applications in different parts of the health field, such as hospitals, emergency departments, pharmacies, and related necessities, in this study, we have tried to use one of these fields and review it. Patients who enter the Intensive Care Unit (ICU) ward for emergency services are inadvertently placed in waiting queues. In this study, the ordering of this queue was investigated by a mathematical model. Applications of multi-criteria decision-making systems should be discussed. In this research, we develop the Vlse Kriterijumsk Optimizacija Kompromisno Resenje Sort (VIKORSort) method based on fuzzy logic. Then, the performance of the newly proposed method is investigated with a real-world application for prioritizing and admitting patients to the ICUs of the hospital.

Keywords: Vlse kriterijumsk optimizacija kompromisno resenje sort, Multi-criteria decision making, Intensive care unit, Fuzzy, Sorting, Decision making.

1 | Introduction

The ICU ward is one of the most critical wards of any hospital, and organizing how to deal with these patients and improve the quality of clinical and medical services for these patients is one of the requirements of health development [1–4]. So that patients in this ward can be ranked according to predefined indicators. The importance of the hospital organization as an influential component of the health care system is not hidden

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from anyone. Providing quality services, in addition to increasing the likelihood of success in medical procedures, differentiates between providers and increases the competitiveness of these organizations [3–5]. Due to the importance and urgency of the situation in the ICU, the ranking of hospital patients, especially in the ICU, is very important. Many methods for ranking have been studied in various issues, including medicine, energy, industry, etc [2–4], [6], [7].

One of the most critical methods in ranking and prioritizing multi-criteria decision-making methods. This problem can be solved with the help of multi-criteria decision-making methods. Recently, many developments have been proposed for multi-criteria decision-making methods.

Ishizaka [8] created an AHP-based problem-sorting algorithm. Unlike the primary technique, which is entirely based on weighing and ranking, this method allocates alternatives to pre-selected categories.

In [9], a new AHP-based risk classification sorting algorithm, AHPSort II, was created to rank Umbrian communities by their vulnerability to wolf attacks. A lesser number of pairwise comparisons are performed in this approach compared to the standard one.

In [10] presented a fuzzy extension of the AHPSort method (FAHPSort). Cost-benefit AHPSort was proposed in [11] to evaluate the efficiency of oshore service providers. An improved version of the AHPSort sorting system was provided, one in which cost and benefit criteria are treated independently.

In [12] developed AHPSort II in interval type-2 fuzzy environment for Sustainable supplier selection problem. In [13] extended a novel method AHPSort-GAIA through a case in the food and drink industry. In [14] presented a new sorting method with consensus, Consensual GAHPSort for sustainable development achievements by European Union countries.

In [15] developed a new method called Analytic hierarchy process-fuzzy sorting based on fuzzy classification in sorting problems. Another developed method in Multi-Criteria Decision-Making (MCDM) sorting was the ANP method, which Ishizaka and López [11] extended in 2019. The ANPSort method is used for the sorting of alternatives with interdependent criteria, illustrated by the classification problem of a researcher.

The new VIKOR-based sorting method was proposed by Demir et al. [1]. Suppliers' environmental performance may be evaluated using this technique. A novel method is presented by Sabokbar et al. [16] TOPSIS-sort based on the traditional TOPSIS. A strong relationship for sorting purposes is used in the TOPSIS-Sort approach.

The approach proposed uses the classes and outer relationships as the preferred models with characteristic profiles. The application of the approach proposed shows that 22 districts of Tehran are classified into five classes representing areas of different environmental quality levels. Sorting using TOPSIS through boundary and characteristic profiles was then suggested by De Lima Silva and De Almeida Filho [17] (TOPSIS-Sort-B and TOPSIS-Sort-C).

Another method developed was the ELECTREE method. The first ELECTRE extension in the sorting environment is ELECTRE-Tri. Then ELECTRE Tri-C, ELECTRE-SORT, ELECTRE Tri-nC, ELECTRE Tri-nB, and a few other options have to be released after this. Nearly all MCDA were modified in the new research, also to resolve sorting problems.

For instance, BWMSort II in an Interval Type-2 Fuzzy Environment, UTA extension is UTADIS in the sorting issue. FlowSort is an extension of the PROMETHEE, and for MACBETH and DEA, MACBETH Sort and DEASORT were applied.

In this research, we develop a method based on fuzzy logic. Then, the performance of the new proposed method is investigated with a real-world application for prioritizing and admitting patients to the ICUs of the hospital.

2 | Preliminaries

The VIKOR method is an efficient tool for finding a suitable solution for a set of criteria that has been widely used in many fields. This method, the abbreviation of the Serbian phrase Vlse Kriterijumsk Optimizacija Kompromisno Resenje, is a model with many different applications in deciding and choosing the best option [5]. The VIKOR method has been developed since 1984 based on the process of collective agreement and with conflicting criteria, and it is often used in solving discrete problems [7].

In reality, the VIKOR model can be used for prioritizing or ranking options by evaluating options based on each criterion [18]. In this method, each criterion is not weighted. Still, other approaches assess the criteria, and after that, the other methods are evaluated and positioned according to the criteria and by combining the value of the criteria [19].

The advantage of the VIKOR model is that it is not always necessary to use the experts' opinions to evaluate the options based on criteria. Still, raw data can be used [20]. For example, in the criterion of "communication road", in order to evaluate which village has favorable conditions, instead of scoring by experts, the distance of the communication road to the village can be measured and included in the model without the need for expert evaluation.

This is the main difference between VIKOR and the others, for example, while the ANP and AHP were developed with pairwise comparisons of criteria and options in mind, the VIKOR model treats each option as if it were a stand-alone entity, eliminating the need for any such comparisons [21]. It is evaluated based on each criterion. This assessment is dependent on either raw data or an expert's opinion. Therefore, the primary purpose of VIKOR is to determine the weight of all alternatives and their ranking [22].

The VIKOR model is used in various geographical topics such as determining the optimal location of hotel construction, supply chain management, maintenance, ranking cities based on services, prioritizing the distribution patterns of urban settlements, prioritizing sample tourism areas, and so on [23–27].

Recently, this technique was created [1] to provide a different way of dealing with multi-criteria decision issues using a ranking strategy. We offer the Vlse Kriterijumsk Optimizacija Kompromisno Resenje Sort (VIKORSort) approach for MCDM, where choices are ranked according to their allocation.

In review, the algorithm of VIKOR is in *Fig. 1*.

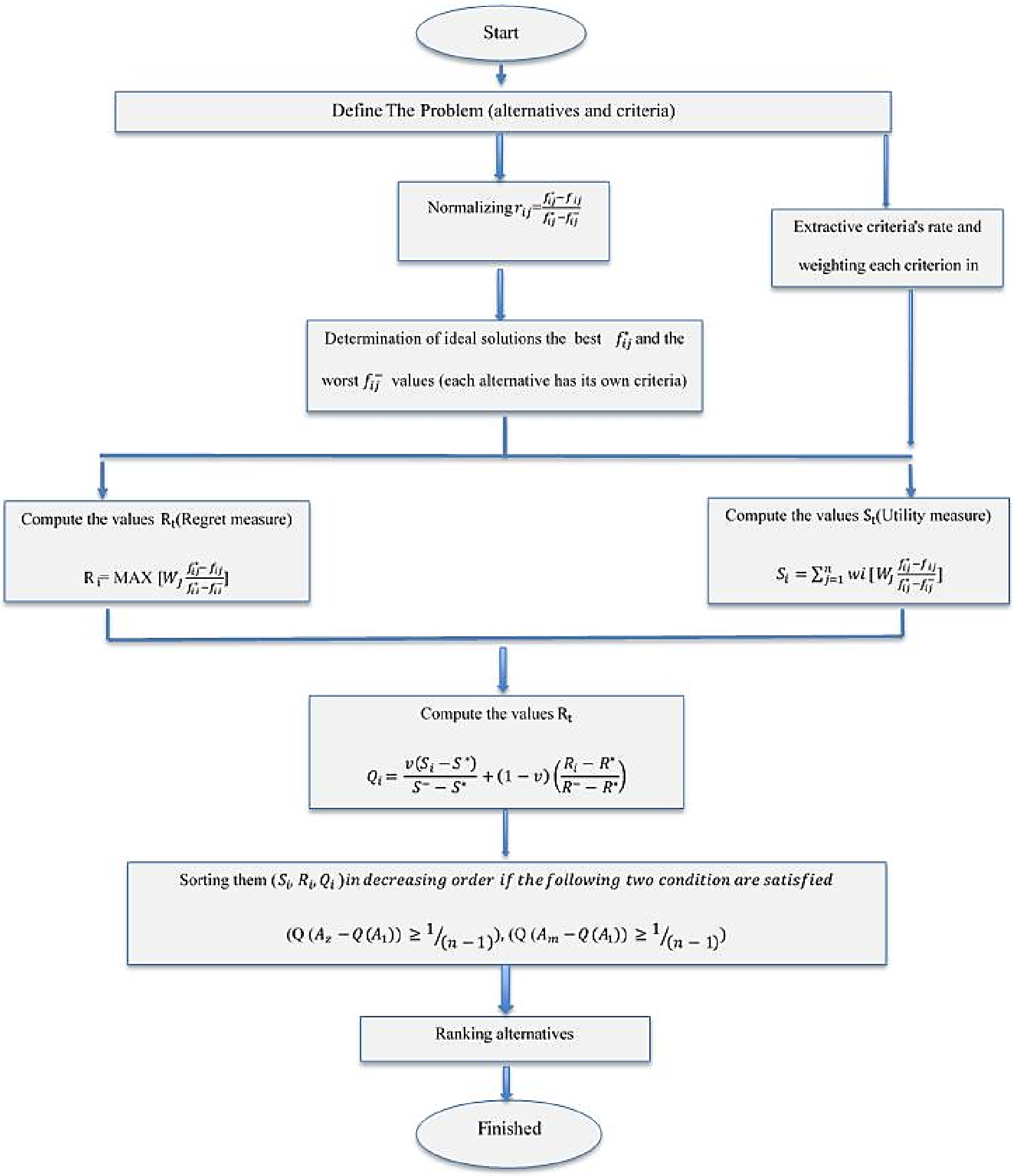


Fig. 1. The algorithm of VIKOR.

2.1 | Applications of the VIKOR Method

The VIKOR method is a well-studied, practical approach for addressing multi-criteria decision-making challenges. The applications that are most important can be seen in *Table 1*, which may be found here.

Table 1. Applications of the VIKOR method.

Subject	Year	Researcher
Personal ranking system	2020	[7]
Evaluating the green performance of the airports	2020	[5]
Sustainable outsourcing partner selection	2020	[28]
Supplier selection	2020	[19]
Material selection for the automotive piston component	2020	[20]
Measurement of customer satisfaction in mobile service	2014	[29]
Water resources planning	2011	[21]
Supplier selection	2010	[22]

2.2|VIKORSort Method

Sorting methods work the same as the ranking problem and choose problem methods, except that they assign options to predefined groups. Decision makers determine these groups. These groups are called classes. These classes can include a classification of {good, bad, and average} or {successful, average, poor, failed} or similar. After determining these classes, it is necessary to introduce limiting profiles by decision makers. VIKORSort method [1] consists of 6 steps, some of which are similar to the classical method, and was presented by [1]. They investigated the application of this method in the matter of supplier selection.

It is expected in this approach, just as it is in the traditional method, that a choice issue has m possibilities $(a_1, a_2, \dots, a_m)$ and n criteria $(k_1, k_2, \dots, k_n)$. As well, the number of categories to which the options are assigned must also be specified in this method. It is assumed to have h groups $(g_1, g_2, \dots, g_{h-1}, g_h)$.

Definition 1. Classes are classifications that are determined by decision makers and are shown as $(g_1, g_2, \dots, g_{h-1}, g_h)$.

Definition 2. Each limit profile lp_{ij} is a marker that specifies the minimum requirements for assigning an a_i option in any criterion j to any predefined class g_h. Decision makers determine these limiting profiles.

For the number h of the class, the number of $h-1$ limiting profiles is required. See the example below to understand restrictive profiles and classes better.

To obtain the marginal boundary of groups and categories, it is necessary to define $h-1$ limit profiles (l) as $(l_1, l_2, \dots, l_{h-1})$. For option a_i, the amount of the criterion j is represented by f_{ij}.

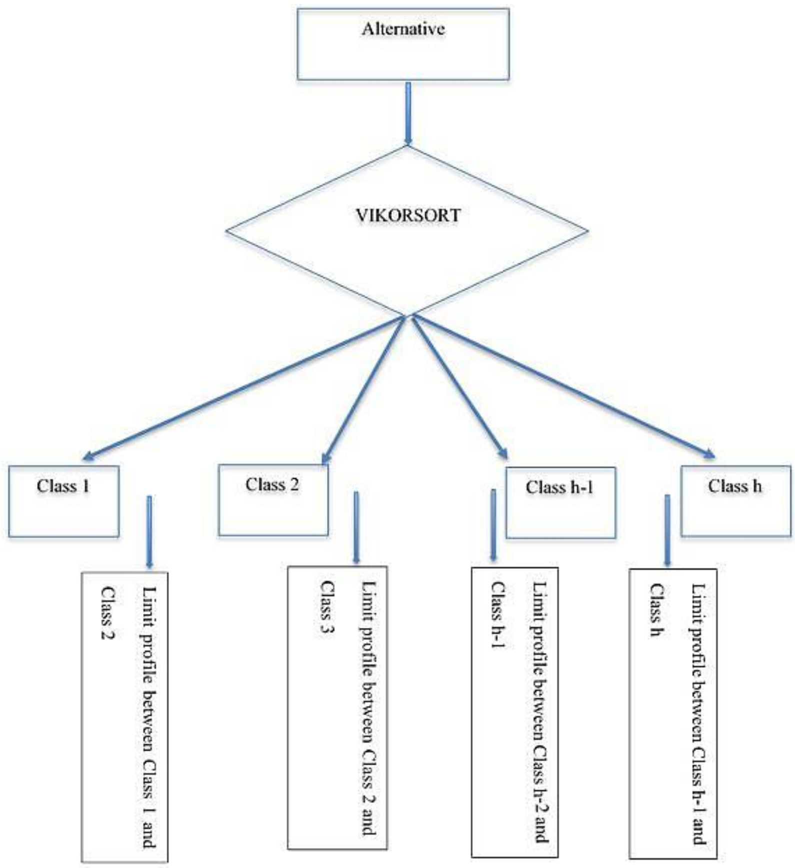


Fig. 2. Classes and limiting profile in VIKORSORT.

The steps of the VIKORSORT method are as follows [1]:

Step 1. Determination of the criteria's weight and sub-criteria.

In this step, like the VIKOR method, the weight of the criteria is calculated through other methods such as the BWM method, AHP, or Entropy, and is entered as input in the VIKORSort method.

Step 2. Determination of values for criteria and profiles.

In this step, values are set for criteria, sub-criteria, and limit profiles.

Step 3. Determination of the best and worst values for the criteria.

In the third step, we determine which values are regarded as the best and which are regarded as the worst for each criterion $(j = 1,2, \dots, m)$. To do this and be of interest to the criteria, the amounts from the best and worst ones are obtained by the following formula:

$$f_j^* = \max f_{ij}, \quad f_j^- = \min f_{ij}. \tag{1}$$

For cost criteria, the two values of the negative and ideal points are calculated according to the following formula:

$$f_i^* = \min f_{ij}, \quad f_i^- = \max f_{ij}. \tag{2}$$

Step 4. Determination of the values of S, R, Q Firstly, the amounts of S_i and R_i $(i = 1,2, \dots, n)$ must be calculated. To do this, through the following equations, the values of S_i and R_i are first calculated for all limiting options and profiles:

$$s_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij})/(f_j^* - f_j^-). \tag{3}$$

$$R_i = \max_j w_j (f_j^* - f_{ij})/(f_j^{*-} - f_j^-). \tag{4}$$

In the above equation, w_j is the weight of the criterion j and shows the comparative significance of that criterion, which was calculated in *Step 1* of the criterion weight.

Now, using the obtained values of S_i and R_i, we calculate the value of Q_j with the following formula, which $j = 1,2, \dots, m$ for each of the limiting options and profiles:

$$Q_i = \frac{v(S_j - S^*)}{(S^- - S^*)} + (1 - v)\left(\frac{R_j - R^*}{R^- - R^*}\right). \tag{5}$$

In the above equation, the values of S^*, S^- are calculated as follows:

$$S^* = \min_i S_i, \quad S^- = \max_i S_i. \tag{6}$$

The values of R^* and R^- are also calculated as follows:

$$R^* = \min_i R_i, \quad R^- = \max_i R_i. \tag{7}$$

According to the above, v represents the strategy weight of the majority of criteria, which is in the range [0, 1], and usually, researchers consider this value to be 0.5. It may be necessary to measure various values in the problem from 0.1 to 0.9, which requires a sensitivity analysis to show what the final result will change if the value of v changes.

Now, the limiting options and profiles must be sorted in hierarchical order according to the values of S, R, and Q.

Step 5. The first step of allocation.

Two conditions should be satisfied for the first allocation, which are as follows:

I. C1: The convincing advantage.

According to VIKOR, the statement below has been employed to examine how much the advantage of this option is convincing, with the smallest value $Q(P_1)$.

$$Q(P_2) - Q(P_1) \geq D(Q). \tag{8}$$

According to the above equation, $D(Q) = \frac{1}{(m-1)}$ and m is considered the number of different options.

Now, in the VIKORSort method, this condition has been modified by considering the limiting profile l as below:

$$Q(l) - Q(a) \geq D(Q). \tag{9}$$

II. C2: Acceptable stability.

In VIKOR, when the option has both a minimum amount of Q and a minimum value of R or S, it is able to define the admitted stability. According to VIKORSort, it is also conceivable to have this form of stability when the R or S amounts appear to be less than the R or S amounts of the limiting profile, which may be written as follows:

$$R, S(a) < R, S(l). \tag{10}$$

If both C_1 and C_2 are met, it is possible to say that one choice has been allocated to a suitable group. During the allocation procedure, the following three distinct situations may be present: (Suppose $g_1 > g_2 > \cdots > g_{h-1} > g_h$ & $l_1 > l_2 > \cdots > l_{h-1}$.

Case 1. If both conditions are met for an option at the same time.

By comparing the option and the limiting profile (l_1) optimistically, it is possible to allocate it directly to the group g_1. Needless to say, this process carries on unless the comparison is made for all options. It is difficult to allot it immediately to group (g_{h-1}) when the choice is compared in a pessimistic manner to the worst limiting profile (l_{h-1}). Each alternative is compared against the one with the best limiting profile (Higher level) in a series of pairwise comparisons. Finally, it is assigned to two better groups based on the limiting profile.

Case 2. If both conditions cannot be satisfied by the option.

When the comparison is optimistically made between the option and the best limiting profile of 1_1, there is no possibility to allocate it to the following group, g_2. This process, called two-by-two comparison, is maintained by comparison between the option and the worst limit (level) profiles unless all the options have been compared, and finally assigns the final split-limiting profile to the two divided groups. Furthermore, if the choice is contrasted to the worst limiting profile (l_{h-1}) in a pessimistic situation, it can be said that it is worse compared to the limiting profile and is assigned directly to the g_h group.

Case 3. The option only fulfills the one condition:

Discussion of alternative allocation cannot be extended in a pessimistic or optimistic situation. Initially, this option is considered for the Non-allocated alternative group, and one of the two assigned groups is allocated to it through the limiting profile, which is investigated using the algorithm's final step.

Step 6. Final allocation of options.

With respect to the conditions below, some options are not likely to be allocated to any group. For option a, we have:

$$\begin{aligned} &\sqrt{Q(a)} = Q(l) \quad \text{and} \quad S(a) = S(l), \quad \text{or} \\ &Q(a) = Q(l) \quad \text{and} \quad R(a) = R(l), \\ &\sqrt{Q(l) - Q(a)} \geq D(Q) \quad \text{and} \quad R, S(a) > R, S(l), \quad \text{or} \\ &Q(l) - Q(a) \leq D(Q) \quad \text{and} \quad R, S(a) < R, S(l). \end{aligned} \tag{11}$$

Now, through the following method, option A is assigned to the target group.

The first step is to choose two groups that are somewhat close to option A by comparing the Q value of option A to the Q values of the limiting profiles.

There is a distance between (Q amounts of all group members) and (Q amount of option a) that must be calculated individually for groups. In addition, the total distance traveled is divided by the total number of people in the group to arrive at an average distance for the group.

Ultimately, the group with the smallest average distance is allocated option "a". We suggest a new technique based on fuzzy sets in this proposal. Finally, we examine the application of this algorithm in the real problem of prioritizing and admitting patients to hospital ICUs.

The algorithm of the problem is as follows:

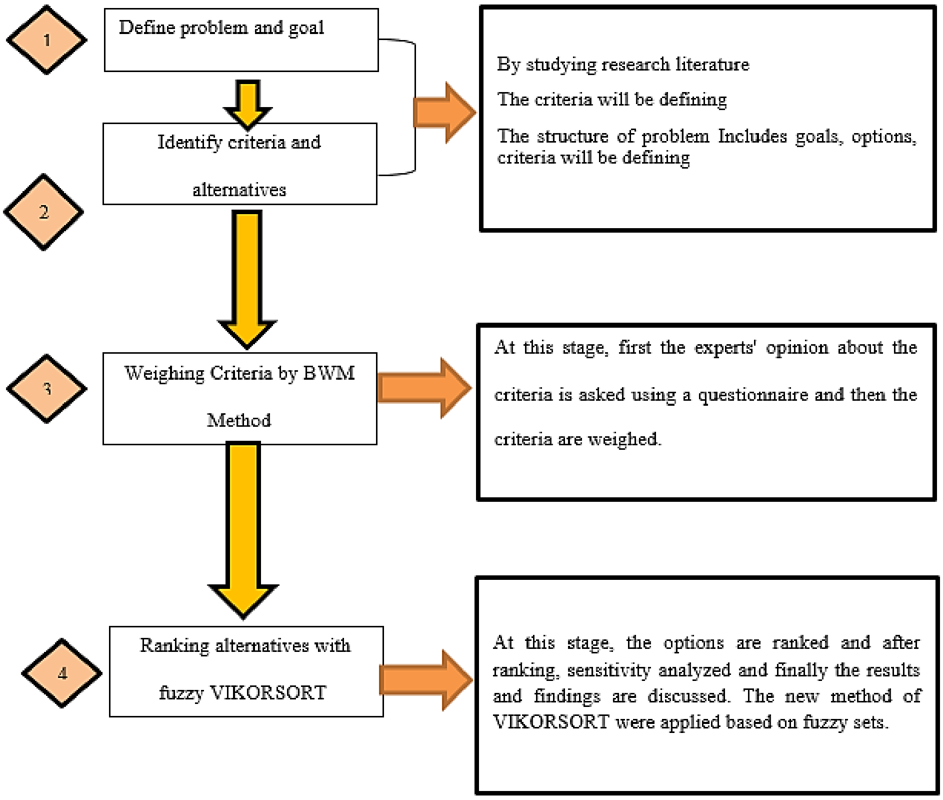


Fig. 3. The algorithm of the problem.

2.3 | Fuzzy Set and Extended Method Based on Fuzzy

Fuzzy VIKORSort

Fuzzy logic is a method of calculating based on "Degrees of truth" as opposed to the conventional "True or false" (1 or 0) Boolean logic used by current computers. Zadeh [30] proposed the concept of fuzzy sets for the first time [27].

Based on what has been mentioned thus far, a fuzzy set defined on a universe of discourse broadens the definition of a set by utilizing the degree of membership of its constituent parts in the set [31].

$$\mu_{\tilde{A}}: X \rightarrow [0,1]. \quad (12)$$

A fuzzy set is constructed using this membership function as its basis. A defined over the domain X is the set of couplings that includes the element X and its members [27], [31].

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x))/x \in X, \mu_{\tilde{A}}(x) \in [0,1]\}. \quad (13)$$

To describe uncertainty and lack of boundaries in various evasive applications, the fuzzy sets theory incorporates the fuzzy linguistic approach grounded on the idea of the language variable.

Definition 3 ([32], [33]). A fuzzy set is a class with a continuum of membership grades. A set of these types has a membership feature that assigns each object to a range of memberships from zero to one. In the fluid set, there is no defined limit between the elements of a group and the elements that do not.

Definition 4 ([32]). The quintuple $(H, T(H), U, G, M)$ of the word H denotes a linguistic variable, i.e. a collection of names of the linguistic value of H, in which each value is a random variable commonly designated by X, spanning from one universe of the discourse U, associated with the fundamental variable u.

There were a number of applications of the fuzzy linguistic variables in computing and modeling uncertainty throughout the decision-making process. Since VIKORSort sorts the many MCDA issue options by class, the correct linguistic description of the word and its semantics must be chosen. This is because VIKORSort works with classes. One method that is often used for the creation of the language term is to supply the set directly while taking into account the whole order, as well as all terms that are dispersed on a scale. An example of this would be a five-day set S [32].

$$S = \{S0: \text{Poor}; S1: \text{Low}; S2: \text{Average}; S3: \text{High}; S4: \text{Good}\}. \quad (14)$$

In these kinds of circumstances, it is necessary to ensure that there is [32], [34].

A negation operator $\text{Neg}(s_i) = s_j$ such that $j = g - i$ ($g + 1$ stands for the number of linguistic terms of the term set).

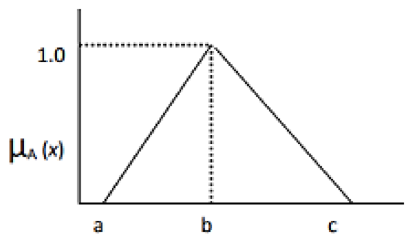
Minimum and maximum operators for the linguistic term set,

$$S: s_i \leq s_j \Leftrightarrow i \leq j. \quad (15)$$

Membership functions, which are described by function types, typically denoted by the interval [0,1], provide the semantics for the terms in a particular language term. In this study, we assume parametric member functions, since the data represented is often approximable. As an example, consider the trapezoidal representation, denoted by the set of points (a, b, d, c), where points (b) and (d) define an interval with a fuzzy set height of 1, and points (a) and (c) define the left and right boundaries of the trapezoidal function, respectively [32–34].

Triangular membership function

There are three vertices for $\mu_A(x)$ in a fuzzy set A. a, b, and c have been used to specify the x coordinates. (a denotes the lower boundary, b represents the center whose membership degree is 1, c represents the boundary at the top, and the membership degree is considered zero).



$$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ \dfrac{x-a}{b-a} & \text{if } a \leq x \leq b \\ \dfrac{c-x}{c-b} & \text{if } b \leq x \leq c \\ 0 & \text{if } x \geq c \end{cases}$$

Fig. 4. Triangular fuzzy.

A trapezoidal fuzzy number $\mu_{\tilde{n}}(x)$ can be challenged (n_1, n_2, n_3, n_4) as indicated in *Fig. 5*, which has the following membership function.

$$\mu_{\tilde{n}} = \begin{cases} 0, & x < n_1, \\ \dfrac{x - n_1}{n_2 - n_1}, & n_1 \le x \le n_2, \\ 1, & n_2 \le x \le n_3, \\ \dfrac{x - n_4}{n_3 - n_4}, & n_3 \le x \le n_4, \\ 0, & x > n_4. \end{cases}$$

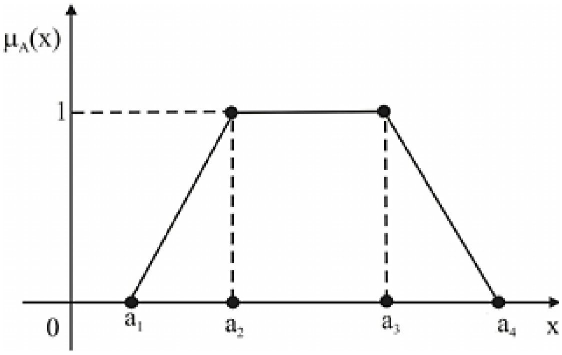


Fig. 5. Trapezoidal fuzzy [32].

One particular illustration of this kind of representation is seen in the triangle membership functions, which are denoted by the notation $b = d$ and are shown as a triplet $(a; b; c)$, as shown in *Fig. 6*.

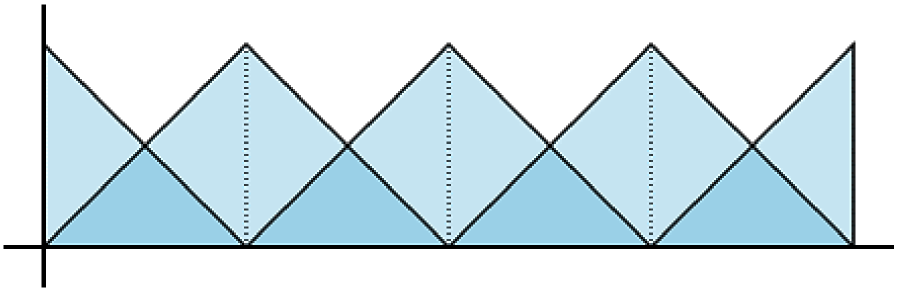


Fig. 6. Linguistic term sets with five labels [32].

Definition 5 ([34]). Suppose $S = \{s_0, s_1, \dots, s_g\}$ be an ordinal term set, $I = [0,1]$ and $IS \equiv I \times S = \{(\alpha, s_i): \alpha \in [0,1]$ and $i = 0,1, \dots, g\}$, where S is the ordered set of $g + 1$ ordinal terms $\{s_0, s_1, \dots, s_g\}$. Given a pair (s_i, s_{i+1}) of two successive ordinal terms of S, any two elements $(\alpha, s_i), (\beta, s_{i+1})$ of IS is nominated as a symbolic proportion pair, and α, β are a pair of symbolic proportions of the pair (s_i, s_{i+1}) if $\alpha + \beta = 1$.

Remark 1. The reality that $\alpha + \beta = 1$ intends that the linguistic term set S is a fuzzy partition in the sense of Ruspini [34].

A symbolic proportion pair $(\alpha, s_i), (1 - \alpha, s_{i+1})$ is presented by $(\alpha. s_i, (1 - \alpha)s_{i+1})$ and the set of all the symbolic proportion pairs is denoted by $\overline{S}$, i.e., $\overline{S} = \{(\alpha. s_i, (1 - \alpha)s_{i+1}): \alpha \in [0,1]$ and $i = 0,1, \dots, g - 1\}$ is referred to as the n ordinal proportional two-tuple set formed by S and the members of the ordinal proportional two-tuple, which are utilized to express the ordinal information for CW processes as required.

A fuzzy process is coupled to the sorting process in order to facilitate the expansion of a unique sorting strategy for the VIKORSort method that is named Fuzzy VIKORSort, so that the proportionate linguistic two-tuples are employed to do this process. It actually eases the soft transition between the classes and also creates soft boundaries among them. At the same time, it makes the extra information regarding the alternative's membership for the corresponding courses. The classes are assigned the membership degree, while the two-by-two comparisons are not supposed to arise. This is also useful for a smaller classification and an accurate imagination/comprehension of the results.

The new sorting approach includes the two extra steps below:

I. Each fuzzy membership function representing a class should have a corresponding fuzzy linguistic scale. In these discussions, students will need to organize potential solutions.

II. Employing the fuzzy membership degrees to allocate to classes: The classes phaseâ€™s allocation of the Macbeth Sort is described again. Then, a novel representation is made for the classes based on which the classes are allocated. There is a proportionate two-tuple representation [31–34], which is very significant. The following subsections explain these steps thoroughly. VIKORSort uses the arranged classes to sort the distinct alternatives in the MCDA problem. These classes are typically labeled based on their linguistic. In this research, the linguistic information is presumed to model the uncertainty concerning the class description and perhaps obtain it by employing a fuzzy representation.

The limiting and central profiles (lp_i and cp_i, respectively) must be used to explain the classes that their alternatives are placed in inside the MCDA. These proposals suggest that language is represented in the classroom in a hazy fashion. This representation must be utilized to calculate the two proportionate tuples; then, the class alternatives will be allocated. The conditions below need to be noticed when using the fuzzy linguistic scale:

The linguistic term set S has the tags to define the classes, and they need to be arranged. Therefore, it is possible to assume the production process.

Parametric functions must be considered for the fuzzy membership functions describing the linguistic tags' semantics to simplify and avoid losing generality.

A fuzzy division is produced as a result of the fuzzy membership functions for the linguistic tags in S [31–34]. They are helpful for allocating classes based on fuzzy and help use proportionate two-tuples appropriately. This process is composed of three steps, and it aims to make the linguistic scale. These steps are defined as follows:

I. Softening class transitions.

II. Choosing the amounts for the parametric functions.

III. Creating the fuzzy membership functions.

The description of these stages is specified below.

Softening the class transitions.

According to the VIKORSort methods, sorting classes are done in descending order of popularity, as shown in *Fig. 7*. According to *Fig. 7*. These classes are described based on a clear and exact interval (sc_i) and depend on the limiting profiles lp_i. The curly brackets represent the interval in *Fig. 6*, which is described formally, as shown here.

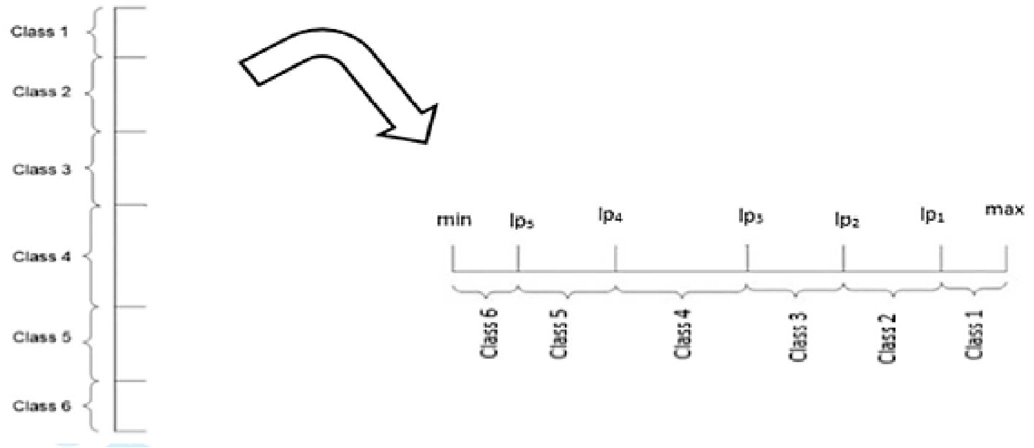


Fig. 7. Clear and exact intervals for the classes.

I. The class preferred least (class): In this part, n classes are assumed, and the class n represents the least preferred class. Between the min value in the discourse universe and the limiting profile lp_{n-1}, there is a distance that may be used to characterize the sci in the least preferred class. This distance is able to explain the distance.

$$sc_i(\text{class n}) = [\min, lp_{n-1}]. \tag{16}$$

II. The class preferred most (Class 1): The class is described in the sci below:

$$sci(\text{class 1}) = [lp_1, \max]. \tag{17}$$

III. Residual classes ($\text{Class i}, 1 < i < n$): The classes are made according to their sci, as shown below:

$$sci(\text{class i}) = [lp_1, lp_{i-1}]. \tag{18}$$

Since there is a slight difference $lp_i \pm \epsilon$ representing the allocation to different classes; the purpose here is to prevent the strict borders between classes. At the same time, there is no representative for a number of real conditions. Hence, fuzzy membership functions are provided in order to smooth out the transitions between the classes and the boundaries that separate them.

To increase sorting flexibility when selecting values for parametric membership functions, we must explain the membership function support that specifies these classes more than the science. In the research, we use the parametric (trapezoidal/triangular) membership functions.

According to the previous sections, the parametric functions are not only able to be considered the trapezoidal ones denoted by (a, b, d, c), but they are also capable of taking the form of triangles, which implies that $b = d$ may be expressed using a triplet (a, b, c). Hence, the current quantities that characterize the characteristics of the classes will be regarded as a reference in order to define the membership functions in accordance with the kind of function that was chosen (triangular or trapezoidal).

Now, in order to complete the membership function that describes the associated classes, we need to add three more values. Employing central profiles cp_i is the primary method to create these functions. According to the VIKORSort methods, the central profiles describe these functions by considering the classes below:

I. The class preferred least (Class n): The membership function in this class is supposed to be considered a trapezoidal one and has a meaning as values less than cp_n are related to this class. Hence, it can be described in the way below:

$$(a_n = \min, b_n = \min, d_n = cp_n, c_n = cp_{n-1}). \tag{19}$$

II. The students in the class favored most (Class 1): As was the case with the previous membership function, the function for determining the class that is most favoured is meant to be a trapezoidal one. Having said that, taking into consideration this circumstance, the function may be characterized as follows:

$$(a_1 = cp_2, b_1 = cp_1, d_1 = \max \text{ and } c_1 = \max). \quad (20)$$

III. Residual classes, (Class_i, $1 < i < n$): According to these conditions, the triangular ones must be selected for the membership functions, and the parameters can be described in the way below:

$$(a_i = cp_{i+1}, b_i = cp_i \text{ and } c_i = cp_{i-1}). \quad (21)$$

Employing triangular membership functions is fairly simple to calculate, despite the fact they restrict the complete membership of an element for this class to the elements corresponding totally with the classâ€™ typical example.

Trapezoidal membership function

In this function, a, b, c, and d represent the x coordinates in the membership function. Then

$$\begin{aligned}
&\text{Trapezoid } (x; a, b, c, d) = 0 \quad \text{if } x \leq a; \\
&= \frac{x-a}{b-a} \quad \text{if } a \leq x \leq b, \\
&= 1 \quad \text{if } b \leq x \leq c, \\
&= \frac{d-x}{d-c} \quad \text{if } c \leq x \leq d, \\
&= 0, \quad \text{if } d \leq x, \\
&\mu_{\text{trapezoid}} = \max(\min((x-a)/(b-a), 1, (d-x)/(d-c)), 0).
\end{aligned} \quad (22)$$

We need to gain four amounts to describe the parameters to calculate the related classes' membership function. It seems to be better if the The value of profile lp_i is chosen because it provides a fair distribution of members across classes i and i + l. As a result, an interval region is intended to apply to the center profile in order for the total membership values for class I of long As a result, an interval region is intended to apply to the center profile in order for the total membership values for class i of long (δ_i) to be fixed. It is important to point out that there is a support for the soft transition that is intended to establish a fuzzy separation between the classes, and this support expresses itself as follows:

$$\varphi_i = lp_{i-1}\text{â€“}(cp_i + \delta_i). \quad (23)$$

Like the triangular membership function, these values must be selected. The process of selecting these values is done based on the distinct classes while considering the limiting profiles as described below:

I. Least preferred class (Class n): The equations below describe the membership function.

$$(a_n = \min, b_n = \min, d_n = lp_{n-1} - \varphi_n, c_n = lp_{n-1} + \varphi_n). \quad (24)$$

II. Most preferred class (Class 1): According to this condition, we have:

$$(a_1 = lp_1 - \varphi_2, b_1 = lp_1 + \varphi_2, b_1 = lp_1 + \varphi_2, d_1 = \max, c_1 = \max). \quad (25)$$

III. Residual classes, (Class i, $1 < i < n$): The equations below describe the parameters.

$$(a_i = lp_i - \varphi_{i+1}), b_i = lp_i + \varphi_{i+1}, d_i = lp_{i-1} - \varphi_i, c_i = lp_{i-1} + \varphi_i). \quad (26)$$

As long as the parameters were recognized, the membership function could be described.

Remark 2. In the absence of losing generality, the membership function description is in the order of popularity. Hence, to clarify and consider the classes (Class i), the parameter a_i must be fixed from φ_{i+1}.

2.4 | Describing the Fuzzy Membership Functions

Now, we create the triangular and trapezoidal descriptions of the membership functions. These descriptions specify the class in the VIKOR-FuzzySort method individually. Actually, we need to consider the functions to create a fuzzy division.

Triangular membership function

The membership function descriptions for the classes are as follows:

I. The class preferred most ($\text{Class } 1$): Similarly, the equation below represents the function's description:

$$\mu_{\text{Class } 1}(x) = \begin{cases} 0, & \text{if } c_1 < x < a_1, \\ \dfrac{x - cp_2}{cp_1 - cp_2}, & \text{if } a_1 < x \leq b_1, \\ 1, & \text{if } b_1 \leq x \leq d_1. \end{cases} \quad (27)$$

II. Residual classes, ($\text{Class i}, \ 1 < i < n$): The functions below are considered triangular.

$$\mu_{\text{Class } 1}(x) = \begin{cases} 0, & \text{if } c_i < x < a_i, \\ \dfrac{x - cp_{i+1}}{cp_i - cp_{i+1}}, & \text{if } a_i \leq x < b_i, \\ \dfrac{x - cp_{i+1}}{cp_i - cp_{i+1}}, & \text{if } b_i < x \leq c_i, \\ 1, & \text{if } x = b_i. \end{cases} \quad (28)$$

Fig. 8 shows the membership functions graphically.

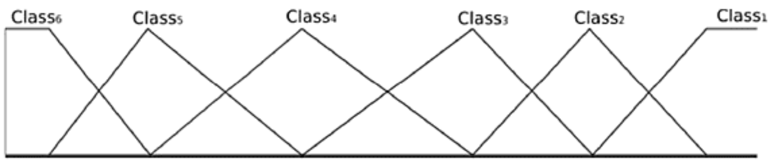


Fig. 8. The membership functions for the classes are based on fuzzy triangular.

These functions are graphically shown in *Fig. 9*.

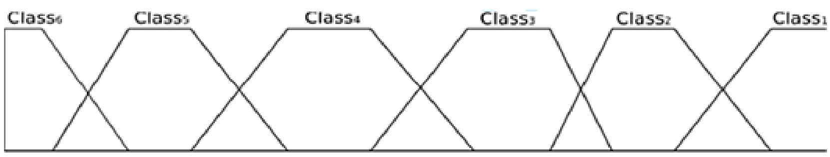


Fig. 9. The classes based on fuzzy trapezoidal membership functions.

Allocation to classes employing fuzzy membership grades. This process is done when the fuzzy membership functions are gained. By utilizing the proportionate two-tuple, we are able to allocate the VIKORSort to the classes again [27], [32–34].

The general priorities p_k, lp_i, or cpi for alternative a_k, limiting, or aggregating local priorities compute central profiles according to *Eq. (2)* and *Eq. (3)*, respectively.

Our suggestion is able to be used with VIKORSort methods. Their combination results in the final alternatives allocation and brings these classes. This allocation is like VIKORSort methods.

In order to make this argument more clear, this idea may be stated by making use of fuzzy trapezoidal membership functions while at the same time maintaining its similarity to triangular ones. In accordance with fuzzy proportional two-tuples, the process of assigning an alternative (a_k) to a class involves taking into consideration the procedures that are listed below:

I. Calculating the general priorities p_k, lp_i, or cp_i.

II. Gaining a proportionate two-tuple for p_k.

III. Using an allocation process according to the proportionate two-tuple.

Gaining a proportionate two-tuple

When the limiting, lpi and central, cpi profiles are gained, the membership functions are described, and the classes are denoted according to their semantics and syntax, showing an order as shown in *Fig. 10*.

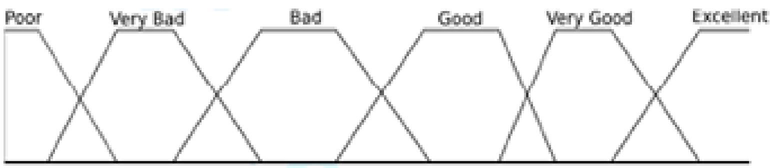


Fig. 10. The linguistic classes based on fuzzy membership functions.

When the general priority p_k calculation process is done for the alternatives a_k individually, the recent macbethSort methods must be compared. As a result, the calculation of a proportionate two-tuple general priority $\bar{p}_k = h(p_k) = (\alpha.s_i, (1-\alpha)s_{i+1})$ is used instead. They are actually produced by the fuzzy linguistic class scale and arranged in the sequential proportionate 2-tuple set.

$$
\begin{aligned}
&h: [\min, \max] \rightarrow \bar{S},\\
&\gamma = \max \frac{\mu_{s_j}(p_k)}{s_j} \in S \;\; \text{and} \;\; s_l = \underset{s_j}{\operatorname{argmax}} \left(\mu_{s_j}(p_k)\right),\\
&\text{If} \;\; \mu_{s_{l+1}}(p_k) > 0 \rightarrow s_i = s_l \;\; \text{and} \;\; \alpha = \gamma,
\end{aligned} \tag{29}
$$

$$\text{otherwise} \;\; s_i - s_{l-1} \;\; \text{and} \;\; \alpha = 1 - \gamma.$$

Therefore,

$$\bar{p}_k = h(p_k) = (\alpha s_i, (1-\alpha)s_{i+1})_k. \tag{30}$$

As a matter of fact, $\bar{S}$ is considered a fuzzy division (As seen in line from p_k in *Fig. 11*).

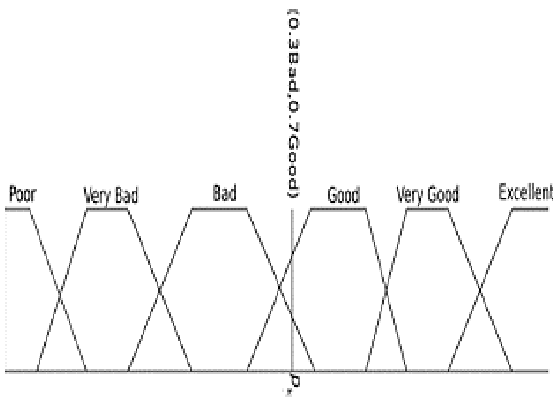


Fig. 11. Computing proportional two tuples from P_k.

The following conditions of proportionate two-tuple representation must be satisfied by the membership degrees.

The next subsection defines the details regarding the allocation process, while the term above denotes the global priority of the alternative a_k.

Allocation process

The proportionate two-tuple $\bar{p}_k = (\alpha.s_i, (1-\alpha)s_{i+1})_k$ is considered an input amount for allocating the alternative a_k to a class. According to *Eq. (6)*, this process is conducted based on the conditions below:

I. When $\alpha > (1-\alpha)$ as a result, alternative ak is allocated to class s_i.

II. When $\alpha < (1-\alpha)$ as a result, alternative a_k is allocated to class s_{i+1}.

III. When $\alpha = (1-\alpha)$ two options must be allocated a_k to a class.

IV. In the optimistic condition: a_k is allocated to s_i.

V. In the pessimistic condition: a_k is allocated to s_{i+1}.

3 | Case Study

Patients who had been hospitalized for at least one day and were receiving care in the ICU at Imam Zaman Hospital in Khorasan Razavi were included in the current research. On this particular ward, there were found to be a total of 17 patients. This number is divided into several categories of medium risk, high risk and very high risk.

First the criteria were introduced:

I. C1: Percentage of disease risk.

II. C2: level of consciousness.

III. C3: Time until surgery.

with using BWM method we find the weight of criteria. For this process we used BWM solver software. The informFation is as *Table 2*:

Table 2. The weight of criteria.

Criteria	Global Weight
C1: Disease risk (0-9)	0.3
C2: Level of consciousness (0-9)	0.4
C3: Time until surgery (0- up to 10)	0.3

Now we used VIKORSORT for sorting patient.

So the classes were determined:

I. Class 1: Low risk.

II. Class 2: Serious risk.

III. Class 3: Very dangerous risk.

The risk and limiting probability profiles were analyzed, and the results are shown in *Table 4*. Due to the fact that there are going to be three different groups established (Very hazardous risk, Severe risk, and Low risk), two limit profiles were needed (l1 and l2). The best and the worst values for all criterion functions, i.e. f_i^* and f_i^- values, were defined. The values are listed in *Table 3*.

Table 3. Criteria values for patient and limit profiles.

Patient Number	Criteria		
	CR1	CR2	CR3
	5	7	5
	4	2	1
	1	5	2
	1	2	2
	2	3	4
	7	3	6
	5	7	9
	1	6	4
	1	2	7
	2	2	2
	4	7	5
	5	9	8
	4	9	6
	7	5	4
	8	2	1
	2	4	4
	2	5	6
L1	3	3	2
L2	5	6	7

Now, the best and the worst values for all criterion functions, i.e. f_i^* and f_i^- values, were determined. (See *Table 4*).

Table 4. Presents those values.

	CR1	CR2	CR3
f_i^*	1	2	1
f_i^-	8	9	9

The next three stages of the algorithm were carried out, and then the fourth step of the method was carried out. Calculations of R, S and Q values for restricting pro les and suppliers were carried out at this stage. *Table 5* displays these numbers in a descending sequence, beginning with the lowest.

Table 5. R, S and Q values.

Patient Number	Index		
	Q	**R**	**S**
	0.67846	0.3481	0.4159
	0.1981	0.0714	0.1414
	0.78486	0.2514	0.5099
	0.50016	0.1981	0.5718
	0.74153	0.2448	0.6414
	0.7853	0.2471	0.7114
	0	0.1157	0.5099
	0.51223	0.2453	0.4417
	0.6558	0.2743	0.6015
	0.71535	0.4638	0.1489
	0.59742	0.2534	0.4632
	0	0.1879	0.4669
	0	0.2029	0.5128
	0.40776	0.1885	0.4927
	0.113661	0.1223	0.1513
	0.663436	0.2981	0.5269
	1	0.0489	0.1921
L1	0.078986	0.2918	0.5169
L2	0.017346	0.1522	0.5924

When contrasting the amount of S, R, Q with limiting profile the risks are classify. The result is in *Table 6*.

Table 6. Classification of risk.

Patient Number	Classes Class 1: Low Risk	 Class 2: Serious Risk	 Class 3: Very Dangerous Risk
		*	
	*		
		*	
	*		
	*		
		*	
			*
		*	
		*	
	*		
		*	
			*
			*
		*	
		*	
		*	
		*	

It is show that patients 7, 12 and 13 urgently need to be admitted to the ICU as soon as possible.

4 | Conclusion

It can observe two advantages in fuzzy VIKORSort. Firstly, sorted classes are acquired in the method algorithm. Secondly, the decision maker, as an expert, may consider his decision with a rational view or even a pessimistic or optimistic approach. PROMSort method can also offer these benefits, making fuzzy VIKORSort easier to run than PROMSORT. In the sorting process, fuzzy VIKORSort uses only the Q, R, and S values of the permissible profiles and other options. But in PROMSort it is necessary to calculate a distance function for all non-dedicated options in the final assignment process. To reach the final assignment of each unallocated option, a cut-off point must be specified in this step. On the other hand, fuzzy VIKORSort needs a decision maker to determine significant values of parameters such as the weight of criteria and limited specifications, and this is the main weakness of this method. Because determining an exact value for those components is hard work for the decision-maker as an expert. To fix it, more sensitivity is needed for analysis. Criteria weight is also determined by an appropriate multi-criteria weighting technique (eg, hierarchical analytical process, fuzzy analytic hierarchical process, or analytical network process) [1], [24]. The usage of fuzzy numbers in VIKOR is controversial owing to the claim that uncertainty is already accounted for in the basic scale, which is something that has to be brought to everyone's attention. The performance of Fuzzy VIKOR would be superior than that of VIKOR, which may even provide inaccurate findings. As a result, the use of fuzzy logic in the creation of a multi-criteria decision procedure might be beneficial.

References

[1] Demir, L., Akpınar, M. E., Araz, C., & Ilgın, M. A. (2018). A green supplier evaluation system based on a new multi-criteria sorting method: VIKORSORT. *Expert systems with applications*, *114*, 479–487. https://doi.org/10.1016/j.eswa.2018.07.071

[2] Saati, S., Hatami-Marbini, A., Tavana, M., & Agrell, P. J. (2013). A fuzzy data envelopment analysis for clustering operating units with imprecise data. *International journal of uncertainty, fuzziness and knowledge-based systems*, *21*(01), 29–54. https://doi.org/10.1142/S0218488513500037

[3] Deutscher, D., Werneke, M. W., Hayes, D., Mioduski, J. E., Cook, K. F., Fritz, J. M., … & Stratford, P. W. (2018). Impact of risk adjustment on provider ranking for patients with low back pain receiving physical therapy. *Journal of orthopaedic & sports physical therapy*, *48*(8), 637–648. https://www.jospt.org/doi/10.2519/jospt.2018.7981

[4] Brinkman, S., Abu-Hanna, A., de Jonge, E., & de Keizer, N. F. (2013). Prediction of long-term mortality in ICU patients: Model validation and assessing the effect of using in-hospital versus long-term mortality on benchmarking. *Intensive care medicine*, *39*(11), 1925–1931. https://doi.org/10.1007/s00134-013-3042-5

[5] Kumar, A., Aswin, A., & Gupta, H. (2020). Evaluating green performance of the airports using hybrid BWM and VIKOR methodology. *Tourism management*, *76*, 103941. https://doi.org/10.1016/j.tourman.2019.06.016

[6] Cengiz, A. E., Aytekin, O., Ozdemir, I., Kusan, H., & Cabuk, A. (2017). A multi-criteria decision model for construction material supplier selection. *Procedia engineering*, *196*, 294–301. https://doi.org/10.1016/j.proeng.2017.07.202

[7] Hu, J., Zhang, X., Yang, Y., Liu, Y., & Chen, X. (2020). New doctors ranking system based on VIKOR method. *International transactions in operational research*, *27*(2), 1236–1261. https://doi.org/10.1111/itor.12569

[8] Ishizaka, A., Pearman, C., & Nemery, P. (2012). AHPSort: An AHP-based method for sorting problems. *International journal of production research*, *50*(17), 4767–4784. https://doi.org/10.1080/00207543.2012.657966

[9] Miccoli, F., & Ishizaka, A. (2017). Sorting municipalities in Umbria according to the risk of wolf attacks with AHPSort II. *Ecological indicators*, *73*, 741–755. https://doi.org/10.1016/j.ecolind.2016.10.034

[10] Krejčí, J., & Ishizaka, A. (2018). FAHPSort: A fuzzy extension of the AHPSort method. *International journal of information technology & decision making*, *17*(04), 1119–1145. https://doi.org/10.1142/S0219622018400011

[11] Ishizaka, A., & López, C. (2019). Cost-benefit AHPSort for performance analysis of offshore providers. *International journal of production research*, *57*(13), 4261–4277. https://doi.org/10.1080/00207543.2018.1509393

[12] Xu, Z., Qin, J., Liu, J., & Martinez, L. (2019). Sustainable supplier selection based on AHPSort II in interval type-2 fuzzy environment. *Information sciences*, *483*, 273–293. https://doi.org/10.1016/j.ins.2019.01.013

[13] Ishizaka, A., Pereira, V., & Siraj, S. (2021). AHPSort-GAIA: A visualisation tool for the sorting of alternative in AHP portrayed through a case in the food and drink industry. *Annals of operations research*, 1–16. https://doi.org/10.1007/s10479-021-04082-4

[14] Labella, Á., Ishizaka, A., & Martínez, L. (2021). Consensual group-AHPSort: Applying consensus to GAHPSort in sustainable development and industrial engineering. *Computers & industrial engineering*, *152*, 107013. https://doi.org/10.1016/j.cie.2020.107013

[15] Ishizaka, A., Tasiou, M., & Martínez, L. (2020). Analytic hierarchy process-fuzzy sorting: An analytic hierarchy process-based method for fuzzy classification in sorting problems. *Journal of the operational research society*, *71*(6), 928–947. https://doi.org/10.1080/01605682.2019.1595188

[16] Sabokbar, H. F., Hosseini, A., Banaitis, A., & Banaitiene, N. (2016). A novel sorting method TOPSIS-sort: An application for Tehran environmental quality evaluation. *E+ m ekonomie a management*, *19*(2), 87–104. https://naos-be.zcu.cz/server/api/core/bitstreams/fd3c13d7-d946-4e57-836d-a33190bf9e29/content

[17] De Lima Silva, D. F., & De Almeida Filho, A. T. (2020). Sorting with TOPSIS through boundary and characteristic profiles. *Computers & industrial engineering*, *141*, 106328. https://doi.org/10.1016/j.cie.2020.106328

[18] Garg, C. P., & Sharma, A. (2020). Sustainable outsourcing partner selection and evaluation using an integrated BWM-VIKOR framework. *Environment, development and sustainability*, *22*(2), 1529–1557. https://doi.org/10.1007/s10668-018-0261-5

[19] Gao, H., Ran, L., Wei, G., Wei, C., & Wu, J. (2020). VIKOR method for MAGDM based on q-rung interval-valued orthopair fuzzy information and its application to supplier selection of medical consumption products. *International journal of environmental research and public health*, *17*(2), 525. https://doi.org/10.3390/ijerph17020525

[20] Dev, S., Aherwar, A., & Patnaik, A. (2020). Material selection for automotive piston component using entropy-VIKOR method. *Silicon*, *12*(1), 155–169. https://doi.org/10.1007/s12633-019-00110-y

[21] Opricovic, S. (2011). Fuzzy VIKOR with an application to water resources planning. *Expert systems with applications*, *38*(10), 12983–12990. https://doi.org/10.1016/j.eswa.2011.04.097

[22] Sanayei, A., Mousavi, S. F., & Yazdankhah, A. (2010). Group decision making process for supplier selection with VIKOR under fuzzy environment. *Expert systems with applications*, *37*(1), 24–30. https://doi.org/10.1016/j.eswa.2009.04.063

[23] Schramm, V. B., Cabral, L. P. B., & Schramm, F. (2020). Approaches for supporting sustainable supplier selection-A literature review. *Journal of cleaner production*, *273*, 123089. https://doi.org/10.1016/j.jclepro.2020.123089

[24] Ishizaka, A., Lokman, B., & Tasiou, M. (2021). A stochastic multi-criteria divisive hierarchical clustering algorithm. *Omega*, *103*, 102370. https://doi.org/10.1016/j.omega.2020.102370

[25] Yildiz, A. (2019). Green supplier selection using topsis method: A case study from the automotive supply industry. *Journal of engineering research and applied science*, *8*(2), 1146–1152. https://journaleras.com/index.php/jeras/article/view/168

[26] Fei, L., Deng, Y., & Hu, Y. (2019). DS-VIKOR: A new multi-criteria decision-making method for supplier selection. *International journal of fuzzy systems*, *21*(1), 157–175. https://doi.org/10.1007/s40815-018-0543-y

[27] Nikabadi, M. S., & Razavian, S. B. (2020). A hesitant fuzzy model for ranking maintenance strategies in small and medium-sized enterprises. *International journal of productivity and quality management*, *29*(4), 558–592. https://doi.org/10.1504/IJPQM.2020.106424

[28] Hashemi, S. H., Karimi, A., & Tavana, M. (2015). An integrated green supplier selection approach with analytic network process and improved Grey relational analysis. *International journal of production economics*, *159*, 178–191. https://doi.org/10.1016/j.ijpe.2014.09.027

[29] Kang, D., & Park, Y. (2014). Based measurement of customer satisfaction in mobile service: Sentiment analysis and VIKOR approach. *Expert systems with applications*, *41*(4), 1041–1050. https://doi.org/10.1016/j.eswa.2013.07.101

[30] Zadeh, L. A. (1965). Fuzzy sets. *Informat Control*. *Vol*, *8*, 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

[31] Yazdani, M., Chatterjee, P., Pamucar, D., & Abad, M. D. (2020). A risk-based integrated decision-making model for green supplier selection: A case study of a construction company in Spain. *Kybernetes*, *49*(4), 1229–1252. https://doi.org/10.1108/K-09-2018-0509

[32] Saaty, T. L. (2013). Analytic hierarchy process. In *Encyclopedia of operations research and management science* (pp. 52–64). Springer. https://doi.org/10.1007/978-1-4419-1153-7_31

[33] Kapur, J. N., & Kesavan, H. K. (1992). Entropy optimization principles and their applications. In *Entropy and energy dissipation in water resources* (pp. 3–20). Springer. https://doi.org/10.1007/978-94-011-2430-

[34] Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009