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Aircraft Selection Process Using Preference Analysis for Reference Ideal Solution (PARIS)

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***Abstract*—**Multiple criteria decision making analysis (MCDMA) methods are applied to many real - life problems in different fields of engineering science and technology. The "preference analysis for reference ideal solution (PARIS)" method is proposed for an efficient MCDMA evaluation of decision problems. The multiple criteria aircraft evaluation approach is based on the integrated the mean weight, entropy weight, PARIS, and TOPSIS method, which eliminates the subjective importance weight assignment process. The evaluation criteria were identified from an extensive literature review of aircraft selection process. The aim of this study is to propose an efficient methodology for handling the aircraft selection process in which the proposed method solves effectively the MCDMA problem. A numerical example is presented to demonstrate the applicability and validity of the proposed MCDMA approach.

***Keywords*—**aircraft selection, aircraft, multiple criteria decision making, multiple criteria decision making analysis, mean weight, entropy weight, MCDMA, PARIS, TOPSIS, VIKOR, ELECTRE, PROMETHEE.

I. Introduction

In decision making problems, it is generally seen that a set of alternatives is evaluated according to often conflicting multiple decision criteria. Multiple criteria decision analysis (MCDMA) methods are very useful for overcoming complexity in such decision problems. MCDMA methods are widely used to solve various decision problems through alternative evaluation. MCDMA methods can be used in any field that can define a problem, alternatives, and criteria in the decision analysis environment [1-8], [21-27].

In the literature, many MCDMA methods have been proposed to deal with the multiple criteria decision problems. These MCDMA methods are generally categorized into compensatory such as technique for order of preference by similarity to ideal solution (TOPSIS) [9-12], vlsekriterijumska optimizacija i kompromisno resenje (VIKOR) [13-15], and noncompensatory ((elimination et choix traduisant la realité (ELECTRE) [16], preference ranking organisational method for enrichment evaluation (PROMETHEE)) approaches [17-20].

VIKOR and TOPSIS methods are applied in the compromise ranking based on aggregation functions representing proximity to reference points. While the VIKOR method finds a compromise solution, the TOPSIS method finds a solution with the shortest distance from the ideal solution and the largest distance from the anti - ideal solution.

The ELECTRE and PROMETHEE methods explicitly account for uncertain input criteria scores by the adoption of the pseudo-criterion model that introduces indifference and preference thresholds [17-20].

In this study, the preference analysis for the reference ideal solution (PARIS) method, which is an efficient method to handle MCDMA problems, is considered to evaluate aircraft selection process. This method is also recommended for dealing with real-life MCDMA problems under uncertainty.

The aircraft selection process is a multiple criteria decision making analysis problem. Because the decision making process considers a set of alternatives along with often conflicting evaluation criteria. From the literature review, it has been found that various compensatory MCDMA methods are used to solve aircraft selection problems [28-51]. In that context, application of TOPSIS in evaluating initial training aircraft under a fuzzy environment was considered for the Taiwan Air Force. The fuzzy multiple criteria decision making analysis method was applied to determine the importance weights of evaluation criteria and to synthesize the ratings of candidate aircraft. Aggregated the evaluators' attitude toward preference; then TOPSIS was employed to obtain a crisp overall performance value for each alternative to make a final decision [29].

Evaluating military training aircrafts problem through the combination of multiple criteria decision making processes with fuzzy logic approach was used to solve a real-life decision problem of interest for the Spanish Air Force. The Analytic Hierarchy Process (AHP) was used to obtain the weights of the criteria and, through the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the alternatives were evaluated. The selection of the best military training aircraft was based on a set of decision criteria [34].

The selection of military aircraft problem for the Pakistan Air Force was considered using the Analytic Hierarchy Process (AHP) and Cost Benefit Analysis (CBA). A set of ten technical and economic criteria were applied over six alternative aircraft [39].

Also, military fighter aircraft selection problem was considered using multiplicative multiple criteria decision making analysis method for evaluating nine alternatives under ten decision criteria Robustness of the proposed model was tested by using other MCDMA techniques [44].

Fighter aircraft selection problem using technique for order preference by similarity to ideal solution (TOPSIS) was handled by functioning multiple criteria decision making analysis, considering three real and two test (best, worst)

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aircraft candidates. Sensitivity analysis was conducted using six objective weighting methods [45].

Multiple criteria decision making analysis problem for selecting and evaluating fighter aircraft was considered by a set of seven aircraft alternatives and ten evaluation criteria [46].

Aircraft selection problem, using multiple criteria decision making analysis method with different data normalization techniques, was considered by a set of four aircraft alternatives and six evaluation criteria [47].

In this study, the multiple criteria aircraft evaluation approach is based on the integrated the mean weight, the entropy weight, PARIS, and TOPSIS method, which eliminates the subjective importance weight assignment process.

The rest of the paper is organized as follows. Chapter 2 presents the procedural steps of the integrated the mean weight, the entropy weight, PARIS, and TOPSIS method. Chapter 3 presents a numerical example to demonstrate the applicability and validity of the proposed approach. The results are analyzed and discussed. Chapter 4 concludes with considerations for future work.

II. Methodology

A. The PARIS method

Suppose that multiple criteria decision making analysis (MCDMA) problem has I alternatives $a_i = (a_1, ..., a_i)$, $i \in \{ i = 1, ..., I \}$, and J criteria $g_j = (g_1, ..., g_j)$, $j \in \{ j = 1, ..., J \}$, and the importance weight of each criterion (ω_j, $j \in \{ j = 1, ..., J \}$) is known. The procedural steps of PARIS method for evaluation of the alternatives with respect to the decision criteria are presented as follows:

Step 1. Construction of decision matrix $X = (x_{ij})_{ixj}$

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

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

In exceptional decision problems, if there are negative values in the decision matrix, first, the decision matrix is transformed by $x_{ij}^t = x_{ij} - \min_j x_{ij}$, then, the values of x_{ij}^t are used in the next procedural steps.

Step 2. Normalization of the decision matrix

a. Normalization Procedure (N1)

If the evaluation attribute g_j is a benefit criteria, then

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^2}}, \; i = 1, ..., I, \; j = 1, ..., J \quad (2)$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^2}}, \; i = 1, ..., I, \; j = 1, ..., J \quad (3)$$

b. Normalization Procedure (N2)

If the evaluation attribute g_j is a benefit criteria, then

$$r_{ij} = \frac{x_{ij}}{x_j^{\max}}, \; i = 1, ..., I, \; j = 1, ..., J \quad (4)$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = \frac{x_j^{\min}}{x_{ij}}, \; i = 1, ..., I, \; j = 1, ..., J \quad (5)$$

c. Normalization Procedure (N3)

If the evaluation attribute g_j is a benefit criteria, then

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (6)$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \quad (7)$$

where x_{ij} are the evaluation indices and $i = 1, ..., I$, number of alternatives, and number of criteria, $j = 1, ..., J$.

$$x_i^{max} = \max_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\}, \; x_i^{min} = \min_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\} \quad (8)$$

Upon normalizing criteria of the decision matrix, all elements x_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3. Computation of the weighted normalized matrix

$$z_{ij} = \omega_j r_{ij} \quad (9)$$

Step 4. Computation of the weighted summation of the evaluation indices

$$\pi_i^{\omega} = \sum_{j=1}^{J} \omega_j r_{ij}, \; i = 1,...,I, \; j = 1,...,J \tag{10}$$

Step 5. Rank the alternatives according to decreasing values of π_i^{ω}. The alternative with the highest appraisal score is the best choice among the candidate alternatives.

Step 6. Determination of the elements of reference ideal solution (z_j^*)

$$z_j^* = \left\{ z_1^*,...,z_j^* \right\} = \left\{ (max_i \; z_{ij} \mid j \in B), (\min_i \; z_{ij} \mid j \in C \right\} \tag{11}$$

Step 7. Computation of distance from the reference ideal solution (z_j^*)

$$\pi_i^* = \sum_{j=1}^{J} (z_j^* - z_{ij}), \; i = 1,...,I, \; j = 1,...,J \tag{12}$$

Step 8. Rank the alternatives according to increasing values of π_i. The alternative with the lowest appraisal score is the best choice among the candidate alternatives.

Step 9. The relative distance from each evaluated alternative to the reference ideal point is calculated to determine the ranking order of all alternatives.

$$R_i = \sqrt{(\pi_i^{\omega} - \pi_i^{\omega,\max})^2 + (\pi_i^* - \pi_i^{*,\min})^2} \tag{13}$$

Step 10. Rank the alternatives according to increasing values of R_i. The alternative with the lowest appraisal score is the best choice among the candidate alternatives.

B. The TOPSIS method

The technique for order of preference by similarity to ideal solution (TOPSIS) method is an MCDMA method which 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, $a_i = \left(a_1,...,a_i\right)$, $i \in$ { $i = 1,...,I$ }, a set of criteria J, $g_j = \left(g_1,...,g_j\right)$, $j \in$ { $j = 1,...,J$ }, and the importance weight of each criterion (ω_j, $j \in$ { $j = 1,...,J$ }) is known. The procedural steps of TOPSIS method are presented as follows [11]:

Step 1. The construction of a decision matrix

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} & g_1 & & g_j \\ & x_{11} & \cdots & x_{1j} \\ & \vdots & \ddots & \vdots \\ & x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \tag{14}$$

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

In exceptional decision problems, if there are negative values in the decision matrix, first, the decision matrix is transformed by $x_{ij}^t = x_{ij} - \min_j x_{ij}$, then, the values of x_{ij}^t are used in the next procedural steps.

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

If the evaluation attribute g_j is a benefit criteria, then

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^{\;2}}}, \; i = 1,...,I, \; j = 1,...,J \tag{15}$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^{\;2}}}, \; i = 1,...,I, \; j = 1,...,J \tag{16}$$

Step 3. Calculation of the weighted normalized values

$$v_{ij} = \omega_j r_{ij} \tag{17}$$

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

$$a_i^* = \left\{ v_1^*,...,v_j^* \right\} = \left\{ (max_i \; v_{ij} \mid j \in B), (\min_i \; v_{ij} \mid j \in C \right\} \tag{18}$$

$$a_i^- = \left\{ v_1^-,...,v_j^- \right\} = \left\{ (max_i \; v_{ij} \mid j \in B), (\min_i \; v_{ij} \mid j \in C \right\} \tag{19}$$

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

$$D_i^* = \sqrt{\sum_{j=1}^{J} \; (v_{ij} - v_j^*)^2} \tag{20}$$

$$D_i^- = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^-)^2} \tag{21}$$

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

$$CC_i = \frac{D_i^-}{D_i^* + D_i^-} \tag{22}$$

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

C. Entropy weight vector calculation

The fundamental of the entropy weight method is the volume of information to calculate the index's objective importance weight. Since the method relies only on unbiased data, this objective weighting can overcome the shortcomings of the subjective weighting method. Therefore, the information entropy method is used to determine the criteria weight. The following procedural steps summarize the basics of the Shannon entropy weighting process [45, 51]:

Step 1. The normalization of the decision matrix $X = (x_{ij})_{ixj}$

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}}, \; i = 1, ..., I \tag{23}$$

Step 2. The calculation of entropy for each index

$$E_j = -\frac{1}{\ln I} \sum_{i=1}^{I} p_{ij} \ln p_{ij}, \; j = 1, ..., J \tag{24}$$

Step 3. The calculation of the degree of deviation of essential information for each criterion g_j

$$D_j = 1 - E_j, \; j = 1, ..., J \tag{25}$$

where D_j measures the degree of deviation of essential information for the *j*th criteria g_j .

Step 4. The calculation of the criteria's entropy weight

$$\omega_j = \frac{D_j}{\sum_{j=1}^{J} D_j} \tag{26}$$

$$\sum_{j=1}^{J} \omega_j = 1 \; , \; \omega_j > 0 \; , \quad j = 1, ..., J$$

where ω_j is the importance weight of the *j*th criteria g_j .

D. Mean weight vector calculation

The mean weight (MW) requires minimal information about the priorities of the criteria and minimal input from the decision maker. The MW method is used in multiple criteria decision analysis when there is no information from the decision maker or there is not enough information to come to a decision. The criteria weights are represented as a uniform distribution over the unit.

$$\omega_j = \frac{1}{J} \; , \; j = 1, ..., J \tag{27}$$

$$\sum_{j=1}^{J} \omega_j = 1 \; , \; \omega_j > 0 \; , \quad j = 1, ..., J$$

where ω_j is the importance weight of the *j*th criteria g_j .

III. Application

An empirical MCDMA study was conducted to verify all identified decision criteria and ranking alternatives, also to validate this integrated method, PARIS, TOPSIS, mean weight, and entropy weight. Therefore, the application of the PARIS, and TOPSIS methods to an aircraft selection problem confronted by a hypothetical airline is presented. This airline desires to determine the most suitable short-to-medium range aircraft {Airbus family of aircraft (A319 (neo) (a_1), A320 (neo) (a_2) , A321 (neo) (a_3), Boeing family of aircraft (B737 (MAX7) (a_4) , B737 (MAX8) (a_5) , B737 (MAX9) (a_6)} for strategic, tactical, and operational planning. From the relevant literature [28-51], six evaluation criteria for the MCDMA problem were determined and employed in the aircraft evaluation process. The evaluation criteria in the aircraft evaluation process are presented as follows:

Aircraft Price: The price of aircraft in million dollars, ($, min, g_1).

Aircraft Fuel Consumption:Aircraft fuel consumption is the measure of the transport energy efficiency of aircraft, (kg/km, min, g_2).

Aircraft Fuel Efficiency per Seat:The fuel economy in aircraft is the measure of the transport energy efficiency of aircraft (L/100 km, min, g_3).

Aircraft Range: Range is the distance that can be flown by an aircraft without refueling, (km, max, g_4).

Aircraft Number of Seats: The seat count is aircraft's sitting capacity, (#, max, g_5).

Aircraft Luggage Volume: It is the luggage volume capacity, (m^3, max, g_6).

Aircraft Maximum Takeoff Weight:The maximum gross weight due to design or operational limitations at which an aircraft is permitted to take off, (kg, max, g_7).

The numerical index values of the seven decision criteria for the six aircraft alternatives are presented in Table 1 by considering the economic, environmental, and technical aspects. In the MCDMA problem, the three decision criteria (Aircraft Price, Aircraft Fuel Consumption, and Aircraft Fuel Efficiency per Seat) are modeled as cost while the other four decision criteria (Aircraft Range, Aircraft's Number of Seats, Aircraft's Luggage Volume, and Aircraft Maximum Takeoff Weight) are modeled as benefit.

Table 1. Decision Matrix

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	101,5	2,82	2,82	6850	140	27	75900
a_2	110,6	2,79	2,25	6300	165	37	79400
a_3	115	3,30	2,19	7400	206	51	97400
a_4	99,7	3,39	2,93	7130	153	32,3	80286
a_5	121,6	3,04	2,28	6575	178	43,69	82191
a_6	128,9	3,30	2,28	6575	193	51,37	88314

For the hypothetical airline, six alternative aircraft were ranked according to PARIS, and TOPSIS methods, using the index values of seven evaluation criteria. In the MCDMA methods, objective weights determined by two different weighting methods, the mean weight (MW) and the entropy weight (EW), were applied to the aircraft selection process.

In the first application, the equal criteria weights were determined by the MW method and the data were evaluated according to these criteria values. Then, the criteria weights were determined by the EW method and the data were evaluated according to these criteria values. The criteria importance weights determined by the mean weight (MW) and the entropy weight (EW) are given in Table 2.

Table 2. Objective decision criteria weights ω_j

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
MW ω_j	1/7	1/7	1/7	1/7	1/7	1/7	1/7
EW ω_j	0,078	0,055	0,133	0,027	0,159	0,483	0,065

In the next computational stages, the following data and results were obtained by applying the procedural steps of the three MCDMA approaches (PARIS, and TOPSIS) used in the aircraft selection problem.

Table 3. Normalized decision matrix with normalization procedure (N1)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,6345	0,6305	0,5351	0,4103	0,3285	0,2662	0,3679
a_2	0,6017	0,6344	0,6291	0,3774	0,3872	0,3647	0,3849
a_3	0,5858	0,5676	0,6390	0,4433	0,4834	0,5028	0,4722
a_4	0,6409	0,5558	0,5170	0,4271	0,3590	0,3184	0,3892
a_5	0,5621	0,6017	0,6241	0,3939	0,4177	0,4307	0,3984
a_6	0,5358	0,5676	0,6241	0,3939	0,4529	0,5064	0,4281

Table 4. MW weighted normalized decision matrix with normalization procedure (N1)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0907	0,0901	0,0765	0,0586	0,0469	0,0380	0,0526
a_2	0,0860	0,0907	0,0899	0,0539	0,0553	0,0521	0,0550
a_3	0,0837	0,0811	0,0913	0,0633	0,0691	0,0718	0,0675
a_4	0,0916	0,0794	0,0739	0,0610	0,0513	0,0455	0,0556
a_5	0,0803	0,0860	0,0892	0,0563	0,0597	0,0615	0,0569
a_6	0,0766	0,0811	0,0892	0,0563	0,0647	0,0724	0,0612

Table 5. EW weighted normalized decision matrix with normalization procedure (N1)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0495	0,0347	0,0712	0,0111	0,0522	0,1286	0,0239
a_2	0,0469	0,0349	0,0837	0,0102	0,0616	0,1762	0,025
a_3	0,0457	0,0312	0,085	0,012	0,0769	0,2428	0,0307
a_4	0,05	0,0306	0,0688	0,0115	0,0571	0,1538	0,0253
a_5	0,0438	0,0331	0,083	0,0106	0,0664	0,208	0,0259
a_6	0,0418	0,0312	0,083	0,0106	0,072	0,2446	0,0278

Table 6. Distance from the reference ideal solution using MW weighted normalized decision matrix with normalization procedure (N1)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	-0,0141	-0,0107	-0,0026	0,0047	0,0221	0,0343	0,0149
a_2	-0,0094	-0,0112	-0,0160	0,0094	0,0137	0,0202	0,0125
a_3	-0,0072	-0,0017	-0,0174	0,0000	0,0000	0,0005	0,0000
a_4	-0,0150	0,0000	0,0000	0,0023	0,0178	0,0269	0,0119
a_5	-0,0038	-0,0066	-0,0153	0,0071	0,0094	0,0108	0,0105
a_6	0,0000	-0,0017	-0,0153	0,0071	0,0044	0,0000	0,0063

Table 7. Distance from the reference ideal solution using EW weighted normalized decision matrix with normalization procedure (N1)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0005	0,0002	0,0138	0,0009	0,0246	0,116	0,0068
a_2	0,0031	0	0,0013	0,0018	0,0153	0,0684	0,0057
a_3	0,0043	0,0037	0	0	0	0,0018	0
a_4	0	0,0043	0,0162	0,0004	0,0198	0,0908	0,0054
a_5	0,0062	0,0018	0,002	0,0013	0,0104	0,0366	0,0048
a_6	0,0082	0,0037	0,002	0,0013	0,0049	0	0,0029

Table 8. Normalized decision matrix with normalization procedure (N2)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,9823	0,9894	0,7766	0,9257	0,6796	0,5256	0,7793
a_2	0,9014	1	0,9733	0,8514	0,801	0,7203	0,8152
a_3	0,867	0,8455	1	1	1	0,9928	1
a_4	1	0,823	0,7474	0,9635	0,7427	0,6288	0,8243
a_5	0,8199	0,9178	0,9605	0,8885	0,8641	0,8505	0,8439
a_6	0,7735	0,8455	0,9605	0,8885	0,9369	1	0,9067

Table 9. MW weighted normalized decision matrix with normalization procedure (N2)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0907	0,0901	0,0765	0,0586	0,0469	0,0380	0,0526
a_2	0,0860	0,0907	0,0899	0,0539	0,0553	0,0521	0,0550
a_3	0,0837	0,0811	0,0913	0,0633	0,0691	0,0718	0,0675
a_4	0,0916	0,0794	0,0739	0,0610	0,0513	0,0455	0,0556
a_5	0,0803	0,0860	0,0892	0,0563	0,0597	0,0615	0,0569
a_6	0,0766	0,0811	0,0892	0,0563	0,0647	0,0724	0,0612

Table 10. EW weighted normalized decision matrix with normalization procedure (N2)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0766	0,0544	0,1033	0,025	0,1081	0,2539	0,0507
a_2	0,0703	0,055	0,1295	0,023	0,1274	0,3479	0,053
a_3	0,0676	0,0465	0,133	0,027	0,159	0,4795	0,065
a_4	0,078	0,0453	0,0994	0,026	0,1181	0,3037	0,0536
a_5	0,064	0,0505	0,1278	0,024	0,1374	0,4108	0,0549
a_6	0,0603	0,0465	0,1278	0,024	0,149	0,483	0,0589

Table 11. Distance from the reference ideal solution using MW weighted normalized decision matrix with normalization procedure (N2)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0663	0,0885	0,0396	0,1179	0,0348	-0,111	0,0922
a_2	0,0726	0,0879	0,0134	0,1199	0,0155	-0,205	0,0899
a_3	0,0753	0,0964	0,0099	0,1159	-0,016	-0,337	0,0779
a_4	0,0649	0,0976	0,0435	0,1169	0,0248	-0,161	0,0893
a_5	0,0789	0,0924	0,0152	0,1189	0,0055	-0,268	0,088
a_6	0,0826	0,0964	0,0152	0,1189	-0,006	-0,34	0,084

Table 12. Distance from the reference ideal solution using EW weighted normalized decision matrix with normalization procedure (N2)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0014	0,0006	0,0297	0,002	0,0509	0,2291	0,0143
a_2	0,0077	0	0,0035	0,004	0,0316	0,1351	0,012
a_3	0,0104	0,0085	0	0	0	0,0035	0
a_4	0	0,0097	0,0336	0,001	0,0409	0,1793	0,0114
a_5	0,014	0,0045	0,0052	0,003	0,0216	0,0722	0,0101
a_6	0,0177	0,0085	0,0052	0,003	0,01	0	0,0061

Table 13. Normalized decision matrix with normalization procedure (N3)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0616	0,05	0,8514	0,5	0	0	0
a_2	0,3733	0	0,0811	0	0,3788	0,4103	0,1628
a_3	0,524	0,85	0	1	1	0,9848	1
a_4	0	1	1	0,7545	0,197	0,2175	0,204
a_5	0,75	0,4167	0,1216	0,25	0,5758	0,6849	0,2926
a_6	1	0,85	0,1216	0,25	0,803	1	0,5774

Table 14. MW weighted normalized decision matrix with normalization procedure (N3)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0088	0,0071	0,1216	0,0714	0	0	0
a_2	0,0533	0	0,0116	0	0,0541	0,0586	0,0233
a_3	0,0749	0,1214	0	0,1429	0,1429	0,1407	0,1429
a_4	0	0,1429	0,1429	0,1078	0,0281	0,0311	0,0291
a_5	0,1071	0,0595	0,0174	0,0357	0,0823	0,0978	0,0418
a_6	0,1429	0,1214	0,0174	0,0357	0,1147	0,1429	0,0825

Table 15. EW weighted normalized decision matrix with normalization procedure (N3)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0048	0,0027	0,1132	0,0135	0	0	0
a_2	0,0291	0	0,0108	0	0,0602	0,1982	0,0106
a_3	0,0409	0,0468	0	0,027	0,159	0,4757	0,065
a_4	0	0,055	0,133	0,0204	0,0313	0,105	0,0133
a_5	0,0585	0,0229	0,0162	0,0068	0,0915	0,3308	0,019
a_6	0,078	0,0468	0,0162	0,0068	0,1277	0,483	0,0375

Table 16. Distance from the reference ideal solution using MW weighted normalized decision matrix with normalization procedure (N3)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1341	0,1357	0,0212	0,0714	0,1429	0,1429	0,1429
a_2	0,0895	0,1429	0,1313	0,1429	0,0887	0,0842	0,1196
a_3	0,068	0,0214	0,1429	0	0	0,0022	0
a_4	0,1429	0	0	0,0351	0,1147	0,1118	0,1137
a_5	0,0357	0,0833	0,1255	0,1071	0,0606	0,045	0,1011
a_6	0	0,0214	0,1255	0,1071	0,0281	0	0,0604

Table 17. Distance from the reference ideal solution using EW weighted normalized decision matrix with normalization procedure (N3)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0732	0,0523	0,0198	0,0135	0,159	0,483	0,065
a_2	0,0489	0,055	0,1222	0,027	0,0988	0,2848	0,0544
a_3	0,0371	0,0083	0,133	0	0	0,0073	0
a_4	0,078	0	0	0,0066	0,1277	0,378	0,0517
a_5	0,0195	0,0321	0,1168	0,0203	0,0675	0,1522	0,046
a_6	0	0,0083	0,1168	0,0203	0,0313	0	0,0275

Table 18. PARIS ranking results π_i^{ω} using weighted summation with normalization procedure (N1)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	6	4	1	5	3	2	Ranking Order
	EW ω_j	6	4	1	5	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Table 19. PARIS ranking results π_i^{ω} using weighted summation with normalization procedure (N2)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	6	4	1	5	3	2	Ranking Order
	EW ω_j	6	4	1	5	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Table 20. PARIS ranking results π_i^{ω} using weighted summation with normalization procedure (N3)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	5	6	1	3	4	2	Ranking Order
	EW ω_j	6	5	1	4	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Table 21. PARIS ranking results π_i^{*} using distance from the reference ideal solution with normalization procedure (N1)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	6	4	1	5	3	2	Ranking Order
	EW ω_j	6	4	1	5	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Table 22. PARIS ranking results π_i^{*} using distance from the reference ideal solution with normalization procedure (N2)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	6	4	1	5	3	2	Ranking Order
	EW ω_j	6	4	1	5	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Table 23. PARIS ranking results π_i^{*} using distance from the reference ideal solution with normalization procedure (N3)

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	5	6	1	3	4	2	Ranking Order
	EW ω_j	6	5	1	4	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

Also, PARIS ranking results R_i using relative distance from the reference ideal solution with normalization procedures (N1, N2, N3) show that alternative (a_3) is the best choice.

Table 24. TOPSIS ranking order of the aircraft using the ideal (a_i^*) solution vector and anti-ideal solution (a_i^-) vector

		Ranking Order in Weighting Index						
Weighting Index	MW ω_j	6	5	1	4	3	2	Ranking Order
	EW ω_j	6	4	1	5	3	2	
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	
		Aircraft Alternatives						

In this study, the PARIS, and TOPSIS procedural steps were implemented by using the mean weight (MW) and the entropy weight (EW) methods for aircraft selection process problem. The procedural computational results of the proposed method and the ranks of aircraft alternatives are presented in Table 1 - Table 24, respectively. The ranking results indicate that the A321 (neo) (a_3) aircraft with the highest appraisal values and relative closeness values is the best aircraft alternative solution for the hypothetical airline.

Evidently, the ranking of the A321 (neo) (a_3) aircraft alternative ranks first in all multiple criteria evaluation methods. Also, the MCDMA sensitivity analysis reveals that the rank of the A321 (neo) (a_3) aircraft has remained the same in the aircraft selection process. It should be noted that the ranking of alternatives in MCDMA is largely dependent on the criteria weights, and these importance weights are assigned subjectively by the decision makers, or determined objectively by mathematical procedures, and sometimes integrated weighting methods are also used to assign the criteria weights.

In this MCMDA problem, the subjective weight assignment process is mathematically eliminated using objective weighting methods, the mean weight (MW) and the entropy weight (EM) methods.

The data normalization procedures (N1, N2 and N3) gave the same ranking results for the A321(neo) (a_3) aircraft which is the best alternative for the hypothetical airline. The validity of the proposed model was carried out by integrating the average weight, entropy weight, PARIS, and TOPSIS method for the aircraft selection process problem.

IV. Conclusion

Selection of the most suitable aircraft type is an important issue in the aviation industry that affects an airline's profitability and effectiveness. In this study, an integrated MCDMA solution approach based on PARIS, TOPSIS, average weight and entropy weight methods is proposed for an aircraft selection process problem. A numerical example containing six aircraft types and seven evaluation criteria is solved using this MCDMA approach.

The purpose of this research is to develop an MCDMA model to evaluate different aircraft alternatives and to support efficient priority decision selection.

The MCDMA decision factors produce a final evaluation ranking for priority among these aircraft alternatives of the proposed model. In order to achieve the objectives of the study, objective data are collected, and comparative analysis is made.

The solution optimality is objectively obtained by solving the decision matrix. Of the proposed method, mean weight, entropy weight, PARIS, and TOPSIS, the A321(neo) (a_3) aircraft is the best aircraft solution for the hypothetical airline.

In addition, the A321(neo) (a_3) aircraft ranks first in the MCDMA assessment. From a theoretical point of view, this research developed an MCDMA model to evaluate the aircraft selection process.

The study ranked the aircraft based on identified factors derived from an extensive literature review. In order to achieve the aim of the study, the preference analysis for the reference ideal solution (PARIS), and technique for order preference by similarity to the ideal solution (TOPSIS) were used. The findings of the study show that the A321(neo) (a_3) aircraft is in the top rank.

The proposed approach is very practical as it does not require the decision maker to assign subjective weights to the aircraft selection criteria. Using objectively meaningful preference evaluation weights, the analyst can determine the importance of decision criteria weight preferences.

Although the proposed approach allows the analyst to calculate evaluation criteria weights using objective weighting procedures, it cannot consider the uncertainty and vagueness associated with the decision maker's preferences. Therefore, the development of an aircraft selection process approach based on fuzzy preference programming could be an interesting future research topic for alternative ranking in the MCDM problem domain.

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APPENDIX

Table 25. Multiple criteria decision making analysis methods for aircraft selection problem

Authors	Methodologies	Criteria	Alternatives
See,T.-K., Gurnani, A., Lewis, K. E. (2004)[28]	Weighted Sum Method, Hypothetical Equivalents and Inequivalents Method	Speed, Max. Range, Number of passengers	Comparison of 4 aircraft types B747, B777, A340, B747
Wang, T. C., Chang, T. H. (2007)[29]	Fuzzy Technique for Order Preference by Similarity to Ideal Situation	Fuel capacity, Power plant, Service ceiling, Maximum G limits, Minimum G limits, Maximum operating speed, Econ cruising speed, Maximum speed with landing gears down, Maximum speed with flaps down, Stalling speed: flameout, Maximum cruising speed, Maximum climbing rate at sea level, Take-off distance, Landing distance, Take-off to 50 feet, Landing from 50 to full stop	Comparison of 7 aircraft types T-34, PC-7, PC-9, PC-7 MK2, T-6A, KT-1, T-27
Ozdemir, Y., Basligil, H., Karaca, M. (2011) [30]	Analytic Network Process	Cost, Time, Physical Attributes and Others: Maintenance cost, Operation and spare cost, Purchasing cost, Salvage cost, Dimensions, Reliability, Security, Suitability for service quality, Delivery time, Useful life	Comparison of 3 aircraft types A319, A320, B737
Gomes, L. F. A. M., Fernandes, J. E. d. M., Soares de Mello, J. C. C. B.(2012) [31]	Novel Approach to Imprecise Assessment and Decision Environments (NAIADE Method)	Financial, Logistics, Quality :Acquisition cost, Liquidity, Operating costs, Range, Flexibility, Cruising speed, Replacement parts availability, Landing and take-off distance, Comfort, Avionics availability, Safety	Comparison of 8 aircraft types Cessna 208, De Havilland DHC-6, LET 410, Fairchild Metro, Beechcraft 1900, Embraer EMB 110, Dornier 228, CASA 212
Dožić,S., Kalić, M. (2014)[32]	Analytic Hierarchy Process	Seat capacity, Price of aircraft, Total baggage, Maximum take-off weight (MTOW), Payment conditions, Total cost per available seat miles (TCASM)	Comparison of 7 aircraft types AT72-500, AT72-600, ERJ190, Q400, NG CRJ700, CRJ900, CRJ1000
Teoh, L. E., Khoo, H. L. (2015)[33]	Analytic Hierarchy Process	Load factor, Passengers carried, Revenue passenger kilometers (RPK), Available seat kilometers (ASK), Fuel efficiency	Comparison of 3 aircraft types A320-200, A330-300, B747-800
Sánchez-Lozano, J.M., Serna,J., Dolón-Payán, A.(2015)[34]	Fuzzy Analytic Hierarchy Process, Fuzzy Technique for Order Preference by Similarity to Ideal Solution	Service ceiling, Cruising speed, Stalling speed, Endurance, Positive Limit Load Factor, Negative Limit Load Factor, Take-off distance, Landing distance, Human factors, Flying and handling qualities, Security systems, Tactical capability	Comparison of 5 aircraft types Pilatus PC-21, Beechcraft T-6C, PZL-130 Orlik (TC-II), KT1 – Basic Trainer, CASA C-101 Aviojet
Dožić, S., Kalić, M. (2015)[35]	Analytic Hierarchy Process, Even Swaps Method	Seat capacity, Price of aircraft, Total baggage, Maximum take-off weight (MTOW), Payment conditions, Total cost per available seat miles (TCASM)	Comparison of 7 aircraft types ATR 72-500, ATR 72-600, ERJ 190, Q400 NG, CRJ 700, CRJ 900, CRJ 1000
Ozdemir, Y., Basligil, H. (2016)[36]	Fuzzy Analytic Network Process, Choquet Integral Method , Fuzzy Analytic Hierarchy Process,	Cost, Time, Physical Attributes and Others : Maintenance cost, Operation and spare cost, Purchasing cost, Salvage cost, Dimensions, Reliability, Security, Suitability for service quality, Delivery time, Useful life	Comparison of 3 aircraft types Hypothetic A, B, C aircraft
Golec, A., Gurbuz, F., Senyigit, E. (2016)[37]	Analytic Hierarchy Process, Weighted Sum Method, Elimination and Choice Expressing the Reality (ELimination Et Choix Traduisant la REalité), Technique for Order Preference by Similarity to Ideal Solution	The country's share in the project, Maintainability of aircraft, Maintenance easiness, Cost effectiveness, Operational effectiveness	Comparison of 3 aircraft types Hypothetic A, B, C aircraft

Silva, M. A., Eller, R. d. A. G., Alves, C. J. P., Caetano, M. (2016)[38]	Analytic Hierarchy Process	Price, Number of seats, Payload, Maximum take-off weight (MTOW), Range	Comparison of 3 aircraft types Embraer 195, SSJ 100, CRJ 900
Ali,Y., Muzzaffar, A. A., Muhammad, N., Salman, A. (2017)[39]	Analytic Hierarchy Process, Cost Benefit Analysis	Service Ceiling, Maximum takeoff weight (MTOW), Precision target capability (PTC), Combat radius, Cruising speed, Maneuverability, Acquisition cost, Operation cost, Maintainability, Availability	Comparison of 6 aircraft types Dassault Rafale, Saab JAS 39 Gripen, Mikoyan Mig-35, Sukhoi Su-35, Chengdu J-10, PAC JF-17 Thunder
Dozic,S., Lutovac,T., Kalic, M. (2018)[40]	Fuzzy Analytic Hierarchy Process	Aircraft characteristics (Aircraft seat capacity, Maximal take-off mass (MTOM), Aircraft range), Costs (Purchasing cost, Maintenance costs, Total cost per available seat miles (TCASM)), Added value indicators (Delivery time, Payment conditions, Fleet commonality, Comfort)	Comparison of 7 aircraft types ATR 72-500, ATR 72-600, ERJ 190, Q400 NG, CRJ 700, CRJ 900, CRJ 1000
Kiraci, K., Bakir, M. (2018)[41]	Analytic Hierarchy Process, Complex Proportional Assessment of Alternatives, Multi-Objective Optimization By Ratio Analysis	Range, Price, Speed, Seating capacity, Fuel consumption, Maximum payload, Amount of greenhouse gas release	Comparison of 4 aircraft types A320, A321, B737-800, B737-900ER
Kiraci, K., Bakir, M. (2018)[42]	Technique for Order Preference by Similarity to Ideal Solution	Range, Price, Speed, Seating capacity, Fuel consumption	Comparison of 4 aircraft types A320, A321, B737-800, B737-900ER
Ilgin, M. A. (2019)[43]	Linear Physical Programming	Price, Fuel consumption, Range, Number of seats, Luggage volume	Comparison of 6 aircraft types A319(neo), A320(neo), A321(neo), B737(MAX7), B737(MAX8), B737(MAX9)
Ardil, C. (2019) [44]	Multiplicative Multiple Criteria Decision Making Analysis	Aircraft price, Maximum takeoff weight (MTOW), Maximum payload, Maximum speed, Combat range, Ferry range, Service ceiling, Avionics, Beyond-visual-range, Maneuverability	Comparison of 9 aircraft types F-16, MiG-35, Su-35, Rafale, Eurofighter, Gripen, Su-57, F-35, Chengdu J-10
Ardil, C. (2019) [45]	Technique for Order Preference by Similarity to Ideal Solution	Maximum speed, Service ceiling, Combat range, Maximum takeoff weight (MTOW), Reliability, Maneuverability	Comparison of 3 aircraft types Su-35, F-35, TF-X (MMU)
Ardil, C., Pashaev, A. M., Sadiqov, R.A., Abdullayev, P. (2019) [46]	Multiple Criteria Decision Making Analysis	Maximum cruising speed, service ceiling, rate of climb, maximum takeoff weight, maximum payload, power, fuel tank capacity, fuel economy, minimum take off distance, minimum landing distance	Comparison of 7 aircraft types A set of Sukhoi fighter aircraft
Ardil, C. (2019) [47]	Multiple Criteria Decision Making Analysis	Price of Aircraft, Fuel Efficiency per Seat, Aircraft Range, Aircraft Seat Capacity, Maximum Takeoff Weight, Maximum Payload	Comparison of 4 aircraft types Airbus A320neo, Airbus A321neo, Boeing B737 MAX8, Boeing B737 MAX9
Sánchez-Lozano, J.M., Rodríguez, O.N. (2020) [48]	Fuzzy Reference Ideal Method Analytic Hierarchy Process	Combat ceiling, Endurance, Thrust, Weight at take-off, Operational speed, Take-off race, Rotational speed, Range, Tactical capability (qualitative), Maneuverability (qualitative), Ergonomics (qualitative), Compatibility (qualitative), Cost (qualitative)	Comparison of 4 training aircraft types KAI-T-50 Golden Eagle, Alenia Aermacchi M-346 Master, Yakovlev YAK-130, Northrop F-5 Freedom Fighter
Yilmaz, A.K., Malagas, K., Jawad, M., Nikitakos, N. (2020) [49]	Technique for Order Preference by Similarity to Ideal Solution Analytic Hierarchy Process	Strategic, Operational, Financial, Maintenance	Comparison of 6 aircraft types Diamond DA 40 Beechcraft Piper Seminole PA (Semiola PA 44) King Air C90 aircraft Cessna 172S Cessna/Reims-Cessna 172/F172 Series Socata TB 20 Trinidad Mushshak Aircraft
Kiraci, K., Akan, E. (2020)[50]	Analytic Hierarchy Process Technique for Order Preference by Similarity to Ideal Solution Interval type-2 fuzzy sets	Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets	Comparison of 4 aircraft types Airbus A320neo, Airbus A321neo, Boeing 737 MAX 8, Boeing 737 MAX 9