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

C. Ardil

Abstract**—**The paper presents a multiple criteria decision making analysis process to determine the most suitable regional aircraft type according to a set of evaluation criteria. The main purpose of this study is to use different decision making methods to determine the most suitable regional aircraft for aviation operators. In this context, the nine regional aircraft types were analyzed using multiple criteria decision making analysis methods. Preference analysis for reference ideal solution (PARIS) was used in regional aircraft selection process. The findings of the proposed model show that the ranking results of the multiple criteria decision making models are consistent with each other, and the proposed method is efficient, and the results are valid. Finally, the Embraer E195-E2 model regional aircraft is chosen as the most suitable aircraft type.

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

I. Introduction

AVIATION industry strives to naturally gain a competitive advantage in the global dynamic market by employing a number of business strategies. Aviation operators often assess the global market circumstances and factors to carry out their aviation operations more efficiently and effectively. Aviation operators need to make strategic decisions with the keen ability to develop and realize a profitable business vision by leveraging a sustainable fleet structure.

Operators prefer aircraft that are suitable for their aviation business model, passenger profile and flight range. For this reason, civil aircraft operators need to carry out profitable operations and gain competitive advantage in the aviation sector with a strategic decision making framework. The strategic decision making process includes a range of alternatives and often conflicting decision criteria that are integrated with multiple criteria decision making analysis methods.

Decision making is the process of choosing from alternative courses of action based on factual and value premises, with the intention of moving towards a desired state. When a selection decision is made, it means a commitment of resources.

In the relevant literature, there are a number of studies on aircraft selection issues [28-55]. Many studies discuss the optimal aircraft or fleet selection according to different decision criteria and using different multiple criteria decision making analysis methods. Some studies focused on different scenarios to determine the most suitable aircraft or fleet structure that provides the best performance to the aviation operator under different scenarios [33, 35].

In addition, some studies focused on determining the most suitable aircraft for certain aviation operators and empirically examining the determinants of aircraft selection for many flight destinations. The areas of aircraft used in choosing the best performing aircraft, determining the selection criteria, and selecting the aircraft are important for decision making studies [32]. Also, a study to determine the most suitable initial training aircraft was conducted using a set of small training propeller aircraft that were ranked according to selected criteria [29].

The selection of the most suitable aircraft for flights from a particular airport was studied, and in the same way, the most suitable aircraft was selected for an aviation operator operating in certain destinations in Southeast Europe [32]. Also, civil mid - range aircraft according to selected evaluation criteria such as cost, time and physical properties were examined [30].

Determining the appropriate aircraft and modeling the appropriate fleet structures according to their flight range is essential for aviation operators. The selection of suitable aircraft paves the way for aviation operators to operate more efficiently and effectively, thereby gaining competitive advantage in the aviation market.

The alternative aircraft types, preferred selection criteria and the decision making methods can significantly affect the comparison results while determining the most appropriate aircraft for aviation operators. The alternative aircraft types, decision criteria, and the decision making methods used in aircraft selection studies are provided in tabularized format [28-55]. The aviation decision can range from setting goals and objectives for the entire organization to specific decisions regarding scheduled operations.

Selecting a civil aircraft for aviation operator is a complex decision process involving multiple candidate alternatives and often conflicting with multiple decision criteria. In real-life decision problems, it is often necessary to evaluate a set of alternatives against multiple criteria, often in conflict with each other in nature. Multiple criteria decision making analysis methods can be applied efficiently to deal with such complex decision problems in the field of science, engineering, and technology [1-27].

In the relevant literature[1-55], various multiple criteria decision making analysis methods including their fuzzy

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

extensions have been proposed to deal with complex 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 process of choosing a regional aircraft was considered as a multiple criteria decision making analysis problem. Because the decision making process considers a set of alternatives for aircraft selection problem that are usually evaluated together with often conflicting evaluation criteria. In addition, a number of aircraft selection problems have been considered to solve various multiple criteria decision analysis methods problems in the fuzzy environment. Most decision problems are considered by integrated approaches based on objective or subjective weighting procedures [28-55]. Therefore, this study uses the method of multiple criteria decision making analysis approach to achieve its goals.

This multiple criteria decision making analysis process employs the preference analysis for reference ideal solution (PARIS) method to address the aircraft selection problem. The objective weighting procedures such as the mean weight, and entropy weight are used to calculate the weight of all evaluation criteria in PARIS calculation, which can effectively avoid the effects of human subjective factors.

Sensitivity analysis and comparison with existing tools in multiple criteria decision making analysis 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 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 multiple criteria decision making analysis 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 multiple criteria decision making analysis methods were selected from the relevant literature [28-54]. In this study, the multiple criteria regional aircraft evaluation problem is based on the integrated objective weighting procedures, the mean weight, entropy weight, PARIS methods

Multiple criteria decision making analysis method was used in this study, as there are various criteria affecting the selection of the appropriate alternative. Each criterion has several attributes that ultimately affect the priorities reached among the alternatives. For this reason, the applied method has been developed as the multiple criteria decision making analysis method. In this procedure, the entropy method is first applied to generate the overall vector weights of the criteria. Accordingly, a final assessment of priorities are made with multiple criteria decision making analysis method. The multiple criteria decision making analysis method evaluates the alternatives and determines the preferences among the alternatives.

The multiple criteria decision making analysis study aims to provide comparative analysis information on aircraft selection problem. The performances of regional aircraft were examined. The integrated use of multiple criteria decision making method to analyze the performance of regional aircraft is considered in the aircraft selection problem.

The ranking results are intended to determine both the best performing aircraft and whether there is consistency between applied decision making methods. Finally, the study presents a unique decision analysis structure using evaluation criteria that are cost, performance, and environmental factors. These evaluation criteria are of great importance for both airlines and air transport sector stake holders.

The remainder of this paper is structured as follows. Chapter 2 presents the multiple criteria decision making analysis methodology, including the mean weight, entropy weight, PARIS method. Chapter 3 presents a numerical application of the proposed methodology including the research results of the mean weight, entropy-weighted PARIS 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 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 [58, 59]:

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 *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. 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, 55]:

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

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}}, \; i = 1,..., I \tag{10}$$

Step 2. The calculation of entropy for each index

$$E_j = -\frac{1}{\ln I} \sum_{i=1}^{I} p_{ij} \ln p_{ij}, \; j = 1,..., J \tag{11}$$

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

$$D_j = 1 - E_j, \; j = 1,..., J \tag{12}$$

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

$$\omega_j = \frac{D_j}{\sum_{j=1}^{J} D_j} \tag{13}$$

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

where ω_j is the importance weight of the jth criteria g_j .

C. 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].

$$\omega_j = \frac{1}{J} \ , \ j = 1, \ldots, J \tag{14}$$

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

where ω_j is the importance weight of the jth criteria g_j .

III. Application

A. Regional aircraft selection

Regional aviation operators typically operate aircraft with a seating capacity ranging from 20 to 130 seats, on short to medium-haul routes. In this study, nine regional aircraft types with seven decision criteria are evaluated using multiple criteria decision making analysis processes.

The relevant literature shows that evaluation criteria, alternatives, and applied multiple criteria decision making analysis methodology are the main elements in aircraft selection problem. In addition, supply and demand are other issues that affect the aircraft selection problem. Evaluation criteria range from environmental factors such as emissions, noise, and fuel consumption to technical/performance characteristics, economic and financial implications, environmental regulations and restrictions, marketing issues, and international political realities [48].

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.

In the literature, a systematic evaluation model was proposed for the Air Force Academy in Taiwan to aid in selecting the most appropriate trainer aircraft in a fuzzy environment. A multiple criteria decision making analysis 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. A combination of Fuzzy multiple criteria decision making analysis 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 [48-49]. In essence, a comprehensive list of research trends in civil and military aviation is provided to reflect important aircraft selection research [28–55].

B. Decision making criteria and decision tree

In this study, an empirical multiple criteria decision making analysis problem is considered to evaluate nine regional aircraft alternatives by integrating objective weighting procedures (mean weight, entropy weight) with PARIS method. This regional aircraft selection problem is set to determine the most suitable aircraft alternative for strategic, tactical, and operational fleet planning.

The evaluation criteria for selecting the appropriate regional aircraft are defined based on the relevant literature as shown in Table 1. A decision making tree for any decision problem is developed by identifying the goal, alternatives and criteria. The goal, which is regional aircraft selection, is on the first line of the tree. The evaluation criteria are on the second line and the alternatives are on the third line. Nine regional aircraft alternatives potentially have the required technical requirements for supporting the decision analysis model. Seven evaluation criteria for the multiple criteria decision making analysis problem were determined and employed in the aircraft evaluation process. The selected evaluation criteria for regional aircraft evaluation process are presented as follows:

Table 1. Decision criteria for choosing the optimum regional aircraft

No	Criteria Explanation	Optimization	Index
1	Maximum takeoff weight (MTOW)	max	g_1
2	Maximum landing weight (MLW)	max	g_2
3	Maximum payload	max	g_3
4	Maximum speed	max	g_4
5	Service ceiling	max	g_5
6	Aircraft range	max	g_6
7	Seating capacity	max	g_7

Maximum takeoff weight (MTOW): It is the maximum weight allowed to attempt to take off, due to structural or other limits., (kg, max, g_1).

Maximum landing weight (MLW): It is the maximum aircraft gross weight due to design or operational limitations at which an aircraft is permitted to land (kg, max, g_2).

Maximum payload: Maximum payload capacity is the maximum certificated takeoff weight of an aircraft less the empty weight, (kg, max, g_3).

Maximum speed: It is the maximum operating speed of aircraft in Mach number, (M, max, g_4).

Service ceiling: It is the maximum height at which a particular type of aircraft can sustain a specified rate of climb, (km, max, g_5).

Aircraft range: It is the maximum distance an aircraft can fly between takeoff and landing, (#, max, g_6).

Seating capacity: It is the number of people who can be seated in aircraft space, (#, max, g_7).

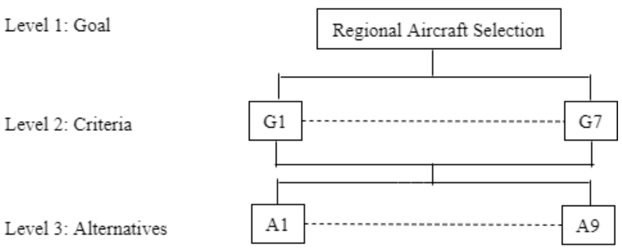

Fig 1. Hierarchy designed for optimum regional aircraft selection

Table 2. Decision Matrix

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	16466	15649	4647	0,43	7620	2084	40
a_2	19505	19050	6100	0,43	7620	1711	50
a_3	30481	28010	8036	0,53	8230	2040	80
a_4	34019	30390	8190	0,82	12497	2553	78
a_5	38330	33345	10247	0,82	12497	2876	90
a_6	41640	36970	11966	0,82	12497	3004	104
a_7	44600	40000	10600	0,82	12497	3704	88
a_8	56400	49050	13500	0,82	12497	5278	106
a_9	61500	54000	16150	0,82	12497	4815	132

The numerical index values of the seven decision criteria for the nine aircraft alternatives {Bombardier Q200 (a_1), Bombardier Q300 (a_2), Bombardier Q400 (a_3), Bombardier CRJ700 (a_4), Bombardier CRJ900 (a_5), Bombardier CRJ1000 (a_6), Embraer E175-E2 (a_7), Embraer E190-E2 (a_8), Embraer E195-E2 (a_9)} are presented in Table 2 by considering the technical performance aspects. In the multiple criteria decision making analysis problem, the decision criteria (maximum takeoff weight (MTOW), maximum landing weight (MLW), maximum payload, maximum speed, service ceiling, aircraft range, seating capacity) are modeled as benefit.

For the regional aviation operators' needs, the nine alternative aircraft were ranked according to PARIS, and TOPSIS methods, using the index values of seven evaluation criteria. In the implementation of multiple criteria decision making analysis methods, objective weights determined by two different weighting methods, 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 3.

Table 3. 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	0,147	0,144	0,145	0,144	0,139	0,137	0,146

Table 4. PARIS normalized decision matrix

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,6735	0,5368	1,0000	0,8824	0,9091	0,8926	0,8613
a_2	1,0000	1,0000	0,9000	1,0000	0,9091	1,0000	0,8613
a_3	0,9592	0,6842	1,0000	0,8171	1,0000	1,0000	1,0000
a_4	0,6735	0,5368	1,0000	0,8824	0,9091	0,8926	0,8613
a_5	1,0000	1,0000	0,9000	1,0000	0,9091	1,0000	0,8613
a_6	0,9592	0,6842	1,0000	0,8171	1,0000	1,0000	1,0000
a_7	0,6735	0,5368	1,0000	0,8824	0,9091	0,8926	0,8613
a_8	1,0000	1,0000	0,9000	1,0000	0,9091	1,0000	0,8613
a_9	0,9592	0,6842	1,0000	0,8171	1,0000	1,0000	1,0000

Table 5. PARIS weighted normalized decision matrix (MW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0383	0,0414	0,0411	0,0749	0,0871	0,0564	0,0433
a_2	0,0453	0,0504	0,054	0,0749	0,0871	0,0463	0,0541
a_3	0,0708	0,0741	0,0711	0,0924	0,0941	0,0552	0,0866
a_4	0,079	0,0804	0,0725	0,1429	0,1429	0,0691	0,0844
a_5	0,0891	0,0882	0,0907	0,1429	0,1429	0,0779	0,0974
a_6	0,0968	0,0978	0,1059	0,1429	0,1429	0,0813	0,1126
a_7	0,1036	0,1059	0,0938	0,1429	0,1429	0,1003	0,0953
a_8	0,131	0,1298	0,1195	0,1429	0,1429	0,1429	0,1148
a_9	0,1429	0,1429	0,1429	0,1429	0,1429	0,1304	0,1429

Table 6. PARIS distance from the reference ideal solution (z_j^*) (MW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1046	0,1015	0,1018	0,068	0,0558	0,0865	0,0996
a_2	0,0976	0,0925	0,0889	0,068	0,0558	0,0966	0,0888
a_3	0,0721	0,0688	0,0718	0,0505	0,0488	0,0877	0,0563
a_4	0,0639	0,0625	0,0704	0	0	0,0738	0,0585
a_5	0,0538	0,0547	0,0522	0	0	0,065	0,0455
a_6	0,0461	0,0451	0,037	0	0	0,0616	0,0303
a_7	0,0393	0,037	0,0491	0	0	0,0426	0,0476
a_8	0,0119	0,0131	0,0234	0	0	0	0,0281
a_9	0	0	0	0	0	0,0125	0

Table 7. PARIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0394	0,0417	0,0417	0,0755	0,0848	0,0541	0,0442
a_2	0,0466	0,0508	0,0548	0,0755	0,0848	0,0444	0,0553
a_3	0,0729	0,0747	0,0721	0,0931	0,0915	0,053	0,0885
a_4	0,0813	0,081	0,0735	0,144	0,139	0,0663	0,0863
a_5	0,0916	0,0889	0,092	0,144	0,139	0,0747	0,0995
a_6	0,0995	0,0986	0,1074	0,144	0,139	0,078	0,115
a_7	0,1066	0,1067	0,0952	0,144	0,139	0,0961	0,0973
a_8	0,1348	0,1308	0,1212	0,144	0,139	0,137	0,1172
a_9	0,147	0,144	0,145	0,144	0,139	0,125	0,146

Table 8. PARIS distance from the reference ideal solution (z_j^*) (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1076	0,1023	0,1033	0,0685	0,0542	0,0829	0,1018
a_2	0,1004	0,0932	0,0902	0,0685	0,0542	0,0926	0,0907
a_3	0,0741	0,0693	0,0729	0,0509	0,0475	0,084	0,0575
a_4	0,0657	0,063	0,0715	0	0	0,0707	0,0597
a_5	0,0554	0,0551	0,053	0	0	0,0623	0,0465
a_6	0,0475	0,0454	0,0376	0	0	0,059	0,031
a_7	0,0404	0,0373	0,0498	0	0	0,0409	0,0487
a_8	0,0122	0,0132	0,0238	0	0	0	0,0288
a_9	0	0	0	0	0	0,012	0

Table 11. PARIS ranking results of unweighted and weighted summation π_i^ω

Ranking Order in Weighting Index										
Weighting Index	UW	9	8	7	6	5	4	3	2	1
	MW ω_j	9	8	7	6	5	4	3	2	1
	EW ω_j	9	8	7	6	5	4	3	2	1
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
		Aircraft Alternatives (a_i)								

Table 12. PARIS ranking results π_i^* using distance from the reference ideal solution

Ranking Order in Weighting Index										
Weighting Index	UW	9	8	7	6	5	4	3	2	1
	MW ω_j	9	8	7	6	5	4	3	2	1
	EW ω_j	9	8	7	6	5	4	3	2	1
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
		Aircraft Alternatives (a_i)								

Table 13. PARIS ranking results R_i using distance from the reference ideal solution

Ranking Order in Weighting Index										
Weighting Index	UW	9	8	7	6	5	4	3	2	1
	MW ω_j	9	8	7	6	5	4	3	2	1
	EW ω_j	9	8	7	6	5	4	3	2	1
	a_i	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
		Aircraft Alternatives (a_i)								

Following the computational procedure, the robustness of the proposed method was tested under different evaluation criteria weights and multiple criteria decision making analysis models (π_i^ω , π_i^* , R_i). 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 multiple criteria decision making analysis approach for unweighted and weighted normalized matrix dataset. The validity of the applied multiple criteria decision making analysis method was revealed according to the comparative ranking results of PARIS method. In addition, it was seen that the ranking results obtained from all multiple criteria decision making analysis models were the same. Accordingly, Embraer E195-E2 (a_9) alternative was selected as the best regional aircraft.

IV. Conclusion

Aircraft selection process is structured on a multiple criteria decision making model for the interest of all stakeholders. There are many evaluation criteria that affect the aircraft selection process. Rational and accurate decisions are needed in the aircraft selection process. Regional aircraft operations are popular around the world. This study aimed to develop a general structure for aircraft selection with the help of multiple criteria decision making analysis technique. PARIS method was applied for aircraft selection problem in the regional aviation market. Considering the requirement of the aviation operators, a new integrated decision making framework is proposed in which the technical performance is systematically measured, and processed to ensure reliable and optimal decision making. All criteria and alternatives were selected after in-depth analysis of other research studies. The proposed research study provides the following contribution:

•The integrated framework (entropy and PARIS) works best in the aircraft selection process. Also, any decision making problem can be solved by changing the relevant criteria.

•The main criteria were selected through extensive data research necessary for the future aviation standard.

•This integrated framework helps operator management or purchasing team make a concrete decision on purchasing an aircraft for regional operation.

Sensitivity analysis is performed to check the robustness of the proposed framework. Integrated method results are based on the selection of evaluation criteria. The result may vary depending on aircraft requirements or changes in aviation standard or government policies. In general, before the aircraft is purchased, cost analysis is performed and it is divided into different categories such as purchasing cost, operating cost, maintenance cost, and recovery cost. In this study, open technical data sources and manufacturer data were considered for regional aircraft selection problem. Finally, the proposed multiple criteria decision making analysis model evaluates Embraer E195-E2 (a_9) regional aircraft as the best alternative.

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APPENDIX

Table 14. Multiple criteria decision making analysis methods for aircraft selection problem

Authors	Methodology	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
Ardil, C. (2020) [48]	Preference Analysis for Reference Ideal Solution Technique for Order Preference by Similarity to Ideal Solution	Aircraft Price, Aircraft Fuel Consumption, and 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), BB737 (MAX7) , B737 (MAX8) , B737 (MAX9)
Ardil, C. (2020) [49]	Preference Analysis for Reference Ideal Solution Technique for Order Preference by Similarity to Ideal Solution	Aircraft Maximum Takeoff Weight, Cruise Speed, Aircraft Range, Service Ceiling, Rate of Climb, Aircraft Capacity	Comparison of 6 aircraft types Cessna 172R Diamond DA40 XL Diamond Star King Air C90GTi PA-44-180 Seminole PAC MFI-17 Mushshak Socata TB 10 Trinidad
Ardil, C. (2020) [50]	Preference Analysis for Reference Ideal Solution Technique for Order Preference by Similarity to Ideal Solution	Maximum takeoff weight (MTOW), Maximum payload, Maximum speed, Combat range, Service ceiling, Reliability, Maneuverability	Comparison of 3 aircraft types Saab Gripen, Dassault Rafale, Eurofighter Typhoon
Sánchez-Lozano, J.M., Rodríguez, O.N. (2020) [51]	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	Comparison of 4 training aircraft types KAI-T-50 Golden Eagle, Alenia Aermacchi M-346 Master, Yakovlev YAK-130, Northrop F-5 Freedom Fighter

		(qualitative), Compatibility (qualitative), Cost (qualitative)	
Yilmaz, A.K., Malagas, K., Jawad, M., Nikitakos, N. (2020) [52]	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) [53]	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
Ahmed, S. K., Sivakumar, G., Kabir, G., Ali, S. M. (2020) [54]	Fuzzy Analytic Hierarchy Process Efficacy Method	Purchase Cost, Seating Capacity , Aircraft Range , Payload, Landing Field Length, Carbon Monoxide, Hydrocarbon, Oxides of Nitrogen , Smoke, Effective perceived noise in decibels, Maximum Zero Fuel Weight, Fuel Capacity, Landing Field Length , Seat Width, Seat Pitch, Cargo Compartment Volume, Design Configuration, Environmental Impact, Fuel Load, Passenger Ergonomics and Interior feature	Comparison of 4 aircraft types MRJ90LR ARJ21-700 Q400 CRJ700