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

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***Abstract*—**This article presents a multiple criteria evaluation for a trainer aircraft selection problem using "preference analysis for reference ideal solution (PARIS)" approach. The available relevant literature points to the use of multiple criteria decision making analysis (MCDMA) methods for the problem of trainer aircraft selection, which often involves conflicting multiple criteria.

Therefore, this MCDMA study aims to propose a robust systematic integrated framework focusing on the trainer aircraft selection problem. For this purpose, an integrated preference analysis approach based the mean weight and entropy weight procedures with PARIS, and TOPSIS was used for a MCDMA compensating solution.

In this study, six trainer aircraft alternatives were evaluated according to six technical decision criteria, and data were collected from the current relevant literature. As a result, the King Air C90GTi alternative was identified as the most suitable trainer aircraft alternative. In order to verify the stability and accuracy of the results obtained, comparisons were made with existing MCDMA methods during the sensitivity and validity analysis process.

The results of the application were further validated by applying the comparative analysis-based PARIS, and TOPSIS method. The proposed integrated MCDMA systematic structure is also expected to address the issues encountered in the aircraft selection process. Finally, the analysis results obtained show that the proposed MCDMA method is an effective and accurate tool that can help analysts make better decisions.

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

I. INTRODUCTION

IN real-life decision making problems, it is often necessary to evaluate a set of available alternatives according to often conflicting multiple criteria. In most challenging decision situations, multiple criteria decision making analysis (MCDMA) methods are efficiently applicable to deal with such complex decision problems in the field of science, engineering and technology [1-27].

In the relevant literature[1-52], different MCDMA methods including their fuzzy extensions have been proposed to deal with decision problems, such as Simple Additive Weighting (SAW) [21], Analytical Hierarchy Process (AHP)[9], ELimination Et ChoixTraduisant la REalité (ELECTRE)[16], Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE)[17-20], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)[11], VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)[13-15],Preference Analysis for Reference Ideal Solution (PARIS) [48]. Also, when it comes to classification of MCDMA methods, they are generally classified as compensatory (AHP, SAW, PARIS, TOPSIS, VIKOR) and noncompensatory (ELECTRE, PROMETHEE) approaches to decision making [48].

In this study, the regional aircraft selection process is considered as a multiple criteria decision making analysis problem. Because the decision making process considers a set of alternatives to be evaluated along with often conflicting evaluation criteria for the aircraft selection problems. Also, a number of aircraft selection problems have been considered to solve various MCDMA problems in the fuzzy environment. Most decision problems are considered based integrated approaches with objective or subjective weighting procedures [28-52]. For this reason, this study employs the multiple criteria decision making analysis (MCDMA) method to meet its objectives in the trainer aircraft selection problem.

The aim of this study is to identify and classify all the important factors of aircraft selection implementation based technical dimensions of the assessment. Also, this study aims to propose a new methodology that helps to identify critical evaluation factors for aircraft selection practice. In this context, this study proposes a multiple criteria decision making analysis (MCDMA) model of key factors, which can help to successfully adapt and implement aircraft selection problem.

This study uses the Preference Analysis for Reference Ideal Solution (PARIS), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to rank all the important factors as well as to identify the critical factors of the aircraft selection application based on their impact on approaching all aspects of the assessment. The mean weight and entropy weight methods are used to calculate the weight of all evaluation criteria in PARIS, and TOPSIS calculation, which can effectively avoid the effects of human subjective factors.

In MCDMA research domain, TOPSIS is an established technique for dealing with the problem of ranking alternatives from best to worst in the decision process. In TOPSIS approach, the preferred option should be closest to the positive ideal and furthest from the anti-ideal solution. Therefore, the ideal solution is one that not only maximizes the benefit criteria but also minimizes the cost criteria. In other words, the ideal solution contains all the highest values of the available criteria, while the anti-ideal solution has the

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worst values of the possible criteria [11].

TOPSIS approach provides impact results for ranking alternatives with absolute data for each indicator [48]. The integration of TOPSIS with other MCDMA approaches can solve problems more efficiently and flexibly [48]. Shannon entropy method is recommended for calculating the weighting of decision criteria as it is an efficient method that makes decision making more reliable and accurate without significant modeling difficulties [52]. Evaluation with subjective weighting methods may cause deviations in the weights of indices due to subjective factors.

On the contrary, objective weighting methods such as entropy weight method can effectively eliminate human induced disturbances because they are driven by the intrinsic knowledge of the indices, and define the objective weight of the indices, which makes the results consistent with the facts [48]. Therefore, the mean weight, entropy weight, and PARIS, TOPSIS integration can effectively help improve the reliability and accuracy of aircraft ranking. An empirical MCMDA study is conducted in the aviation industry to demonstrate the performance and efficiency of this hybrid method.

Sensitivity analysis and comparison with existing tools in MCDMA methods to rank alternatives are used to verify the stability and accuracy of the results. In essence, there is a need to identify the factors that will help the successful implementation of aircraft selection in the aviation industry. Also, it is necessary to introduce a methodology for ranking the aircraft and then identify the optimal MCDMA solution. The method proposed in this study can not only be used by other studies to address aircraft selection problems, particular projects, or other circumstances, but can also be applied in other fields of science, engineering, and technology.

The proposed MCDMA model can be a reference for comparison with aircraft selection problems identified by future studies in aviation industry. In this context, the key elements of the proposed method such as the multiple evaluation criteria, alternatives, and MCDMA methods were selected from the relevant literature [28-62]. In this study, the multiple criteria trainer aircraft evaluation problem is based on the integrated objective weighting procedures, the mean weight, entropy weight, and PARIS, and TOPSIS methods.

The remainder of this paper is structured as follows. Chapter 2 presents the MCDMA methodology, including the mean weight, entropy weight, PARIS, and TOPSIS methods. Chapter 3 presents a numerical application of the proposed methodology including the research results of the mean weight, entropy-weighted PARIS, and TOPSIS calculations as well as a discussion. Finally, Chapter 4 presents the conclusion.

II. METHODOLOGY

A. The PARIS method

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

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

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \left(\begin{array}{ccc} g_1 & & g_j \\ x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{array} \right)_{ixj} \tag{1}$$

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. Normalization of the decision matrix

If the evaluation attribute g_j is a benefit criteria, then

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

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = \frac{x_j^{\min}}{x_{ij}}, \; i = 1, ..., I, \; j = 1, ..., J \tag{3}$$

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

$$x_i^{max} = \max_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\}, \; x_i^{min} = \min_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\} \tag{4}$$

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

$$z_{ij} = \omega_j r_{ij} \tag{5}$$

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

$$\pi_i^{\omega} = \sum_{j=1}^{J} \omega_j r_{ij}, \; i = 1, ..., I, \; j = 1, ..., J \tag{6}$$

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^*)

$$z_j^* = \left\{z_1^*,...,z_j^*\right\} = \left\{(max_i\, z_{ij} \mid j \in B), (\min_i z_{ij} \mid j \in C\right\} \tag{7}$$

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

$$\pi_i^* = \sum_{j=1}^{J} (z_j^* - z_{ij}),\ i = 1,...,I,\ \ j = 1,...,J \tag{8}$$

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.

$$R_i = \sqrt{(\pi_i^\omega - \pi_i^{\omega,\max})^2 + (\pi_i^* - \pi_i^{*,\min})^2} \tag{9}$$

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

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} g_1 & & g_j \\ x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \tag{10}$$

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

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^{\ 2}}},\ i = 1,...,I,\ j = 1,...,J \tag{11}$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^{\ 2}}},\ i = 1,...,I,\ j = 1,...,J \tag{12}$$

Step 3. Calculation of the weighted normalized values

$$v_{ij} = \omega_j r_{ij} \tag{13}$$

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

$$a_i^* = \left\{v_1^*,...,v_j^*\right\} = \left\{(max_i\, v_{ij} \mid j \in B), (\min_i v_{ij} \mid j \in C\right\} \tag{14}$$

$$a_i^- = \left\{v_1^-,...,v_j^-\right\} = \left\{(max_i\, v_{ij} \mid j \in B), (\min_i v_{ij} \mid j \in C\right\} \tag{15}$$

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

$$D_i^* = \sqrt{\sum_{j=1}^{J}\ (v_{ij} - v_j^*)^2} \tag{16}$$

$$D_i^- = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^-)^2} \tag{17}$$

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

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$$CC_i = \frac{D_i^-}{D_i^* + D_i^-} \tag{18}$$

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 [48, 52]:

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

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}}, \; i = 1,...,I \tag{19}$$

Step 2. The calculation of entropy for each index

$$E_j = -\frac{1}{\ln I}\sum_{i=1}^{I} p_{ij} \ln p_{ij}, \; j = 1,...,J \tag{20}$$

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

$$D_j = 1 - E_j, \; j = 1,...,J \tag{21}$$

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

$$\omega_j = \frac{D_j}{\sum_{j=1}^{J} D_j} \tag{22}$$

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

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 [48].

$$\omega_j = \frac{1}{J} \; , \; j = 1,...,J \tag{23}$$

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

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

III. APPLICATION

In aviation industry, aircraft selection is a strategic decision making process for aviation organizations such as airlines, professional aviation organizations, civil and military universities. This decision making process is closely related to their capacities and performance management in aviation industry. In addition, these organizations have a wider range of options and higher uncertainty about the demand that needs to be addressed. Therefore, this decision making process should be carried out with particular attention to the specific decision criteria set for evaluating available aircraft type alternatives [34, 48]. It is therefore important that the aircraft selection process considers all relevant evaluation aspects and uses appropriate mathematical methods to evaluate them.

The relevant literature shows that the main issues that distinguish the research from each other are the decision criteria and methodology used in the aircraft selection problem. In addition, supply and demand are other issues that affect the aircraft selection problem. In addition, environmental issues are widely used in the aircraft selection process as different aircraft types offer different environmental performance efficiency factors such as emissions, noise, and fuel consumption.

Meanwhile, the lower service frequency and the operation of larger aircraft produce less emissions and noise, which are relatively small and sensitive to considered mathematical modelling. Aircraft acquisition selection is significantly influenced by technical/performance characteristics, economic and financial implications, environmental regulations and restrictions, marketing issues, and international political realities [48].

From strategic point of view, the two approaches used in aircraft acquisition selection are the top-down strategy based on changes in traffic forecasts and/or operating costs; and the bottom-up strategy based on changes to individual route characteristics, although it is extremely difficult to consider future competitive strategies. In fact, the first strategy is used more often.

Most of the relevant literature has focused on the aircraft selection process for airlines, but useful lessons for aviation training organizations can also be obtained for the criteria and methodology used [28-52].

In the relevant literature, a systematic evaluation model was proposed for the Air Force Academy in Taiwan to assist

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in selecting the most appropriate trainer aircraft in a fuzzy environment. A MCDMA method was used to evaluate the initial propeller-driven aircraft selection process with AHP and TOPSIS in a fuzzy model [29].

Also, the selection of the best military trainer aircraft for the Spanish Air Force was considered. Selection was carried out using the AHP method to obtain the criteria weights influencing the decision and the TOPSIS method to evaluate various alternatives. These two methods are combined with fuzzy logic because of the quantitative and qualitative criteria used [34].

In another study, a new military trainer aircraft for the Spanish Air Force was evaluated in the field of multiple criteria decision making analysis (MCDMA). A combination of Fuzzy MCDM approaches was used to evaluate trainer aircraft alternatives, along with quantitative or technical criteria (battle ceiling, operational speed, takeoff race, etc.) and qualitative criteria (maneuverability, ergonomics, etc.). The Analytical Hierarchy Process (AHP) was applied to obtain the weights of the criteria, while the Reference Ideal Method (RIM) and its Fuzzy version (FRIM) were used to evaluate alternatives based on a reference ideal alternative [48].

In this study, an empirical MCDMA problem is considered to evaluate a set of trainer aircraft alternatives by integrating objective weighting procedures (mean weight, entropy weight) with PARIS, and TOPSIS methods.

This aircraft selection problem is set to determine the most suitable trainer aircraft alternative { Cessna 172R (a_1), Diamond DA40 XL Diamond Star (a_2) , King Air C90GTi (a_3), PA-44-180 Seminole (a_4) , PAC MFI-17 Mushshak (a_5), and Socata TB 10 Trinidad (a_6) for strategic, tactical, and operational planning decisions. From the literature review, 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 [28-52]:

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_1).

Cruise Speed: Cruising speed is the speed at which an aircraft usually moves when it is traveling at a fast speed for a long distance, (km/h, max, g_2).

Aircraft Range: Range is the distance that can be flown by an aircraft without refueling, (km, max, g_3).

Service Ceiling: The service ceiling is the maximum usable altitude of an aircraft, (km, max, g_4).

Rate of Climb: The rate of climb is an aircraft's vertical speed, that is the positive or negative rate of altitude change with respect to time, (m/s, max, g_5).

Aircraft Capacity: Aircraft capacity reflects the planned total seat capacity, (#, max, g_6).

The numerical index values of the six decision criteria for the six aircraft alternatives are presented in Table 1 by considering the technical aspects. In the MCDMA problem, the six decision criteria (Aircraft Maximum Takeoff Weight, Cruise Speed, Aircraft Range, Service Ceiling, Rate of Climb, Aircraft Capacity) are modeled as benefit.

Table 1. Decision Matrix

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	1111	226	1289	4100	3,66	3
a_2	1150	279	1341	5000	5,69	3
a_3	4582	416	2446	9144	10,2	7
a_4	1724	301	1695	5200	6,8	3
a_5	1200	210	815	4100	5,2	2
a_6	1150	235	1210	3960	4	4

In the aircraft selection problem, six alternative aircraft are ranked according to PARIS, and TOPSIS methods, using the index values of six 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. First, 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
MW ω_j	1/6	1/6	1/6	1/6	1/6	1/6
EW ω_j	0,3954	0,0616	0,1210	0,1098	0,1332	0,1789

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. PARIS normalized decision matrix

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,2425	0,5433	0,5270	0,4484	0,3588	0,4286
a_2	0,2510	0,6707	0,5482	0,5468	0,5578	0,4286
a_3	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
a_4	0,3763	0,7236	0,6930	0,5687	0,6667	0,4286
a_5	0,2619	0,5048	0,3332	0,4484	0,5098	0,2857
a_6	0,2510	0,5649	0,4947	0,4331	0,3922	0,5714

Table 4. PARIS weighted normalized decision matrix (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0404	0,0905	0,0878	0,0747	0,0598	0,0714
a_2	0,0418	0,1118	0,0914	0,0911	0,0930	0,0714
a_3	0,1667	0,1667	0,1667	0,1667	0,1667	0,1667
a_4	0,0627	0,1206	0,1155	0,0948	0,1111	0,0714
a_5	0,0436	0,0841	0,0555	0,0747	0,0850	0,0476
a_6	0,0418	0,0942	0,0824	0,0722	0,0654	0,0952

Table 5. PARIS distance from the reference ideal solution (z_j^*) (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,1263	0,0761	0,0788	0,0919	0,1069	0,0952
a_2	0,1248	0,0549	0,0753	0,0755	0,0737	0,0952
a_3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
a_4	0,1040	0,0461	0,0512	0,0719	0,0556	0,0952
a_5	0,1230	0,0825	0,1111	0,0919	0,0817	0,1190
a_6	0,1248	0,0725	0,0842	0,0945	0,1013	0,0714

Table 6. PARIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0959	0,0334	0,0638	0,0492	0,0478	0,0767
a_2	0,0993	0,0413	0,0664	0,0601	0,0743	0,0767
a_3	0,3954	0,0616	0,1210	0,1098	0,1332	0,1789
a_4	0,1488	0,0445	0,0839	0,0625	0,0888	0,0767
a_5	0,1036	0,0311	0,0403	0,0492	0,0679	0,0511
a_6	0,0993	0,0348	0,0599	0,0476	0,0522	0,1022

Table 7. PARIS distance from the reference ideal solution (z_j^*) (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,2996	0,0281	0,0572	0,0606	0,0854	0,1022
a_2	0,2962	0,0203	0,0547	0,0498	0,0589	0,1022
a_3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
a_4	0,2467	0,0170	0,0372	0,0474	0,0444	0,1022
a_5	0,2919	0,0305	0,0807	0,0606	0,0653	0,1278
a_6	0,2962	0,0268	0,0612	0,0623	0,0810	0,0767

Table 8. PARIS ranking results of unweighted and weighted summation π_i^ω

<table>
<tr><td colspan="9">Ranking Order in Weighting Index</td></tr>
<tr><td rowspan="4">Weighting Index</td><td>UW</td><td>5</td><td>3</td><td>1</td><td>2</td><td>6</td><td>4</td><td rowspan="4">Ranking Order</td></tr>
<tr><td>MW ω_j</td><td>5</td><td>3</td><td>1</td><td>2</td><td>6</td><td>4</td></tr>
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<tr><td>a_i</td><td>a_1</td><td>a_2</td><td>a_3</td><td>a_4</td><td>a_5</td><td>a_6</td></tr>
<tr><td colspan="2"></td><td colspan="6">Aircraft Alternatives</td><td></td></tr>
</table>

Table 9. PARIS ranking results π_i^* using distance from the reference ideal solution

<table>
<tr><td colspan="9">Ranking Order in Weighting Index</td></tr>
<tr><td rowspan="3">Weighting Index</td><td>MW ω_j</td><td>5</td><td>3</td><td>1</td><td>2</td><td>6</td><td>4</td><td rowspan="3">Ranking Order</td></tr>
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<tr><td colspan="2"></td><td colspan="6">Aircraft Alternatives</td><td></td></tr>
</table>

Table 10. PARIS ranking results R_i using relative distance from the reference ideal solution

<table>
<tr><td colspan="9">Ranking Order in Weighting Index</td></tr>
<tr><td rowspan="3">Weighting Index</td><td>MW ω_j</td><td>5</td><td>3</td><td>1</td><td>2</td><td>6</td><td>4</td><td rowspan="3">Ranking Order</td></tr>
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<tr><td colspan="2"></td><td colspan="6">Aircraft Alternatives</td><td></td></tr>
</table>

Table 11. TOPSIS normalized decision matrix

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,2053	0,3222	0,3392	0,3015	0,2367	0,3062
a_2	0,2125	0,3978	0,3528	0,3677	0,368	0,3062
a_3	0,8467	0,5931	0,6436	0,6724	0,6597	0,7144
a_4	0,3186	0,4292	0,446	0,3824	0,4398	0,3062
a_5	0,2217	0,2994	0,2144	0,3015	0,3363	0,2041
a_6	0,2125	0,3351	0,3184	0,2912	0,2587	0,4082

Table 12. TOPSIS weighted normalized decision matrix (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0537	0,0565	0,0502	0,0395	0,0510	0,0537
a_2	0,0663	0,0588	0,0613	0,0613	0,0510	0,0663
a_3	0,0989	0,1073	0,1121	0,1099	0,1191	0,0989
a_4	0,0715	0,0743	0,0637	0,0733	0,0510	0,0715
a_5	0,0499	0,0357	0,0502	0,0560	0,0340	0,0499
a_6	0,0558	0,0531	0,0485	0,0431	0,0680	0,0558

Table 13. TOPSIS the ideal and anti-ideal solutions (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_i^*	0,1411	0,0989	0,1073	0,1121	0,1099	0,1191
a_i^-	0,0342	0,0499	0,0357	0,0485	0,0395	0,0340

Table 14. TOPSIS the Euclidean distance of alternatives from the ideal (D_i^*) solutions (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,1069	0,0452	0,0507	0,0618	0,0705	0,0680
a_2	0,1057	0,0326	0,0485	0,0508	0,0486	0,0680
a_3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
a_4	0,0880	0,0273	0,0329	0,0483	0,0366	0,0680
a_5	0,1042	0,0490	0,0715	0,0618	0,0539	0,0851
a_6	0,1057	0,0430	0,0542	0,0635	0,0668	0,0510

Table 15. TOPSIS the Euclidean distance of alternatives from the anti-ideal (D_i^-) solutions (MW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0000	0,0038	0,0208	0,0017	0,0000	0,0170
a_2	0,0012	0,0164	0,0231	0,0127	0,0219	0,0170
a_3	0,1069	0,0490	0,0715	0,0635	0,0705	0,0851
a_4	0,0189	0,0216	0,0386	0,0152	0,0338	0,0170
a_5	0,0027	0,0000	0,0000	0,0017	0,0166	0,0000
a_6	0,0012	0,0059	0,0173	0,0000	0,0037	0,0340

Table 16. TOPSIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0812	0,0198	0,0410	0,0331	0,0315	0,0548
a_2	0,0840	0,0245	0,0427	0,0404	0,0490	0,0548
a_3	0,3348	0,0365	0,0779	0,0739	0,0879	0,1278
a_4	0,1260	0,0264	0,0540	0,0420	0,0586	0,0548
a_5	0,0877	0,0184	0,0260	0,0331	0,0448	0,0365
a_6	0,0840	0,0206	0,0385	0,0320	0,0345	0,0730

Table 17. TOPSIS the ideal and anti-ideal solutions (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_i^*	0,3348	0,0365	0,0779	0,0739	0,0879	0,1278
a_i^-	0,0840	0,0184	0,0260	0,0320	0,0345	0,0365

Table18. TOPSIS the Euclidean distance of alternatives from the ideal (D_i^*) solutions (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,2536	0,0167	0,0368	0,0407	0,0563	0,0730
a_2	0,2508	0,0120	0,0352	0,0335	0,0389	0,0730
a_3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
a_4	0,2088	0,0101	0,0239	0,0319	0,0293	0,0730
a_5	0,2471	0,0181	0,0519	0,0407	0,0431	0,0913
a_6	0,2508	0,0159	0,0394	0,0419	0,0534	0,0548

Table 19. TOPSIS the Euclidean distance of alternatives from the anti-ideal (D_i^-) solutions (EW)

	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,0028	0,0014	0,0151	0,0011	0,0029	0,0183
a_2	0,0000	0,0061	0,0168	0,0084	0,0146	0,0183
a_3	0,2508	0,0181	0,0519	0,0419	0,0534	0,0913
a_4	0,0419	0,0080	0,0280	0,0100	0,0241	0,0183
a_5	0,0037	0,0000	0,0000	0,0011	0,0103	0,0000
a_6	0,0000	0,0022	0,0126	0,0000	0,0000	0,0365

Table 20. TOPSIS ranking results CC_i

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

Table 21. TOPSIS ranking results of unweighted and weighted summation

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

Sensitivity analysis was performed on unweighted and weighted normalized matrix dataset. As a result of the experimental studies, no change was observed in the ranking order of the MCDMA approach for unweighted and weighted normalized matrix dataset. The validity of the applied MCDMA method was revealed according to the comparative ranking results of PARIS, and TOPSIS methods. In addition, it was seen that the ranking results obtained from all three MCDMA methods were the same. Accordingly, King Air

C90GTi (a_3) alternative was selected as the best trainer aircraft.

IV. CONCLUSION

The selection of aircraft for training purposes is of great importance in terms of performance and efficiency outputs in the decision making process. Modern aircraft training is generally carried out by professional aviation organizations, and many of them operate in the military and civilian university infrastructure, providing students with useful training services.

The selection of aircraft is a very important and complex decision process that must be considered by the management of the organization. The selection of available alternatives and decision criteria are the starting point of studies focused on fleet modeling and planning. Also, current training aircraft are those that respond better to aviation students and school training needs. Analyzing the training aircraft types, small single- and twin-engine aircraft are often potential candidates for aviation training schools. Aviation organization management therefore tends to better respond to increasing standards of aircraft training, features such as wide flight envelope, large power, performance and jet aircraft modern avionics, and safety systems with modern generation turbo prop aircraft.

This study focuses more on the technical/operational characteristics that will better meet the performance and efficiency demands evaluation of aircraft types. The decision criteria to assess the aircraft types of alternatives were identified from the literature review, and mainly based on strategic, tactical, and operational decision aspects. In addition, the use of appropriate MCDMA methods to evaluate aircraft alternatives based on certain decision criteria is important for decision analysis. In decision making processes, PARIS, and TOPSIS methods can be used together to provide comparative outputs to validate ranking results.

Since the three methods include effective and efficient computational methodology, it allows the best available alternative to be tracked using decision criteria that are easy to understand and apply and can be easily evaluated by a simple mathematical analysis.

In this study, it was important to use strategic, tactical, operational decision criteria to properly evaluate trainer aircraft alternatives. These evaluation dimensions seem important for aircraft selection, as the decision criteria used are important and should be closely related to the decision situation. Also, the three methods, PARIS, and TOPSIS, were successfully integrated to achieve the robust results of this research.

Finally, according to the research findings, a uniform fleet structure is most suitable for the optimum aircraft fleet to minimize the risks related to strategic, tactical, operational, maintenance, and financial decision aspects. Finally, the decision criteria results revealed that the King Air C90GTi (a_3) trainer aircraft alternative is the most effective solution for aviation training organization. Although the current study examines the specific technical characteristics of trainer aircraft, also, this study makes an important contribution to the optimization of the fleet selection process in aviation industry.

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APPENDIX

Table 22. 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)[47]	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

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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
Ardil, C. (2020) [48]	Preference Analysis for Reference Ideal Solution Technique for Order Preference by Similarity to Ideal Solution	Aircraft Price, Aircraft Fuel Consumption, Aircraft Fuel Efficiency per Seat, Aircraft Range, Aircraft's Number of Seats, Aircraft's Luggage Volume, and Aircraft Maximum Takeoff Weight	Comparison of 6 aircraft types A319(neo), A320(neo), A321(neo), B737(MAX7), B737(MAX8), B737(MAX9)
Sánchez-Lozano, J.M., Rodríguez, O.N. (2020) [49]	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) [50]	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)[51]	Analytic Hierarchy Process	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,

	Technique for Order Preference by Similarity to Ideal Solution Interval type-2 fuzzy sets		Boeing 737 MAX 9

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