

Fuzzy logic based-discrete multicriterion decision making

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Abstract

The study aim to formulate and solve discrete multi criteria decision making (D - MCDM) problems by using similarity analysis method. This major advantages of this approach is that data, functions, many D-MCDM methods and decision makers preference in D-MCDM can be integrated in logical structure. The combination of fuzzy logic and multiple criteria decision making (MCDM) provides a promising theoretical framework for the evaluation of alternative farming system. In this paper to study concepts of fuzzy logic and MCDM are integrated and applied to a case study for selecting the best performing irrigation subsystem.

Keywords: Multicriterion decision making, fuzzy logic, aggregation, distance based MCDM, similarity analysis

1. Introduction

There are many situations with components that are intrinsically vague, called uncertain. According to Bojadziev and Bojadziev, 1997, different situations that lead to uncertainty are unquantifiable information, incomplete information, non-obtainable information and partial ignorance. In Multicriterion Decision-Making (MCDM) environment, uncertainty mainly occurs in two situations while (a) assessing weights of the criteria (b) evaluating the alternatives with reference to the criteria. Bojadziev and Bojadziev (1997) defined fuzziness as “not sharply focused, clearly reasoned or expressed; confused; lacking of clarity; blurred”. The objective of this chapter is to give an initial thrust/overview to researchers, students and others who are interested in the area of fuzzy-based decision-making. In this regard, simple and effective fuzzy based discrete MCDM methods are presented under three groups. i.e., distance, utility/ priority, miscellaneous in the present chapter. Information about sources of numerous fuzzy-based MCDM methods are available.

Multicriterion decision making (MCDM) has emerged as an effective methodology due to its ability to combine quantitative criteria for selection of the best alternative (Pomerol and Romero, 2000). Concurrently, fuzzy logic is gaining importance due to its flexibility in handling imprecise subjective data. Multiple and conflicting objectives such as 'minimize cost' and 'maximize quality of service' are the real stuff of the decision-making' daily concerns. Keeping this in mind, this paper introduces innovative decision aid methodologies for an evaluation cum selection policy analysis, based on the theory of the similarity analysis (Distance Based MCDM) methods.

1.1 Salient features of triangular and trapezoidal membership functions

1.1.1 Triangular membership function

A fuzzy number with Triangular membership function \tilde{A} is characterized by (a_1, b_1, c_1) , a_1, b_1, c_1 as shown in Figure. Its membership function features are presented in Table 1.1

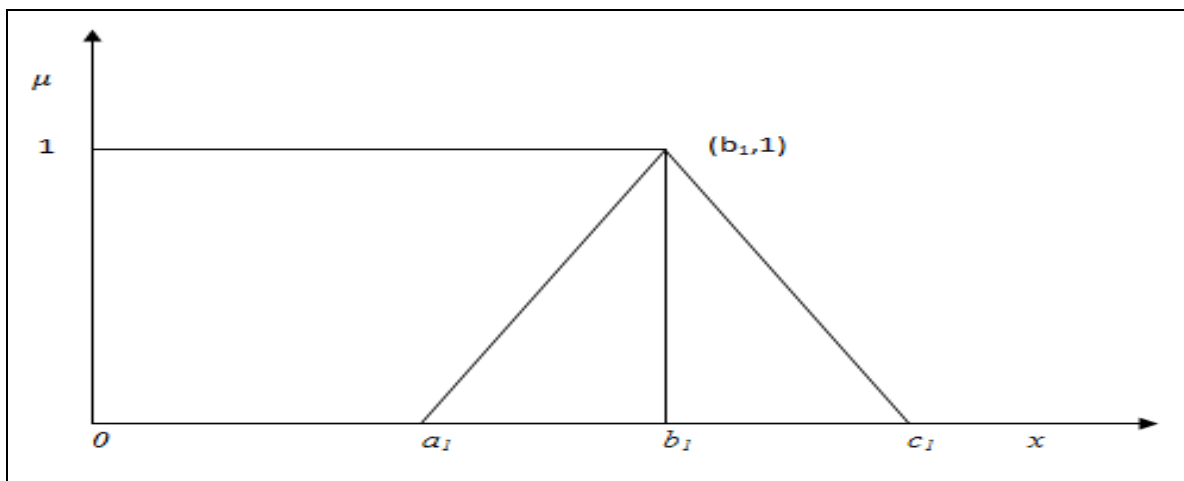


Fig 1.1: Fuzzy Number A with triangular membership function

Table1.1: Triangular membership function features

	Membership function	Ranges
$\mu_{A(x)}$	0	$x = a_1$
	$\frac{(x - a_1)}{(b_1 - a_1)}$	$b_1 \geq x \geq a_1$
	$\frac{(c_1 - x)}{(c_1 - b_1)}$	$c_1 \geq x \geq b_1$
	0	$x = c_1$

Arithmetic operations related to fuzzy numbers with triangular membership function

If $\tilde{A} = (a_1, b_1, c_1)$ and $\tilde{B} = (a_2, b_2, c_2)$ are two Triangular fuzzy numbers, then

Addition

$$A (+) \tilde{B} = (a_1, b_1, c_1) (+) (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$

Subtraction

$$A (-) \tilde{B} = (a_1, b_1, c_1) (-) (a_2, b_2, c_2) = (a_1 - c_2, b_1 - b_2, c_1 - a_2)$$

Multiplication

$$A (\times) \tilde{B} = (a_1, b_1, c_1) (\times) (a_2, b_2, c_2) = (a_1 a_2, b_1 b_2, c_1 c_2)$$

Division

$$\tilde{A} (\div) \tilde{B} = (a_1, b_1, c_1) (\div) (a_2, b_2, c_2) = (a_1 / a_2, b_1 / b_2, c_1 / c_2)$$

Average

$$(A (+) B) / 2 = ((a_1 + a_2) / 2, (b_1 + b_2) / 2, (c_1 + c_2) / 2)$$

Inverse of $\tilde{A} = \tilde{A}^{-1} = (a_1, b_1, c_1)^{-1} = (1 / a_1, 1 / b_1, 1 / c_1)$

Multiplication of crisp number / constant h with \tilde{A}

$$= A (\times) h = (a_1, b_1, c_1) (\times) h = (ha_1, hb_1, hc_1)$$

Division by crisp number / constant h with \tilde{A}

$$= A (\div) h = (a_1, b_1, c_1) (\div) h = (a_1 / h, b_1 / h, c_1 / h)$$

1.1.2 Trapezoidal Membership Function

A fuzzy number with Trapezoidal membership function \tilde{A} is characterized by (a_1, b_1, c_1, d_1) , where a_1, b_1, c_1, d_1 as shown in figure 1.2. Its membership function features are shown in Table1.2

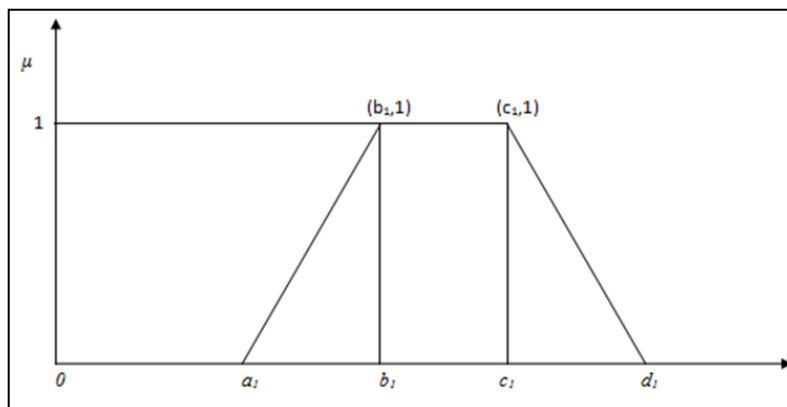


Fig 1.2: Fuzzy Number \tilde{A} Trapezoidal Membership Function

Table1.1: Trapezoidal membership function features

	Membership function	Ranges
$\mu_{A(x)} =$	0	$x = a_1$
	$\frac{(x - a_1)}{(b_1 - a_1)}$	$b_1 \geq x \geq a_1$
	1	$b_1 \geq x \geq c_1$
	$\frac{(x_1 - d_1)}{(c_1 - b_1)}$	$c_1 \geq x \geq d_1$
	0	$x = d_1$

Arithmetic operations related to fuzzy numbers with Trapezoidal membership function

If $\tilde{A} = (a_1, b_1, c_1, d_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2)$ are two Trapezoidal fuzzy numbers, then

Addition

$$\tilde{A} (+) \tilde{B} = (a_1, b_1, c_1, d_1) (+) (a_2, b_2, c_2, d_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2)$$

Subtraction

$$\tilde{A} (-) \tilde{B} = (a_1, b_1, c_1, d_1) (-) (a_2, b_2, c_2, d_2) = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2)$$

Multiplication

$$\tilde{A} (\times) \tilde{B} = (a_1, b_1, c_1, d_1) (\times) (a_2, b_2, c_2, d_2) = (a_1 a_2, b_1 b_2, c_1 c_2, d_1 d_2)$$

Division

$$\tilde{A} (\div) \tilde{B} = (a_1, b_1, c_1, d_1) (\div) (a_2, b_2, c_2, d_2) = (a_1 / a_2, b_1 / b_2, c_1 / c_2, d_1 / d_2)$$

Average

$$(\tilde{A} (+) \tilde{B}) / 2 = ((a_1 + a_2) / 2, (b_1 + b_2) / 2, (c_1 + c_2) / 2, (d_1 + d_2) / 2)$$

Multiplication of crisp number / constant h with \tilde{A}

$$\tilde{A} (\times) h = (a_1, b_1, c_1, d_1) (\times) h = (ha_1, hb_1, hc_1, hd_1)$$

Division by crisp number / constant h with \tilde{A}

$$\tilde{A} (\div) h = (a_1, b_1, c_1, d_1) (\div) h = (a_1/h, b_1/h, c_1/h, d_1/h)$$

1.2 Distance Based MCDM Methods

1.2.1 Similarity Analysis:

Similarity Analysis (SA) uses the concept of degree of similarity measure, and the alternative with respect to a reference alternative, is considered to be the best (Chen, 1994) [2]. In this methodology, criteria are represented by interval valued fuzzy sets (real interval) as compared to crisp real values between zero to one. Alternative A_i ($i = 1, 2, \dots, m$) evaluated on various criteria C_1, C_2, \dots, C_j ($j = 1, 2, \dots, J$) with weights of criteria $W = w_1, w_2, \dots, w_j$ is represented as interval valued fuzzy sets as mentioned below.

$$A_i = (C_1 [y_{i1}, y'_{i1}], C_2 [y_{i2}, y'_{i2}], \dots, C_j [y_{ij}, y'_{ij}]) \tag{1.1}$$

Where $[y_{ij}, y'_{ij}]$ represents fuzzy interval for i th alternatives for j th criteria within the range of $[0 \leq y_{ij} \leq y'_{ij} \leq 1]$. Also equation (1) can be defined in matrix notation as below.

$$A_i = [y_{i1}, y'_{i1}, y_{i2}, y'_{i2}, \dots, y_{ij}, y'_{ij}] \tag{1.2}$$

The objective of the methodology is to choose such an alternative as the best, whose characteristics are most similar to the interval valued fuzzy reference set, R , which is expressed in the matrix notation as below.

$$R = [x_1, x'_1, x_2, x'_2, \dots, x_j, x'_j] \tag{1.3}$$

Where $[x_j, x'_j]$ mentions fuzzy interval for the reference alternative for the j th criteria. Degree of similarity $S(A_i, R, W)$ between interval valued fuzzy reference set R and any given alternative A_i for a specified weight set W is expressed as (Chen, 1994) [2].

$$S(A_i, R, W) = \frac{\sum_{j=1}^J [w_j \times (1 - (0.5 \times (|y_{ij} - x_j| + |y'_{ij} - x'_j|)))]}{\sum_{j=1}^J w_j} \quad (1.4)$$

Degree of similarity values vary from zero to one. The higher the value of S (A_i, R, W), the higher the similarity between the interval valued fuzzy sets A_i and R. The alternative with the highest degree of similarity is considered to be the best.

1.2.2 Fuzzy Technique for Order Preference by Similarity to an Ideal Solution

F-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is based on the principle that the selected alternative should have the smallest distance from the ideal solution and longest distance from the negative ideal solution (Chen, 2000; Opricovic and Tzeng, 2004). The methodology consists of

1. Formulation of fuzzy payoff matrix (Table 1.3 with elements such as \tilde{X}_{ij} . Here \tilde{X}_{ij} represents Triangular Fuzzy Number (a_{ij}, b_{ij}, c_{ij}) and i, j represent alternatives and criteria.
2. Normalize the fuzzy payoff matrix as explained.
3. Input weights of the criteria.
4. Computation of weighted normalized fuzzy payoff matrix.
5. Identify ideal and negative ideal values for each criterion from weighted normalized fuzzy payoff matrix.
6. Compute separation measures D_i^+, D_i^- in j-dimensional Euclidean distance for each alternative.

(a) Compute the distance of each criterion from its ideal value and summing these for all criterion for a given alternative i yields

$$D_i^+ = \sum_{j=1}^J d(\tilde{X}_{ij}, \tilde{X}_j^*) = d(\tilde{X}_{i1}, \tilde{X}_1^*) + d(\tilde{X}_{i2}, \tilde{X}_2^*) + \dots + d(\tilde{X}_{ij}, \tilde{X}_j^*) \quad (1.5)$$

i = 1, 2, …, m; j = 1, 2, …, J

Criteria Alternatives	C ₁	C ₂	C ₃	C ₄	C _j
A ₁	$\tilde{X}_{11}(a_{11}, b_{11}, c_{11})$	$\tilde{X}_{12}(a_{12}, b_{12}, c_{12})$	.....	.....	$\tilde{X}_{1j}(a_{1j}, b_{1j}, c_{1j})$
A ₂	$\tilde{X}_{21}(a_{21}, b_{21}, c_{21})$	$\tilde{X}_{22}(a_{22}, b_{22}, c_{22})$		.....	$\tilde{X}_{2j}(a_{2j}, b_{2j}, c_{2j})$
A ₃	$\tilde{X}_{31}(a_{31}, b_{31}, c_{31})$	$\tilde{X}_{32}(a_{32}, b_{32}, c_{32})$	.....	.....	$\tilde{X}_{3j}(a_{3j}, b_{3j}, c_{3j})$
A ₄	.....	.....	.....	.....	.....
.....
A _i	$\tilde{X}_{m1}(a_{m1}, b_{m1}, c_{m1})$	$\tilde{X}_{m2}(a_{m2}, b_{m2}, c_{m2})$		.....	$\tilde{X}_{ij}(a_{ij}, b_{ij}, c_{ij})$
Ideal	$\tilde{X}_1^*(a_1^*, b_1^*, c_1^*)$	$\tilde{X}_2^*(a_2^*, b_2^*, c_2^*)$	.....	.....	$\tilde{X}_j^*(a_j^*, b_j^*, c_j^*)$
Negative Ideal	$\tilde{X}_1^{**}(a_1^{**}, b_1^{**}, c_1^{**})$	$\tilde{X}_2^{**}(a_2^{**}, b_2^{**}, c_2^{**})$	.....	.....	$\tilde{X}_j^{**}(a_j^{**}, b_j^{**}, c_j^{**})$

(b) Compute the distance of each criterion from its negative value and summing these for all criteria for a given alternative i yields

$$D_i^- = \sum_{j=1}^J d(\tilde{X}_{ij}, \tilde{X}_j^{**}) = d(\tilde{X}_{i1}, \tilde{X}_1^{**}) + d(\tilde{X}_{i2}, \tilde{X}_2^{**}) + \dots + d(\tilde{X}_{ij}, \tilde{X}_j^{**}) \quad (1.6)$$

i = 1, 2 … m; j = 1, 2, …, J

Here $(\tilde{X}_j^*, \tilde{X}_j^{**})$ indicates ideal and negative ideal values for criterion j. For example, if $\tilde{X}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{X}_j^* = (a_j^*, b_j^*, c_j^*)$, then distance $d(\tilde{X}_{ij}, \tilde{X}_j^*)$ between \tilde{X}_{ij} and \tilde{X}_j^* can be computed as (Opricovic and Tzeng, 2004):

$$\sqrt{\frac{[(a_{ij} - a_j^*)^2 + (b_{ij} - b_j^*)^2 + (c_{ij} - c_j^*)^2]}{3}} \tag{1.7}$$

Similarly, distance between can also be computed.

7. Computation of relative closeness C_i of each alternative i with reference to negative ideal measure

$$D_i^- \text{ is } C_i = \frac{D_i^-}{(D_i^- + D_i^+)} \tag{1.8}$$

8. Rank the alternatives based on the C_i values. Higher the C_i value, better is the alternative.

1.2.3 Fuzzy Compromise Programming

Fuzzy compromise programming (FCP) is an extension of compromise programming (CP) in fuzzy environment. It mainly differs CP in terms of formulation of payoff matrix using fuzzy numbers instead of crisp inputs. The methodology of FCP is same as explained in F-TOPSIS methodology upto step 6 with the exception that FCP method need not require negative ideal values in its L_p - metric computations. Rearranging Eq 1.5 as per CP method.

$$L_p(A_i) = \sum_{j=1}^J d(\tilde{X}_{ij}, \tilde{X}_j^*)^p = d(\tilde{X}_{i1}, \tilde{X}_1^*)^p + d(\tilde{X}_{i2}, \tilde{X}_2^*)^p + \dots + d(\tilde{X}_{ij}, \tilde{X}_j^*)^p \tag{1.9}$$

$i = 1, 2, \dots, m.$

p value in Eq 1.9 represents the parameter/ balancing factor reflecting the attitude of the decision- maker with respect to compensation between deviations as explained. Less value of L_p -metric desirable and is the basis for selecting best/suitable alternative. More details on FCP are available in Bardossy and Duckstein (1992).

1.2.4 Fuzzy composite programming

Fuzzy composite programming (FCoP) is an extension of composite programming (CoP) in fuzzy environment. It mainly differs from CoP in terms of formulation of payoff matrix using fuzzy numbers instead of crisp inputs. More details and application on FCoP are available in Bardossy and Duckstein (1992), Jones and Barnes (2000).

1.3 Utility / Priority-Based Methods

1.3.1 Weighted Average Method

Overall utility for a given alternative i , U_i is expressed as weighted sum of utility values of each criterion, i.e., $U_i = w_1u_1 + w_2u_2 + \dots + w_ju_j$

Where w_1, w_2, \dots, w_j are weights assigned to the criterion (either crisp or fuzzy represented by Triangular/Trapezoidal Fuzzy Numbers) and u_1, u_2, \dots, u_j are corresponding utility values of criterion (represented by Triangular /Trapezoidal Fuzzy Numbers). The alternative having the highest overall utility is the best. Five scenario are considered while computing overall utility vale which are explained below:

Scenario 1

Weights of criterion and utility value of the criterion are represented as triangular fuzzy numbers. If Triangular Fuzzy Numbers (p_1, q_1, r_1) represents weight of criterion j and Triangular Fuzzy Number (p_2, q_2, r_2) represents utility value of criterion j , then product is expressed using fuzzy arithmetic operations as $(p_1 p_2, q_1 q_2, r_1 r_2)$ which is also a Triangular Fuzzy Number. It is represented as (p_m, q_m, r_m) for further analysis. Defuzzification is another process that can be performed to transform fuzzy number into a crisp number. Even though numerous defuzzification methods are available (Ross, 1995; Ganesh, 2006) ^[14], only three simple defuzzification methods are discussed in the present chapter (Bojadziev and Bojadziev, 1994). Mathematical expressions of the defuzzification methods which transform Triangular Fuzzy Numbers into crisp numbers are presented in Eq. 1.10 (a) to 1.10(a).

Method 1

$$\frac{p_m + q_m + r_m}{3} \tag{1.10(a)}$$

Method 2

$$\frac{p_m + 2 \times q_m + r_m}{4} \tag{1.10(b)}$$

Method 3

$$\frac{p_m + 4 \times q_m + r_m}{6} \quad 1.10(c)$$

Scenario 2

Weights of criterion are represented as crisp numbers, and utility value of the criterion are represented by Trapezoidal Fuzzy Numbers.

If crisp number w_j represents weight of criterion j and Triangular Fuzzy Number (p_2, q_2, r_2) represents utility value of criterion j , then product is expressed as $(w_j p_2, w_j q_2, w_j r_2)$ which is also a Triangular Fuzzy Number. Defuzzification methods which are explained in scenario 1 are also valid for scenario 2.

Scenario 3

Weights of criterion and utility value of the criterion are represented by Trapezoidal Fuzzy Numbers.

If Trapezoidal Fuzzy Numbers (p_1, q_1, r_1, s_1) represents weight of criterion j and Trapezoidal Fuzzy Numbers (p_2, q_2, r_2, s_2) represents utility value of criterion j , then product is expressed (using fuzzy arithmetic operations) as $(p_1 p_2, q_1 q_2, r_1 r_2, s_1 s_2)$ which is also a Trapezoidal Fuzzy Number. It represented as (p_m, q_m, r_m, s_m) for further analysis. Mathematical expression of the defuzzification methods which transform Trapezoidal Fuzzy Numbers into crisp numbers are presented in [Eqs. 1.11) a to (1.11) c].

Method 1

$$\frac{p_m + 0.5 \times q_m + 0.5 \times r_m + s_m}{3} \quad 1.11(a)$$

Method 2

$$\frac{p_m + q_m + r_m + s_m}{4} \quad 1.11(b)$$

Method 3

$$\frac{p_m + 2 \times q_m + 2 \times r_m + s_m}{6} \quad 1.11(c)$$

Scenario 3

Weights of criterion are represented as crisp numbers, and utility value of the criterion are represented as Trapezoidal Fuzzy Numbers.

If crisp number w represents weight of criterion j and Trapezoidal Fuzzy Number (p_2, q_2, r_2, s_2) represents utility value of criterion j , then product can be expressed as $(w_j p_2, w_j q_2, w_j r_2, w_j s_2)$ which is also a trapezoidal Fuzzy Number. Defuzzification methods which are explained in scenario 3 are also valid for scenario 4.

Scenario 5

If specific criterion, represented as a Triangular Fuzzy Number (p_1, q_1, r_1) , is required to be expressed as Trapezoidal Fuzzy Number, it can be presented to have been transformed as (p_1, q_1, r_1, s_1) . Defuzzification methods which are explained in scenario 3, are also valid for scenario 5.

1.4 Example

Three experts (E_1 to E_3) evaluated four irrigation projects A_1 to A_4 on six performance criteria, namely, environment impact (C_1), participation of farmers (C_2), conjunctive use of surface and ground water resources(C_3), economic impact(C_4), social impact (C_5) and productivity (C_6). Description of criteria is available in normalized weights of the criteria for C_1 to C_6 are 0.146, 0.065, 0.089, 0.312, 0.190 and 0.198. Table 1.4 presents payoff Matrix in fuzzy environment where the criterion values are represented by fuzzy numbers. Interval values for the reference set are [1, 1]. Compute degree of similarity of each irrigation subsystem using Similarity Analysis Method (sam). Identify preferred irrigation subsystem.

Table 1.4: Pay off matrix in fuzzy environment

Alternatives	Expert	Criterion					
		C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
A ₁	E ₁	0.4	0.6	0.6	0.8	0.6	0.8
	E ₂	0.6	0.4	0.4	0.8	0.6	0.8
	E ₃	0.4	0.2	0.4	0.6	0.4	0.6
A ₂	E ₁	0.4	0.2	0.4	0.8	0.6	0.8
	E ₂	0.4	0.0	0.0	0.6	1.0	1.0
	E ₃	0.4	0.0	0.6	0.6	0.6	0.8

A ₃	E ₁	0.4	0.2	0.8	0.8	0.8	0.6
	E ₂	0.6	0.0	0.6	0.8	0.8	0.4
	E ₃	0.4	0.2	0.6	0.6	1.0	0.6
A ₄	E ₁	0.2	0.4	1.0	1.0	1.0	1.0
	E ₂	0.2	0.2	1.0	0.8	0.8	0.8
	E ₃	0.2	0.2	0.8	1.0	0.8	1.0

Solution

Based on the evaluations given by the three experts (Table 1.4) for each criterion for each irrigation subsystem (i.e. 3 values), The lowest and highest values are considered for the interval for that scenario. For example, for subsystem, A₄ and criterion C₂, three experts have given their fuzzy rating as 0.4, 0.2 and 0.2. Accordingly, interval was given as [0.2, 0.4]. If all the experts Have given the same rating such as 0.2, 0.2 and 0.2, then the interval was given as [0.2, 0.2]. Table 1.5 present payoff matrix in the interval form.

Table 1.5: Pay off matrix in interval form

Alternatives	Criteria					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
A ₁	[0.4,0.6]	[0.2,0.6]	[0.4,0.6]	[0.6,0.8]	[0.4,0.6]	[0.6,0.8]
A ₂	[0.4,0.4]	[0.0,0.2]	[0.0,0.6]	[0.6,0.8]	[0.6,1.0]	[0.8,1.0]
A ₃	[0.4,0.6]	[0.0,0.2]	[0.6,0.8]	[0.6,0.8]	[0.8,1.0]	[0.4,0.6]
A ₄	[0.2,0.2]	[0.2,0.4]	[0.8,1.0]	[0.8,1.0]	[0.8,1.0]	[0.8,1.0]

Higher degree of similarity of an alternative with respect to the reference alternative is considered to be the best. Substituting (1) Criterion values in interval form for irrigation subsystems from table 1.5, (2) Normalised weights of the six criteria, i.e., 0.146, 0.065, 0.089, 0.312, 0.190, 0.198 (sum of weights of criteria are equal to 1, i.e.

$$\sum_{j=1}^J w_j = 1$$

(3) Reference set [1, 1] in Eq. (1.4) yields degree of similarity for A₁ to A₄. Detailed computation for irrigation subsystem A₁ is as follows.

$$A_j = \sum_{j=1}^J \left[1 - \frac{|y_{ij} - u| + |y'_{ij} - u|}{2} \right] \times W(c_j)$$

Where

$$\sum_{j=1}^J w_j = 1$$

From this, we get

$$A_1 = 0.5955, A_2 = 0.6402, A_3 = 0.6302, A_4 = 0.7588$$

And their Ranking: A₄ > A₂ > A₃ > A₁

Degrees of similarity for irrigation subsystems A₁ to A₄ are presented in the last column of Table 1.5. It is observed that A₄ is found to be best due to high degree of similarity A₄ (0.7588, rank 1)), followed by A₂ (0.6402, rank2)), A₃ (0.6302, rank3)) and A₁ (0.5955, rank 4)). Here A₄ is the preferred subsystem.

Conclusion

Thus a Fuzzy logic based Multi-criteria decision making model (D-FCDM) can be used to evaluate the usefulness of technology and also used to identify and eliminate gratifying nature of technology in industries and helps organization in selecting a suitable technology to their operations taking into consideration quantitative and qualitative factors of both manufacturing objectives and technology benefits. A further research would be to apply this methodology in a real setting and therefore to capture the industrialist's choice to the correct technology.

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