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A Comparative Analysis of Multiple Criteria Decision Making Analysis Methods for Strategic, Tactical, and Operational Decisions in Military Fighter Aircraft Selection

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Abstract**—**This paper considers a comparative analysis of multiple criteria decision making analysis methods for strategic, tactical, and operational decisions in military fighter aircraft selection for the air force fleet planning. The evaluation criteria governing the decision analysis process are determined from the literature for the three existing military combat aircraft. Military fighter aircraft selection problem is structured using "preference analysis for reference ideal solution (PARIS)" approach in multiple criteria decision analysis.

Systematic comparisons were made with existing multiple criteria decision making analysis methods (PARIS, and TOPSIS) to verify the stability and accuracy of the results obtained. The proposed integrated multiple criteria decision making analysis systematic approach is expected to address the issues encountered in the aircraft selection process. The comparative analysis results show that the proposed method is an effective and accurate tool that can help analysts make better strategic, tactical, and operational decisions.

Keywords**—**aircraft, military fighter aircraft selection, multiple criteria decision making, multiple criteria decision making analysis, mean weight, entropy weight, MCDMA, PARIS, TOPSIS, Saab Gripen, Dassault Rafale, Eurofighter Typhoon.

I. Introduction

DECISION making is at the center of all modern military activities such as planning, organizing, staffing, directing, or controlling. 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 military decision is made, it means a commitment of resources.

The military decision can range from setting goals and objectives for the entire organization to specific decisions regarding routine operations. Some military decisions may have only short-term results, while others may have long-term effects on the organization. From these perspectives, military decisions can be broadly classified into three categories: strategic, tactical, and operational decisions.

a. Strategic decisions: Strategic military decisions are key action choices and affect all or most of the organization. Strategic military decisions directly contribute to the achievement of the common goals of the organization. It has long-term effects on the organization.

Strategic military decisions may contain major deviations from previously followed practices and procedures. In general, strategic military decision is unstructured and therefore a decision maker must apply organization judgment, evaluation, and intuition to the definition of the problem. These strategic military decisions are based on partial knowledge of environmental factors that are uncertain and dynamic in nature. Such strategic military decisions are taken at the higher organization level.

b. Tactical decisions: Tactical military decisions are related to the implementation of strategic decisions. Tactical military decisions are geared towards developing divisional plans, structuring workflows, establishing distribution channels, and acquiring resources such as human resource, material, and finance. These tactical military decisions are taken at the middle organization level.

c. Operational decisions: Operational military decisions relate to the day-to-day operations of the organization. Operational military decisions have a short-term horizon because they are taken repeatedly. These operational military decisions are based on factual facts and do not require much organization judgment. Operational military decisions are made at lower levels of organization. Information systems need to focus on organization decision making, as information is needed to help the decision maker make rational, and well-informed decisions.

Selecting a military fighter aircraft for the Air Force 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. 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[1-53], various multiple criteria decision making analysis methods including their fuzzy 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

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(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 military combat 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 making analysis problems in the fuzzy environment. Most decision problems are considered by integrated approaches based on objective or subjective weighting procedures [28-53]. Therefore, this study uses the method of multiple criteria decision making analysis approach to achieve its goals.

This multiple criteria decision making analysis study employs the Preference Analysis for Reference Ideal Solution (PARIS), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) 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, and TOPSIS calculation, which can effectively avoid the effects of human subjective factors.

TOPSIS, the widely used multiple criteria decision making analysis method, is an established technique for dealing with the problem of ranking alternatives from best to worst in decision making problem. 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 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 multiple criteria decision making analysis approaches can solve problems more efficiently and flexibly [48]. Shannon entropy procedure 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 [53]. 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 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 multiple criteria decision making analysis 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 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 [28-53]. In this study, the multiple criteria regional aircraft evaluation problem is based on the integrated objective weighting procedures, the mean weight, entropy weight, and PARIS, and TOPSIS 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 will be made with other multiple criteria decision making analysis methods such as PARIS, and TOPSIS. The multiple criteria decision making analysis method evaluates the alternatives and determines the preferences among the alternatives.

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, 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 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 [48 - 49]:

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

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

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 $x^t_{ij}=x_{ij}-\min_j x_{ij}$, then, the values of x^t_{ij} 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 multiple criteria decision making analysis 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

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

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

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

If the evaluation attribute g_j is a cost criteria, then

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

Step 3. Calculation of the weighted normalized values

$$v_{ij} = \omega_j r_{ij} \quad (13)$$

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

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

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

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

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

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

$$CC_i = \frac{D_i^-}{D_i^* + D_i^-} \quad (18)$$

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, 53]:

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

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}},\ i=1,...,I \quad (19)$$

Step 2. The calculation of entropy for each index

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

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

$$D_j = 1 - E_j,\ j=1,...,J \quad (21)$$

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

$$\omega_j = \frac{D_j}{\sum_{j=1}^{J} D_j} \quad (22)$$

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

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].

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

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

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

III. Application

A. Military fighter aircraft generations

Military fighter aircraft generations classify major technology leaps in the historical development of the fighter aircraft. Five generations are now widely recognized, and the development of the sixth generation continues.

First generation: The oldest military fighters emerged during and after the last years World War II. With their flat, unswept wings and wood and/or light alloy construction, they were in many ways similar to their piston-engined contemporaries. They had little or no avionics, their primary weapon being manually-controlled weapons. This category comprised the earliest fighters. Classic cases were Germany's Me 262 and Britain's Meteor, both of which entered service in 1944 toward the end of World War II, and the US F-80, which came along the next year. The hallmark of the First generation fighter was its revolutionary advance in speed over its piston-engine predecessors.

Second generation: The 1950-1953 Korean War forced a major rethink. As guns proved unsuitable at such high speeds, the need for multirole capability in battlefield support was rediscovered. Post-war interceptor types took advantage of afterburning engines to give Mach 2 performance, while radar and infrared homing missiles greatly improved their accuracy and firepower. Second generation fighters starred in the Korean War. Most notable were the USAF F-86 and the Soviet MiG-15. This generation sought to maximize fighter performance by tailoring the airframe to the potential of the engine. Example: the use of highly swept wings.

Third generation: The new generation of fighters was designed from the start to be multirole. They were expected to carry a wide range of weapons and other munitions such as air-to-ground missiles and laser-guided bombs, as well as to engage in air-to-air engagement beyond visual range. Among its supporting avionics were pulsed doppler radar, out-of-sight targeting and terrain warning systems. The advent of more economical turbofan engines brought longer range and sortie times, while the increased thrust could only provide partially better performance and maneuverability across the speed range. Some designers resorted to variable geometry or vectored propulsion to reconcile these contrasts.

State of the art in the late 1950s and early 1960s, fighters of the third generation included USAF's "Century Series" fighters—F-100, F-101, F-102, F-104, F-105, F-106—and the Soviet MiG-17 and MiG-21. They featured advanced missiles, supersonic speed, and more-sophisticated engines. The F-4 Phantom was a late third generation fighter, and perhaps iconic of the group.

Fourth generation: Following the mixed successes of the multirole generation, advanced technologies were being developed, such as fly-by-wire, composite materials, greater thrust-to-weight ratios than unity, hyper maneuverability, advanced digital avionics, and sensors such as synthetic radar, and infrared search-and-track, and stealth. As these appeared piecemeal, the designers returned to the fighter first and foremost, but with support roles mapped out as anticipated developments. These fighters debuted in the mid-1970s and are still tops in most of the world. This group includes USAF's F-15 and F-16 and Russia's Su-27 and MiG-29 and offshoots. Weapons, engines, and avionics of aircraft are superior.

4.5 generation: Advanced improvements have pushed some fighters into a group known as "Generation 4.5." Later variants of these and other aircraft progressively improved their characteristic technologies and increasingly combined aspects of each other's, as well as adopting some emerging fifth-generation technologies such as high-capacity digital communications and identified as intermediate generations (4.5 or 4+ and 4++). The Mikoyan-Gurevich MiG-35 is a development of the MiG-29 with fifth generation avionics. Wholly new 4.5 generation types include the HAL Tejas, CAC/PAC JF-17 Thunder, Eurofighter Typhoon, Dassault Rafale, Sukhoi Su-35, Saab Gripen, F-15s and F-16s for overseas customers.

Fifth generation: Huge advances in digital computing and mobile networking, beginning in the 1990s, led to a new model of sophisticated forward C3 (command, control, and communication) presence above the battlefield. Such aircraft were previously large transport types adapted for the role, but information technology had advanced to the point that a much smaller and more agile aircraft could carry the necessary data systems. Sophisticated automation and human interfaces could greatly reduce crew workload, and it was now possible to combine the C3, fighter and ground support roles in a single, agile aircraft. Such a fighter-and-its-pilot would need to be able to loiter for a long period, hold its own in combat, maintain battlefield awareness, and seamlessly switch roles as the situation developed. Parallel advances in materials, engine technology and electronics made such a machine possible. The stealth fighter aircraft carry missiles and bombs in an internal weapons bay to avoid radar detection. However, for some missions requiring heavier weapons load, these are mounted on external pylons, at the expense of stealth.

The class is defined by all-aspect stealth, internal carriage of precision weapons, active electronically scanned array (AESA) radars, and "plug and play" electronics. These include F-22, F-35, Su-57, TF-X (MMU), Chengdu J-20, and Shenyang FC-31.

Sixth generation: With the fifth generation only slowly coming into service, attention is already turning to the replacement sixth generation. The requirements of such a fighter are discussed. Fifth generation abilities for battlefield survivability, air superiority and ground support will need to be developed and adapted to the future threat environment. Development time and cost are likely to prove major factors in laying out practical roadmaps. One big unknown is the extent to which drones, and other remote unmanned technologies will be able to participate, either as satellite aircraft under a sixth-generation command fighter or even replacing the pilot in an autonomous or semi-autonomous command aircraft.

B. Military fighter aircraft selection

In military aviation, military fighter aircraft selection is a strategic, tactical, and operational decision process for military decision making. Also, this decision making process is closely related to the Air Force's capacity, capability, and air supremacy performance in military aviation. Additionally, the Air Force has a limited range of options and higher uncertainty about the defense demand that needs to be addressed. Therefore, this decision making process must be carried out with particular attention to the specific decision criteria established to evaluate alternatives to existing military fighter aircraft types [34, 48].

Therefore, it is important that the military fighter aircraft selection process considers all relevant evaluation aspects and uses appropriate mathematical methods to evaluate them. The relevant literature shows that the main points that distinguish the research from each other are the decision criteria and decision making methodology used in the aircraft selection problem. In addition, supply and demand are other issues that affect the aircraft selection problem. In addition, environmental considerations 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 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].

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 military aviation can be obtained for the criteria and methodology used [28-53]. In the literature, a systematic evaluation model was proposed for the Air Force Academy in Taiwan to assist 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].

C. Decision making criteria and decision tree

In this study, an empirical multiple criteria decision making analysis problem is considered to evaluate three military fighter aircraft alternatives by integrating objective weighting procedures (mean weight, entropy weight) with PARIS, and TOPSIS methods. This military fighter aircraft selection problem is set to determine the most suitable fighter aircraft { Saab Gripen (a_1), Dassault Rafale (a_2) ,and Eurofighter Typhoon (a_3)} alternative for strategic, tactical, and operational planning. These fighter aircraft alternatives are selected from the 4.5 generation fighter aircraft with NATO standards.

The criteria for selecting the appropriate military fighter aircraft are defined based on the relevant literature. Table 1 shows the criteria which are considered in the military fighter aircraft selection. A decision making tree for any decision problem is developed by identifying the goal, alternatives and criteria. The goal, which is military fighter 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. Three military fighter aircraft alternatives potentially have the required technical requirements for supporting the decision analysis model.

From the relevant literature [28-53], seven evaluation criteria for the multiple criteria decision making analysis problem were determined and employed in the aircraft evaluation process. The evaluation criteria for aircraft evaluation process are presented as follows:

Table 1. Decision criteria for choosing the optimum military fighter aircraft

No	Criteria Explanation	Optimization	Index
1	Maximum takeoff weight (MTOW)	max	g_1
2	Maximum payload	max	g_2
3	Maximum speed	max	g_3
4	Combat range	max	g_4
5	Service ceiling	max	g_5
6	Reliability	max	g_6
7	Maneuverability	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 payload: Maximum payload capacity is the maximum certificated takeoff weight of an aircraft less the empty weight, (kg, max, g_2).

Maximum speed: Maximum speed is the maximum operating speed of aircraft in Mach number, (M, max, g_3).

Combat range: Combat range is the maximum distance an aircraft can travel away from its base along a given course with normal load and return without refueling. Combat range is always smaller than maximum range, (kg, max, g_4).

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

Reliability: Aircraft reliability is the ability to perform a required function under given conditions for a given time interval, (#, max, g_6).

Maneuverability: Maneuverability is the ability to change the speed and flight direction of a military fighter aircraft, (#, max, g_7).

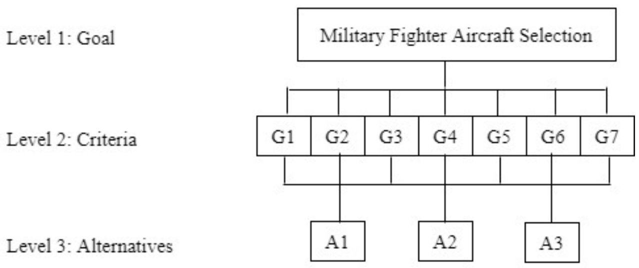

Fig 1. Hierarchy designed for optimum military fighter aircraft selection

The linguistic index values for reliability and maneuverability criteria are assigned from an 11-point linguistic scale, as given in Table 2.

Table 2. Conversion of linguistic terms into crisp scores (11-point linguistic scale)

Linguistic term	Symbol	Crisp score
Exceptionally low	L1	0,045
Extremely low	L2	0,135
Very low	L3	0,255
Low	L4	0,335
Below average	L5	0,410
Average	L6	0,500
Above average	L7	0,590
High	L8	0,665
Very high	L9	0,745
Extremely high	L10	0,865
Exceptionally high	L11	0,955

The numerical index values of the seven decision criteria for the three aircraft alternatives are presented in Table 3 by considering the technical performance aspects. In the multiple criteria decision making analysis problem, the decision criteria (maximum takeoff weight (MTOW), maximum payload, maximum speed, combat range, service ceiling, reliability, maneuverability) are modeled as benefit.

Table 3. Decision Matrix

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	16500	5100	2	1500	15240	L8	L9
a_2	24500	9500	1,8	1700	15240	L9	L9
a_3	23500	6500	2	1389	16764	L9	L10

For the Air Force needs, the three alternative military fighter aircraft with NATO standards and code requirements were ranked according to PARIS, and TOPSIS methods, using the index values of seven evaluation criteria. In the 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 4.

Table 4. 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	0,249	0,582	0,021	0,061	0,018	0,024	0,045

Table 5. 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

Table 6. PARIS weighted normalized decision matrix (MW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0962	0,0767	0,1429	0,1261	0,1299	0,1276	0,1231
a_2	0,1429	0,1429	0,1286	0,1429	0,1299	0,1429	0,1231
a_3	0,1371	0,0978	0,1429	0,1168	0,1429	0,1429	0,1429

Table 7. 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	0,0467	0,0662	0,0000	0,0168	0,0130	0,0153	0,0198
a_2	0,0000	0,0000	0,0143	0,0000	0,0130	0,0000	0,0198
a_3	0,0058	0,0451	0,0000	0,0261	0,0000	0,0000	0,0000

Table 8. PARIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1677	0,3124	0,0210	0,0538	0,0164	0,0214	0,0388
a_2	0,2490	0,5820	0,0189	0,0610	0,0164	0,0240	0,0388
a_3	0,2388	0,3982	0,0210	0,0498	0,0180	0,0240	0,0450

Table 9. 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	0,0813	0,2696	0,0000	0,0072	0,0016	0,0026	0,0062
a_2	0,0000	0,0000	0,0021	0,0000	0,0016	0,0000	0,0062
a_3	0,0102	0,1838	0,0000	0,0112	0,0000	0,0000	0,0000

Table 10. PARIS ranking results of unweighted and weighted summation π_i^ω

Ranking Order in Weighting Index

Weighting Index					Ranking Order
	UW	3	1	2	
	MW ω_j	3	1	2	
	EW ω_j	3	1	2	
	a_i	a_1	a_2	a_3	
Dassault Rafale (a_2) is optimal fighter aircraft choice		Aircraft Alternatives			

Table 11. PARIS ranking results π_i^* using distance from the reference ideal solution

Ranking Order in Weighting Index

Weighting Index					Ranking Order
	MW ω_j	3	1	2	
	EW ω_j	3	1	2	
	a_i	a_1	a_2	a_3	
Dassault Rafale (a_2) is optimal fighter aircraft choice		Aircraft Alternatives			

Table 12. PARIS ranking results R_i using relative distance from the reference ideal solution

Ranking Order in Weighting Index

Weighting Index					Ranking Order
	MW ω_j	3	1	2	
	EW ω_j	3	1	2	
	a_i	a_1	a_2	a_3	
Dassault Rafale (a_2) is optimal fighter aircraft choice		Aircraft Alternatives			

Table 13. TOPSIS normalized decision matrix

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,4371	0,4051	0,5965	0,5642	0,5581	0,5337	0,5465
a_2	0,6491	0,7546	0,5369	0,6394	0,5581	0,5980	0,5465
a_3	0,6226	0,5163	0,5965	0,5224	0,6140	0,5980	0,6345

Table 14. TOPSIS weighted normalized decision matrix (MW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,0625	0,0579	0,0852	0,0806	0,0798	0,0763	0,0781
a_2	0,0928	0,1078	0,0767	0,0914	0,0798	0,0854	0,0781
a_3	0,0890	0,0738	0,0852	0,0747	0,0877	0,0854	0,0907

Table 15. TOPSIS the ideal and anti-ideal solutions (MW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_i^*	0,0928	0,1078	0,0852	0,0914	0,0877	0,0854	0,0907
a_i^-	0,0625	0,0579	0,0767	0,0747	0,0798	0,0763	0,0781

Table 16. 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	g_7
a_1	0,0303	0,0499	0,0000	0,0107	0,0080	0,0092	0,0126
a_2	0,0000	0,0000	0,0085	0,0000	0,0080	0,0000	0,0126
a_3	0,0038	0,0341	0,0000	0,0167	0,0000	0,0000	0,0000

Table 17. 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	g_7
a_1	0,0000	0,0000	0,0085	0,0060	0,0000	0,0000	0,0000
a_2	0,0303	0,0499	0,0000	0,0167	0,0000	0,0092	0,0000
a_3	0,0265	0,0159	0,0085	0,0000	0,0080	0,0092	0,0126

Table 18. TOPSIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1088	0,2358	0,0125	0,0344	0,0100	0,0128	0,0246
a_2	0,1616	0,4392	0,0113	0,0390	0,0100	0,0144	0,0246
a_3	0,1550	0,3005	0,0125	0,0319	0,0111	0,0144	0,0286

Table 19. TOPSIS weighted normalized decision matrix (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,1088	0,2358	0,0125	0,0344	0,0100	0,0128	0,0246
a_2	0,1616	0,4392	0,0113	0,0390	0,0100	0,0144	0,0246
a_3	0,1550	0,3005	0,0125	0,0319	0,0111	0,0144	0,0286

Table 20. TOPSIS the ideal and anti-ideal solutions (EW)

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_i^*	0,1616	0,4392	0,0125	0,0390	0,0111	0,0144	0,0286
a_i^-	0,1088	0,2358	0,0113	0,0319	0,0100	0,0128	0,0246

Table 21. 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	g_7
a_1	0,0528	0,2034	0,0000	0,0046	0,0010	0,0015	0,0040
a_2	0,0000	0,0000	0,0013	0,0000	0,0010	0,0000	0,0040
a_3	0,0066	0,1387	0,0000	0,0071	0,0000	0,0000	0,0000

Table 22. 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	g_7
a_1	0,0000	0,0000	0,0013	0,0025	0,0000	0,0000	0,0000
a_2	0,0528	0,2034	0,0000	0,0071	0,0000	0,0015	0,0000
a_3	0,0462	0,0647	0,0013	0,0000	0,0010	0,0015	0,0040

Table 23. TOPSIS ranking results CC_i

Ranking Order in Weighting Index					
Weighting Index	MW ω_j	3	1	2	Ranking Order
	EW ω_j	3	1	2	
	a_i	a_1	a_2	a_3	
Dassault Rafale (a_2) is optimal fighter aircraft choice		Aircraft Alternatives			

Table 24. TOPSIS ranking results of unweighted and weighted summation

Ranking Order in Weighting Index					
Weighting Index	UW	3	1	2	Ranking Order
	MW ω_j	3	1	2	
	EW ω_j	3	1	2	
	a_i	a_1	a_2	a_3	
Dassault Rafale (a_2) is optimal fighter aircraft choice		Aircraft Alternatives			

The robustness of the proposed model was tested under different evaluation criteria weights and multiple criteria decision making analysis methods. 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, and TOPSIS methods. In addition, it was seen that the ranking results obtained from all multiple criteria decision making analysis methods were the same. Accordingly, Dassault Rafale (a_2) alternative was selected as the best fighter aircraft. Saab Gripen operators are Brazil, Czechia, Hungary, South Africa, Sweden, Thailand, and United Kingdom. Dassault Rafale operators are Egypt, France, Greece, India, and Qatar. Eurofighter Typhoon operators are Austria, Germany, Italy, Kuwait, Oman, Qatar, Saudi Arabia, Spain, and United Kingdom.

IV. Conclusion

In this study, a comparative analysis of multiple criteria decision making analysis methods for strategic, tactical and operational decisions in military fighter aircraft selection is given. While making the strategic, tactical and operational planning of the Air Force, a decision support system is needed for objective analysis of the decision making process and taking the right decisions. The objective criteria weight-based PARIS, and TOPSIS method yielded consistent evaluation results for military fighter aircraft selection problem.

The problem of military fighter choice can also be influenced by international political realities and strategic cooperation perspectives. The choice of fighter aircraft is an ultracritical technology choice for air superiority and an effective defense system for the next 50 years. This preference also includes the upgrade, maintenance, support services of fighter aircraft and the Air Force fleet planning. The Saab Gripen fighter aircraft offers lighter military technology, while the Dassault Rafale and Eurofighter Typhoon offer heavier military technology for strategic, tactical and operational decisions. Saab Gripen, Dassault Rafale, and Eurofighter Typhoon military fighter aircraft are products of NATO – EU countries. The proposed multiple criteria decision making analysis model evaluates the Dassault Rafale (a_2) fighter aircraft as the best alternative.

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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
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
Sánchez-Lozano, J.M., Rodríguez, O.N. (2020) [50]	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) [51]	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)[52]	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