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Military Combat Aircraft Selection Using Trapezoidal Fuzzy Numbers with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

C. Ardil

***Abstract*—**This article presents a new approach to uncertainty, vagueness, and imprecision analysis for ranking alternatives with fuzzy data for decision making using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

In the proposed approach, fuzzy decision information related to the aircraft selection problem is taken into account in ranking the alternatives and selecting the best one. The basic procedural step is to transform the fuzzy decision matrices into matrices of alternatives evaluated according to all decision criteria. A numerical example illustrates the proposed approach for the military combat aircraft selection problem.

***Keywords*—**Trapezoidal fuzzy numbers, multiple criteria decision making analysis, decision making, aircraft selection, MCDMA, fuzzy TOPSIS.

I. Introduction

Multiple criteria decision making analysis (MCDMA) theory is widely used to rank alternatives and select the optimal one with respect to a set of conflicting decision criteria. Under conditions of uncertainty, ambiguity, and imprecise information, classical MCDMA models that require precise information may not be permanently applicable in real-life problems [1-2].

Multiple criteria decision making problem is characterized by the ratings of each alternative with respect to each criterion and the importance weights given to each criterion. Classical MCDMA methods assume that the ratings of alternatives and the importance weights of criteria are crisp numbers, but this is impossible in real-life situations [2-3].

MCDMA model belongs to the class of vector optimization problems. The decision criteria can be divided into two groups: criteria where the maximum value is optimal, and criteria where the minimum value is optimal in decision making problems [5-6].

MCDMA problems can be solved with the accuracy of many non-dominated alternatives. Achieving a single solution can only be implemented on the basis of some compromise scheme that reflects the decision maker's preferences [7].

MCDMA methods for solving the decision-making problem can be divided into two large categories: methods that use the aggregation of all alternatives by all criteria and the solution of the resulting single-criteria problem (compensatory), the second category is associated with the pairwise comparison procedure and stepwise aggregation (outranking) [1-7].

The first category includes methods composite programming [2-3], compromise programming [2-3], preference analysis for reference ideal solution (PARIS) [4-7], analytical hierarchical process (AHP) [8-10], VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [11-13], technique for order of preference by similarity to ideal solution (TOPSIS) [14-17], the second category includes preference ranking organization method for enrichment evaluation (PROMETHEE) [18-21], and ÉLimination et Choix Traduisant la REalité (ELECTRE) [22-23].

Also, fuzzy [24-30], intuitionistic [31], and neutrosophic [32] decision making techniques are widely used in the evaluation of uncertainty, vagueness, and imprecision problems. The MCDMA works provide information on the applicability of various methods of multiple criteria decision making [33-37].

This paper discusses the TOPSIS method with trapezoidal fuzzy numbers for aircraft selection problem. This mathematical method is very popular for solving multiple criteria analysis problems under certain conditions. This TOPSIS method regards the principle that the chosen alternative should have the shortest distance from the ideal solution and the longest distance from the negative ideal solution [14].

The reminder of paper unfolds as follows: Trapezoidal fuzzy numbers with TOPSIS method are presented in Section 2. In Section 3, the proposed model was utilized for a case study of aircraft selection. Finally, conclusions and future directions are presented in Section 4.

II. Methodology

A. Classical TOPSIS Programming

The technique for order of preference by similarity to ideal solution (TOPSIS) method is a mathematical MCDMA method that has been used in numerous real-life problems and extended in different uncertain environments. In the TOPSIS method, the evaluation process of alternatives is conducted with respect to the distances from the ideal and anti-ideal solutions.

Suppose that, given a set of alternatives I, $a_i = (a_1, ..., a_i)$, $i \in \{ i = 1, ..., I \}$, a set of criteria J, $g_j = (g_1, ..., g_j)$, $j \in$

C. Ardil is with the National Aviation Academy, Baku, Azerbaijan.
https://orcid.org/0000-0003-2457-7261

{ $j = 1,...,J$ }, and the importance weight of each criterion (ω_j , $j \in$ { $j = 1,...,J$ }) is known. The procedural steps of TOPSIS method are presented as follows [14]:

Step 1. The construction of a decision matrix

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} \overset{g_1}{x_{11}} & \cdots & \overset{g_j}{x_{1j}} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \tag{1}$$

where $X = (x_{ij})_{ixj}$ represents the decision matrix and x_{ij} is the value of ith alternative with respect to jth indicator g_j

Step 2. Determination of the normalized values of the decision matrix

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{\max_i x_{ij}} & if \quad j \in B \\ \dfrac{\max_i x_{ij}}{x_{ij}} & if \quad j \in C \end{cases} \tag{2}$$

where $i = 1,...,m,...,I$ (set of alternatives), and $j = 1,...,n,...,J$ (set of criteria), B and C are the sets of benefit and cost criteria.

Step 3. Calculation of the weighted normalized values

$$v_{ij} = \omega_j r_{ij} \tag{3}$$

Step 4. Determination of the ideal and anti-ideal solutions based on the weighted normalized values

$$a_i^* = \left\{v_1^*,...,v_j^*\right\} = \left\{(max_i\, v_{ij} \mid j \in B), (\min_i v_{ij} \mid j \in C\right\} \tag{4}$$

$$a_i^- = \left\{v_1^-,...,v_j^-\right\} = \left\{(max_i\, v_{ij} \mid j \in B), (\min_i v_{ij} \mid j \in C\right\} \tag{5}$$

where B and C are the sets of benefit and cost criteria, respectively.

Step 5. Calculation of the Euclidean distance of alternatives from the ideal (d_i^*) and anti-ideal (d_i^-) solutions

$$d_i^+ = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^*)^2} \tag{6}$$

$$d_i^- = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^-)^2} \tag{7}$$

Step 6. Calculation of the closeness coefficient (CC_i) of each alternative

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{8}$$

Step 7. Rank the alternatives in decreasing order of the closeness coefficient values (CC_i)

B. Fuzzy TOPSIS Programming

In this section, the problem in which the decision maker makes decisions in linguistic form is addressed. The procedural stages of the fuzzy TOPSIS method are considered.

Suppose that, given a set of alternatives I , $a_i = (a_1,...,a_i)$, $i \in$ { $i = 1,...,I$ }, a set of criteria J , $g_j = (g_1,...,g_j)$, $j \in$ { $j = 1,...,J$ }, and the importance weight of each criterion (ω_j , $j \in$ { $j = 1,...,J$ }) is known. The procedural steps of fuzzy TOPSIS method are presented as follows [14]:

Step 1. Determine the linguistic variables for the decision making problem

First, the criteria weight importance and linguistic variables for decisions with trapezoidal fuzzy numbers are defined.

Table 1. Linguistic variables for the decision problem

Linguistic variables for the importance weight of the criteria	Trapezoidal fuzzy numbers	Linguistic variables for the ratings	Trapezoidal fuzzy numbers
Very Low (VL)	(0,0,0,0.1)	Very Poor (VP)	(0,0,0,1)
Low (L)	(0,0.1,0.1,0.3)	Poor (P)	(0,1,1,3)
Medium Low (ML)	(0.1,0.3,0.3,0.5)	Medium Poor (MP)	(1,3,3,5)
Medium (M)	(0.3,0.5,0.5,0.7)	Fair (F)	(3,5,5,7)
Medium High (MH)	(0.5,0.7,0.7,0.9)	Medium Good (MG)	(5,7,7,9)
High (H)	(0.7,0.9,0.9,1)	Good (G)	(7,9,9,10)
Very High (VH)	(0.9,1,1,1)	Very Good (VG)	(9,10,10,10)

Step 2. Establish the linguistic decisions as the matrix of outcomes (alternatives - criteria): n - number of criteria, m - number of alternatives. MCDMA problem representation is given by

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} \overset{g_1}{x_{11}} & \cdots & \overset{g_j}{x_{1j}} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \tag{9}$$

where $X = (x_{ij})_{ixj}$ represents the decision matrix and x_{ij} is the value of ith alternative with respect to jth indicator g_j .
$x_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ is representation of trapezoidal fuzzy numbers of linguistic terms.

Step 3. Calculate normalized fuzzy decision matrix $R = (r_{ij})_{ixj}$, $i = 1,...,I$, $j = 1,...,J$

$$r_{ij} = (\frac{a_{ij}}{d_l^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}),\ j \in B \quad (10)$$

$$r_{ij} = (\frac{a_j^*}{d_{ij}}, \frac{a_j^*}{c_{ij}}, \frac{a_j^*}{b_{ij}}, \frac{a_j^*}{a_{ij}}),\ j \in C \quad (11)$$

where

$$d_j^* = \max_i d_{ij},\ j \in B$$
$$a_j^* = \min_i a_{ij},\ j \in C \quad (12)$$

where B and C represent the maximization criteria set, and minimization criteria set respectively.

Step 4. Calculate weighted normalized fuzzy decision matrix

$$V = (v_{ij}), i = 1,...m,...I,\ j = 1,...n,...J \quad (13)$$

where $v_{ij} = v_{ij} \otimes \omega_j, i = 1,...m,...I,\ j = 1,...n,...J$

Step 5. Determine positive and negative ideal solutions

$$A^+ = (v_1^+,...,v_n^+)$$
$$A^- = (v_1^-,...,v_n^-) \quad (14)$$

where

$$v_1^+ = (1,1,1,1)$$
$$v_1^- = (0,0,0,0) \quad (15)$$

Step 6. Calculate distances between decisions and positive and negative ideal solutions

$$d_i^+ = \sum_{j=1}^{J} d(v_{ij}^+, v_j^+),\ j = 1,...,n,...J \quad (16)$$

$$d_i^- = \sum_{j=1}^{J} d(v_{ij}^-, v_j^-),\ j = 1,...,n,...J \quad (17)$$

where distance is calculated by

$$d(A,B) = \sqrt{\frac{1}{4}[(a_1-b_1)^2 + (a_2-b_2)^2 + (a_3-b_3)^2 + (a_4-b_4)^2]}$$

Step 7. Calculate closeness coefficient (CC_i) for all alternatives

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1,...,m,...I \quad (18)$$

Step 8. Determine acceptance level of decisions

Table 2. Acceptance criteria

Closeness Coefficient (CC_i)	Evaluation
$CC_i \in [0, 0.2)$	Not recommended
$CC_i \in [0.2, 0.4)$	Recommended with high risk
$CC_i \in [0.4, 0.6)$	Recommended with low risk
$CC_i \in [0.6, 0.8)$	Acceptable
$CC_i \in [0.8, 1.0)$	Accepted and preferred

Step 9. Ranking the alternatives

The ranking of the alternatives is based on the final values of the utility functions. It is desirable that an alternative has the highest possible value of the utility function.

Step 10. Select optimal decision with maximum of closeness coefficient (CC_i)

III. Application

In this section, selection of military combat aircraft using trapezoidal fuzzy numbers for multiple criteria decision making analysis problem is considered as a practical numerical example.

Consider a multiple attribute decision making problem with *m* alternatives and *n* attributes. Let $a_i = \{a_1, a_2, ..., a_m\}$, $g_j = \{g_1, g_2, ..., g_n\}$,and $\omega_j = \{\omega_1, \omega_2, ..., \omega_n\}$ denote the alternatives, attributes, and criteria importance respectively.

Alternatives and attributes for the decision making problem were determined from the analysis of the research data on aircraft evaluation and selection problems. The decision dataset can be established using characteristics of the alternatives with respect to the decision attributes. In this decision problem, fuzzy dataset was used to generate decision solutions

Alternatives are indicated by α_1, α_2, and α_3, a set of military combat aircraft candidates. Attributes, characteristics of military combat aircraft are defined as follows:

g_1: Maximum takeoff weight (kg)
g_2: Payload (kg)
g_3: Avionics
g_4: Maximum speed (km/h)
g_5: Range (km)
g_6: Service ceiling (km)
g_7: Combat radius (km)
g_8: Maneuverability
g_9: Reliability

In the fuzzy dataset, optimal decision is maximum for all decision criteria. Application of fuzzy TOPSIS method is considered for this decision analysis problem.

Table 3. Presentation of decisions in linguistic decision matrix

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	VG	G	G
g_2	ω_2	G	MG	G
g_3	ω_3	MG	VG	MG
g_4	ω_4	MG	G	VG
g_5	ω_5	G	G	G
g_6	ω_6	VG	MG	MG
g_7	ω_7	MG	MG	G
g_8	ω_8	G	MG	MG
g_9	ω_9	MG	G	G

The vector of criteria importance (ω_j) is presented as $\omega_j = \{MG, VH, VH, H, MG, MG, H, VH, VH\}$

Table 4. Convert linguistic presentation in trapezoidal fuzzy numbers

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	(9,10,10,10)	(7,9,9,10)	(7,9,9,10)
g_2	ω_2	(7,9,9,10)	(5,7,7,9)	(7,9,9,10)
g_3	ω_3	(9,10,10,10)	(9,10,10,10)	(5,7,7,9)
g_4	ω_4	(5,7,7,9)	(7,9,9,10)	(9,10,10,10)
g_5	ω_5	(7,9,9,10)	(7,9,9,10)	(7,9,9,10)
g_6	ω_6	(9,10,10,10)	(5,7,7,9)	(5,7,7,9)
g_7	ω_7	(5,7,7,9)	(5,7,7,9)	(7,9,9,10)
g_8	ω_8	(7,9,9,10)	(5,7,7,9)	(5,7,7,9)
g_9	ω_9	(5,7,7,9)	(7,9,9,10)	(7,9,9,10)

The vector of criteria importance (ω_j) is determined as ω_j ={(0.5,0.7,0.7,0.9), (0.9,1,1,1), (0.9,1,1,1), (0.7,0.9,0.9,1) (0.5,0.7,0.7,0.9), (0.5,0.7,0.7,0.9), (0.7,0.9,0.9,1), (0.9,1,1,1), (0.9,1,1,1)}

Table 5. Calculated normalized fuzzy decision matrix

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	(0.9,1,1,1)	(0.7,0.9,0.9,1)	(0.7,0.9,0.9,1)
g_2	ω_2	(0.7,0.9,0.9,1)	(0.5,0.7,0.7,0.9)	(0.7,0.9,0.9,1)
g_3	ω_3	(0.5,0.7,0.7,0.9)	(0.9,1,1,1)	(0.5,0.7,0.7,0.9)
g_4	ω_4	(0.5,0.7,0.7,0.9)	(0.7,0.9,0.9,1)	(0.9,1,1,1)
g_5	ω_5	(0.7,0.9,0.9,1)	(0.7,0.9,0.9,1)	(0.7,0.9,0.9,1)
g_6	ω_6	(0.9,1,1,1)	(0.5,0.7,0.7,0.9)	(0.5,0.7,0.7,0.9)
g_7	ω_7	(0.5,0.7,0,7,0.9)	(0.5,0.7,0.7,0.9)	(0.7,0.9,0.9,1)
g_8	ω_8	(0.7,0.9,0.9,1)	(0.5,0.7,0.7,0.9)	(0.5,0.7,0.7,0.9)
g_9	ω_9	(0.5,0.7,0.7,0.9)	(0.7,0.9,0.9,1)	(0.7,0.9,0.9,1)

Table 6. Calculated weighted normalized fuzzy decision matrix

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	(0.45,0.7,0.7,0.9)	(0.35,0.63,0.63,0.9)	(0.35,0.63,0.63,0.9)
g_2	ω_2	(0.63,0.9,0.9,1)	(0.45,0.7,0.7,0.9)	(0.63,0.9,0.9,1)
g_3	ω_3	(0.45,0.7,0.7,0.9)	(0.81,1,1,1)	(0.45,0.7,0.7,0,9)
g_4	ω_4	(0.35,0.63,0.63,0.9)	(0.49,0.81,0.81,1)	(0.63,0.9,0.9,1)
g_5	ω_5	(0.35,0.63,0.63,0.9)	(0.35,0.63,0.63,0.9)	(0.35,0.63,0.63,0.9)
g_6	ω_6	(0.45,0.7,0.7,0.9)	(0.25,0.49,0.49,0.81)	(0.25,0.49,0.49,0.81)
g_7	ω_7	(0.35,0.63,0.63,0.9)	(0.35,0.63,0.63,0.9)	(0.49,0.81,0.81,1)
g_8	ω_8	(0.63,0.9,0.9,1)	(0.45,0.7,0.7,0.9)	(0.45,0.7,0.7,0.9)
g_9	ω_9	(0.45,0.7,0.7,0.9)	(0.63,0.9,0.9,1)	(0.63,0.9,0.9,1)

Table 7. Calculated distance between decisions and positive ideal solutions

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	0,061563	0,088288	0,088288
g_2	ω_2	0,027813	0,039063	0,017813
g_3	ω_3	0,049063	0,015313	0,039063
g_4	ω_4	0,054335	0,017587	0,011062
g_5	ω_5	0,057755	0,047560	0,049269
g_6	ω_6	0,043844	0,083539	0,081623
g_7	ω_7	0,055044	0,049287	0,023385
g_8	ω_8	0,021732	0,035184	0,035055
g_9	ω_9	0,044370	0,011375	0,011503

Table 8. Calculated distances between decisions and negative ideal solutions

g_j	ω_j	α_1	α_2	α_3
g_1	ω_1	0,249063	0,215788	0,291175
g_2	ω_2	0,377113	0,249063	0,377113
g_3	ω_3	0,249063	0,457013	0,249063
g_4	ω_4	0,215788	0,319038	0,377113
g_5	ω_5	0,215788	0,215788	0,215788
g_6	ω_6	0,249063	0,149850	0,149850
g_7	ω_7	0,215788	0,215788	0,319038
g_8	ω_8	0,377113	0,249063	0,249063
g_9	ω_9	0,249063	0,377113	0,377113

Finally, after calculating the distances between the alternatives and the positive and negative ideal solutions, the closeness coefficients for all alternatives are calculated and the ranking results are given in Table 9.

Table 9. Calculated closeness coefficients (CC_i) and ranking of alternatives

a_i	d_i^+	d_i^-	CC_i	Ranking
α_1	0,415518	2,397838	0,852305	3
α_2	0,387195	2,448500	0,863457	2
α_3	0,357059	2,605313	0,879469	1

According to the acceptance criteria of the alternatives, all military combat aircraft alternatives are designated as "Accepted and Preferred". Alternative α_3 is optimal selection since the closeness coefficients are ordered from largest to smallest as $CC_3 \succ CC_2 \succ CC_1$. Therefore, alternative (α_3) is selected as the best military combat aircraft candidate for the Air Force.

IV. Conclusion

In this paper, multiple criteria decision making analysis in fuzzy TOPSIS environment is presented. The fuzzy TOPSIS programming method contributes to the multiple criteria decision making problem for military fighter aircraft selection. An analysis of available methods for solving such a selection problem is given. The fuzzy TOPSIS programming is widely used as a mathematical method to solve decision analysis problems.

Practical application stages of fuzzy TOPSIS method with trapezoidal fuzzy numbers were discussed using the decision making process. Military combat aircraft selection problem with nine decision criteria and three alternatives was considered as a practical problem. The results of the solution at all stages for the decision making problem were presented. From the fuzzy TOPSIS decision analysis results, it was concluded that alternative (a_3) military combat aircraft was selected as the best aircraft for the Air Force.

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