Aircraft Selection Using Preference Optimization Programming (POP)

C. Ardil

***Abstract*—**A multiple-criteria decision support system is proposed for the best aircraft selection decision. Various strategic, economic, environmental, and risk-related factors can directly or indirectly influence this choice, and they should be taken into account in the decision-making process. The paper suggests a multiple-criteria analysis to aid in the airline management's decision-making process when choosing an appropriate aircraft. In terms of the suggested approach, an integrated entropic preference optimization programming (POP) for fleet modeling risk analysis is applied. The findings of the study of multiple criteria analysis indicate that the A321(neo) aircraft type is the best alternative in this particular optimization instance. The proposed methodology can be applied to other complex engineering problems involving multiple criteria analysis.

***Keywords*—**Aircraft selection, decision making, multiple criteria decision making, preference optimization programming, POP, entropic weight method, TOPSIS, WSM, WPM.

I. Introduction

For fleet planning and modeling, the proper aircraft must be chosen and made available for airline strategic, tactical, and operational requirements. Therefore, choosing the kind of aircraft that would please clients depends on their needs and demands in fleet modeling.

Choosing an aircraft is a difficult procedure, therefore careful consideration is needed in the fleet modeling process. This choice has to do with how many aircraft to buy or lease for fleet planning. When an airline plans its fleet, some fleet types with similar capabilities are viewed as competitors, even though there are currently a wide variety of alternatives from which to choose for fleet planning.

Additionally, because fleet planning involves a sizable capital investment with a long-term vision, it is a mid - and long-term strategic choice that affects the financial condition of airlines. The fleet planning process for the airline is a crucial multiple-criteria decision-making (MCDM) analysis process that considers a number of essential evaluation criteria [1].

In this situation, the right MCDM techniques should be applied to help airline management efficiently evaluate the many aircraft alternatives based on pertinent criteria. The weight of the selection criteria to select the best alternative is determined using the entropic weight method (EWM). As a strong and adaptable decision-support tool, it enables decision-makers to model complicated problems while taking both quantitative and qualitative factors into consideration.

Numerous selection criteria can be successfully considered using the EWM methodology, and it also permits the objective consideration of criteria while allocating resources. The different options are also assessed using the preference optimization programming (POP) method.

Decision-makers can choose solutions from a finite number of options using this MCDM approach to choose the best course of action. Combining these two techniques yields significant results when choosing the right aircraft type to meet the needs of the airline in the situation under consideration. Therefore, entropic preference optimization programming (POP), a relatively new MCDM technique, is applied to select the best possible aircraft alternatively based on different criteria [1].

In the chosen fleet planning scenario, the airline management recommends replacing the current aircrafts with new, modern, and sophisticated aircrafts that will improve capabilities and meet the most recent strategic, tactical, and operational needs with the least amount of maintenance and operating expense. In order to perform this study, a number of seasoned aviation industry participants with in-depth expertise in the subject evaluated the numerous aircraft types of options based on the predetermined criteria to prepare a shortlist of the potential alternatives.

Determining the appropriate aircraft types based on the precise criteria established by experts, which should be chosen for the purpose of fleet optimization in a specific airline, using both the entropic weight method (EWM) and preference optimization programming (POP) is the MCDM research problem. The selection of aircraft for airlines is more prevalent challenge in the pertinent literature [1-26].

The principles of the aircraft selection problem are thoroughly reviewed in the literature on choosing different types of aircraft. The selection problems in these MCDM investigations use both traditional and fuzzy approaches. When there is incomplete knowledge of the multiple criteria decision problems, fuzzy methodologies are more practical and efficient to deal with uncertainty [28-54].

Since airlines have some unique characteristics that may affect the aircraft selection process, this research adds to the body of knowledge about the choice of aircraft by airlines. Additionally, the criteria for choosing an aircraft are related to the requirement to comprehend airline operations and structure. It is hoped that this research will be useful and aid in the decision-making process. Additionally, it will assist airline management who are involved in the selection of aircraft in reaching the best choice.

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

The rest of the paper is organized as follows: The entropic POP model is then presented in Section 2. The proposed approach is used to address the problem of multiple criteria decision-making in Section 3. The paper concludes by outlining its findings, its limits, and its suggestions for future study.

II. Methodology

A. Entropic Weight Method (EWM)

The measured value of the *j*th factor in the *i*th sample is recorded as x_{ij} in this approach, which uses *J* factors and *I* samples for the evaluation [52-53].

Step 1. The normalization of measured values is the initial stage.The method used to calculate the *j*th factor's standardized value in the *i*th sample is designated as p_{ij}

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}} \tag{1}$$

Step 2. The entropy value E_j of the *j*th factor is defined as

$$E_j = -\frac{\sum_{i=1}^{I} p_{ij} \ln p_{ij}}{\ln I} \tag{2}$$

In the actual evaluation using the EWM, $p_{ij} \ln p_{ij} = 0$, is generally set when $p_{ij} = 0$ for the convenience of calculation.

The range of entropy value E_j is [0, 1]. The larger the E_j is, the greater the differentiation degree of factor *J* is, and more information can be derived. Hence, a higher weight should be given to the factor.

Step 3. The calculation method of entropic weight ω_j is given by

$$\omega_j = \frac{1 - E_j}{\sum_{j=1}^{J} (1 - E_j)} \tag{3}$$

B. POP Method

The POP method is performed according to the following procedural steps [1]:

Step 1. Constructing the decision matrix $X = [x_{ij}]_{ixj}$

$$X = \begin{pmatrix} \overset{g_1}{x_{11}} & \cdots & \overset{g_j}{x_{1j}} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \tag{4}$$

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 defined.

Step 2. Normalizing the decision matrix $N = [n_{ij}]_{ixj}$. The decision matrix of the alternatives is normalized using the linear normalization scale.

If g_j is the criterion, the bigger the better ($j \in B$)

$$n_{ij} = \frac{x_{ij}}{x_j^{\max}} \tag{5}$$

If g_j is the criterion, the smaller the better ($j \in C$)

$$n_{ij} = \frac{x_j^{\min}}{x_{ij}} \tag{6}$$

where *B* represents a criterion as large as possible, *C* represents a criterion as small as possible. n_{ij} is an element of the normalized matrix $N = [n_{ij}]_{ixj}$.

Step 3. Calculating the weighted normalized value $Z = [z_{ij}]_{ixj}$

$$z_{ij} = \omega_j n_{ij} \tag{7}$$

Step 4. Determining the preference optimization value (μ_i)

$$\mu_i = \sum_{j=1}^{J} z_{ij} \tag{8}$$

Step 5. Ranking the options in accordance with the principle that the choice with the highest value (μ_i) is the best option.

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

$$z_j^* = \left\{ z_1^*, z_2^*, ..., z_J^* \right\} = \left\{ (\max_i z_{ij} \mid j \in B, (\min_i z_{ij} \mid j \in C \right\} \tag{9}$$

Step 7. Computing the distance of each alternative from (z_j^*) and (z_{ij})

$$\pi_i = \sum_{j=1}^{J} (z_j^* - z_{ij}) \tag{10}$$

where $d_i = (z_j^* - z_{ij})$ is the distance measurement between two crisp numbers, and (π_i) is the preference optimization value.

Step 8. Ranking the options in accordance with the principle that the choice with the lowest value (π_i) is the best option.

C. Weighted Sum Model

$$\varphi_i = \sum_{j=1}^{J} \omega_j n_{ij} \tag{11}$$

D. Weighted Product Model

$$\phi_i = \left(\prod_{j=1}^{J} n_{ij}^{\omega_j}\right)^{1/J} \tag{12}$$

E. TOPSIS Method

Steps 1-4 of POP method are the same in TOPSIS

Step 5. Determining ideal (A^*) and anti-ideal (A^-)solutions

$$A^* = \left\{z_1^*, z_2^*, ..., z_J^*\right\} = \left\{(\max_i z_{ij} \mid j \in B, (\min_i z_{ij} \mid j \in C\right\} \tag{13}$$

$$A^- = \left\{z_1^-, z_2^-, ..., z_J^-\right\} = \left\{(\min_i z_{ij} \mid j \in B, (\max_i z_{ij} \mid j \in C\right\} \tag{14}$$

Step 6. Calculating the separation measures

$$S_i^* = \sqrt{\sum_{j=1}^{J} (z_{ij} - z_j^*)^2} \tag{15}$$

$$S_i^- = \sqrt{\sum_{j=1}^{J} (z_{ij} - z_j^-)^2} \tag{16}$$

Step 7. Calculating relative closeness (C_i^*) to the ideal solution

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{17}$$

where $0 \le C_i^* \le 1$ value indicates the performance of the *i*th alternative, and higher values indicate higher performance.

Step 8. Alternatives are ranked according to their relative closeness (C_i^*) to the ideal solution.

III. Application

In this section, according to chosen fleet planning scenario, the airline management recommends replacing the current aircrafts with new, modern, and sophisticated aircrafts that will improve capabilities and meet the most recent strategic, tactical, and operational needs with the least amount of maintenance and operating expense. The established experts committee thoroughly reviewed the literature to determine the alternatives and decision criteria for the selection of the passenger aircraft. Briefly, price (Million \$) (g_1), fuel consumption (kg/km) (g_2), range (km) (g_3), number of seats (g_4), luggage volume (m^3) (g_5), and MTOW (maximum takeoff weight, (kg)) (g_6) are the six factors for making a decision in the aircraft selection problem. Price (Million \$) (g_1), and fuel consumption (kg/km) (g_2) are cost criteria, and other decision criteria are considered benefit criteria. Therefore, the proposed entropic POP approach is applied to the aircraft selection problem. The passenger aircraft alternatives are listed in the initial decision-making matrix as shown in Table 1.

Table 1. Initial decision-making matrix

Alternatives	**Decision criteria**					
Aircrafts	g_1	g_2	g_3	g_4	g_5	g_6
A319(neo)	101,5	2,82	6850	140	27	75500
A320(neo)	110,6	2,79	6300	165	37	79000
A321(neo)	129,5	3,3	7400	206	51	97000
B737(MAX7)	96	2,85	7130	153	32,3	80000
B737(MAX8)	117,1	3,04	6570	178	44	82600
B737(MAX9)	124,1	3,3	6570	193	51,3	88300

The objective criteria weights determined by the entropic weight method are given in Table 2.

Table 2. Entropic weights of decision criteria

Entropy	**Decision criteria**					
	g_1	g_2	g_3	g_4	g_5	g_6
E_j	0,997	0,999	0,999	0,995	0,985	0,998
$1-E_j$	0,003	0,001	0,001	0,005	0,015	0,002
ω_j	0,115	0,053	0,031	0,180	0,547	0,074

The priority vector of decision criteria is determined by the EWM as follows: $g_3 \prec g_2 \prec g_6 \prec g_1 \prec g_4 \prec g_5$. The graphical representation of the priority vector of decision criteria is shown in Fig. 1.

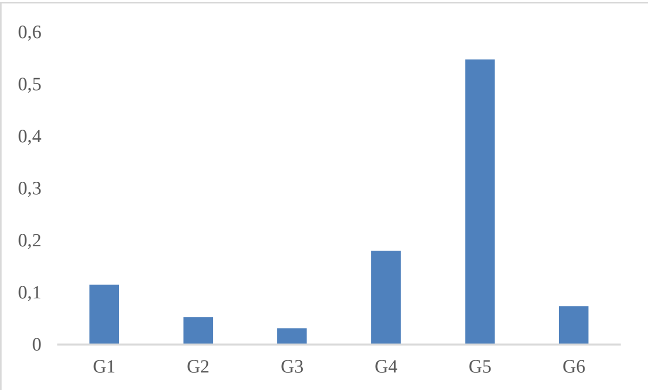

Fig. 1 Graphical representation of priority vector of evaluation criteria

The normalization of the measured values of the initial decision matrix is given in Table 3.

Table 3. Normalized decision-making matrix

Alternatives	Decision criteria					
	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,946	0,989	0,926	0,680	0,526	0,778
a_2	0,868	1,000	0,851	0,801	0,721	0,814
a_3	0,741	0,845	1,000	1,000	0,994	1,000
a_4	1,000	0,979	0,964	0,743	0,630	0,825
a_5	0,820	0,918	0,888	0,864	0,858	0,852
a_6	0,774	0,845	0,888	0,937	1,000	0,910

The weighted normalized decision-making matrix is obtained by using Equation (7) and the weighted normalized decision-making matrix is shown in Table 4.

Table 4. Weighted normalized decision-making matrix

Alternatives	Decision criteria					
	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,109	0,053	0,029	0,123	0,288	0,057
a_2	0,100	0,053	0,026	0,144	0,394	0,060
a_3	0,085	0,045	0,031	0,180	0,543	0,074
a_4	0,115	0,052	0,030	0,134	0,344	0,061
a_5	0,094	0,049	0,028	0,156	0,469	0,063
a_6	0,089	0,045	0,028	0,169	0,547	0,067

The optimal values are determined by Equation (9) and the optimal values are shown in Table 5.

Table 5. The vector of optimal values (z_j^*)

Optimal values	Decision criteria					
	g_1	g_2	g_3	g_4	g_5	g_6
z_j^*	0,115	0,053	0,031	0,180	0,547	0,074

The distance of each alternative from (z_j^*) and (z_{ij}) is calculated and the computed distance values $d_i = (z_j^* - z_{ij})$ are given in Table 6.

Table 6. Computed distance values (d_i)

Alternatives	Decision criteria					
	g_1	g_2	g_3	g_4	g_5	g_6
a_1	0,006	0,001	0,002	0,058	0,259	0,016
a_2	0,015	0,000	0,005	0,036	0,152	0,014
a_3	0,030	0,008	0,000	0,000	0,003	0,000
a_4	0,000	0,001	0,001	0,046	0,202	0,013
a_5	0,021	0,004	0,003	0,025	0,078	0,011
a_6	0,026	0,008	0,003	0,011	0,000	0,007

The ranking order of alternatives based on the results of Table 4 and Table 6 is given in Table 7.

Table 7. POP ranking order of alternatives

Alternatives	Ranking orders of alternatives			
	μ_i	Rank	π_i	Rank
a_1	0,658	6	0,342	6
a_2	0,778	4	0,222	4
a_3	0,959	1	0,041	1
a_4	0,736	5	0,264	5
a_5	0,858	3	0,142	3
a_6	0,944	2	0,056	2

The ranking orders of alternatives based on the results of the weighted sum and weighted product models are given in Table 8.

Table 8. WSM and WPM ranking orders of alternatives

	WSM and WPM ranking orders of alternatives			
Alternatives	**WSM (φ_i)**	**Rank**	**WPM (ϕ_i)**	**Rank**
a_1	0,658	6	0,914	6
a_2	0,778	4	0,950	4
a_3	0,959	1	0,991	1
a_4	0,736	5	0,937	5
a_5	0,858	3	0,970	3
a_6	0,944	2	0,988	2

TOPSIS ideal (A^*) and anti-ideal (A^-) solutions are shown in Table 9.

Table 9. TOPSIS ideal (A^*) and anti-ideal (A^-) solutions

	Decision criteria					
	g_1	g_2	g_3	g_4	g_5	g_6
A^*	0,115	0,053	0,031	0,180	0,547	0,074
A^-	0,085	0,045	0,026	0,123	0,288	0,057

The relative proximity (C_i^*) and the ranking order of the alternatives is given in Table 10.

Table 10. The relative proximity (C_i^*) and the ranking order of the alternatives

	TOPSIS ranking order of alternatives			
Alternatives	S_i^*	S_i^-	C_i^*	**Rank**
a_1	0,266	0,025	0,086	6
a_2	0,158	0,110	0,411	4
a_3	0,031	0,263	0,894	2
a_4	0,208	0,065	0,239	5
a_5	0,085	0,185	0,685	3
a_6	0,031	0,263	0,896	1

Finally, to demonstrate the validation and effectiveness of the proposed method, a correlation analysis of the ranking orders of POP, WSM, WPM, and TOPSIS methods is performed, and the correlation analysis results are shown in Table 11.

Table 11. Correlation analysis of the ranking orders of POP, WSM, WPM , and TOPSIS methods

	POP	WSM	WPM	TOPSIS
POP	1			
WSM	1	1		
WPM	1	1	1	
TOPSIS	0,94	0,94	0,94	1

The validation of results of the proposed POP method is tested with other classical MCDM methods: WSM, WPM, and TOPSIS. Multiple criteria analysis results indicate that POP, WSM, and WPM methods yield the same ranking orders of alternatives. However, TOPSIS method changes the ranking order of alternatives (a_3) and (a_6) and favors the alternative (a_6) as the optimal solution. Also, POP, WSM, and WPM methods select the same alternative (a_3) as the best solution for the aircraft selection problem. Even when identical data set and weights for the decision criteria are used, MCDM algorithms can produce different rankings of the alternatives. This is because each MCDM technique has a unique solution algorithm.

IV. Conclusion

The effectiveness of airlines' organizations depends on making logical decisions, like choosing an appropriate aircraft for strategic, tactical, and operational requirements in fleet planning. The management of the airline should consider the choosing of the optimal aircraft.

The beginning points that concentrate on fleet modeling are the available alternatives and the choice of decision criteria. Experts have identified the criteria to evaluate the choices for aircraft types, which are primarily focused on operational, strategic, economic, and most recently environmental aspects. The proper evaluation of the aircraft choices required the use of strategic, economic, operational, and maintenance factors for multiple criteria analysis process. These concerns appear crucial for selecting aircraft since the relevant criteria should be directly tied to the particular instance.

The aircrafts that are readily available are those that respond best to consumer needs in aviation industry. An essential factor determining an airline's ability to operate profitably and efficiently is the choice of the best type of aircraft for fleet planning and modeling. Additionally, it is important to utilize the right MCDM techniques to evaluate different aircraft options according to decision criteria. It is possible to apply an integrated entropic POP approach that produces insightful results in aircraft selection process. The proposed method allows for the pursuit of the best alternatives using criteria that are easily evaluated by a straightforward mathematical programming since it is composed of an effective and efficient methodology that is simple to comprehend and apply.

An entropic POP-based solution technique for an aircraft selection problem was proposed in this multiple criteria analysis problem. This method was used to resolve a numerical example with six aircraft types and six decision criteria. The suggested method is highly useful since it spares the decision-maker from having to give weights to aircraft selection criteria.

Successful integration of the entropic POP approach yielded reliable aircraft selection process outcomes. The results of the research lead to the conclusion that, in order to reduce risks, a single type of fleet structure is best for the particular airline. In conclusion, the current study focuses on a specific airline fleet modeling with unique characteristics, it significantly improves the fleet selection process.

Finally, developing a method for choosing aircraft based on fuzzy preference optimization programming could be an interesting area for future research.

References

[1] Ardil, C. (2022). Fighter Aircraft Selection Using Fuzzy Preference Optimization Programming (POP). International Journal of Aerospace and Mechanical Engineering, 16(10), 279 - 290.

[2] Ardil, C. (2022). Vague Multiple Criteria Decision Making Analysis Method for Fighter Aircraft Selection. *International Journal of Aerospace and Mechanical Engineering*, 16(5),133-142.

[3] Ardil, C. (2022).Fuzzy Uncertainty Theory for Stealth Fighter Aircraft Selection in Entropic Fuzzy TOPSIS Decision Analysis Process. *International Journal of Aerospace and Mechanical Engineering*, 16(4), 93 - 102.

[4] Ardil, C. (2022). Aircraft Selection Problem Using Decision Uncertainty Distance in Fuzzy Multiple Criteria Decision Making Analysis. *International Journal of Mechanical and Industrial Engineering*, 16(3), 62 - 69.

[5] Ardil, C. (2022). Fighter Aircraft Selection Using Neutrosophic Multiple Criteria Decision Making Analysis. *International Journal of Computer and Systems Engineering*, 16(1), 5 - 9.

[6] Ardil, C. (2022). Military Attack Helicopter Selection Using Distance Function Measures in Multiple Criteria Decision Making Analysis. *International Journal of Aerospace and Mechanical Engineering*, 16(2), 20 - 27.

[7] Ardil, C. (2021). Airline Quality Rating Using PARIS and TOPSIS in Multiple Criteria Decision Making Analysis. *International Journal of Industrial and Systems Engineering*, 15(12), 516 - 523.

[8] Ardil, C. (2021). Fighter Aircraft Evaluation and Selection Process Based on Triangular Fuzzy Numbers in Multiple Criteria Decision Making Analysis Using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). *International Journal of Computer and Systems Engineering*, 15(12), 402 - 408.

[9] Ardil, C. (2021). Military Combat Aircraft Selection Using Trapezoidal Fuzzy Numbers with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). *International Journal of Computer and Information Engineering*, 15(12), 630 - 635.

[10] Ardil, C. (2021). Freighter Aircraft Selection Using Entropic Programming for Multiple Criteria Decision Making Analysis. *International Journal of Mathematical and Computational Sciences*, 15(12), 125 - 132.

[11] Ardil, C. (2021). Advanced Jet Trainer and Light Attack Aircraft Selection Using Composite Programming in Multiple Criteria Decision Making Analysis Method. *International Journal of Aerospace and Mechanical Engineering*, 15(12), 486 - 491.

[12] Ardil, C. (2021). Comparison of Composite Programming and Compromise Programming for Aircraft Selection Problem Using Multiple Criteria Decision Making Analysis Method. *International Journal of Aerospace and Mechanical Engineering*, 15(11), 479 - 485.

[13] Ardil, C. (2021). Neutrosophic Multiple Criteria Decision Making Analysis Method for Selecting Stealth Fighter Aircraft. *International Journal of Aerospace and Mechanical Engineering*, 15(10), 459 - 463.

[14] Ardil, C. (2020). Regional Aircraft Selection Using Preference Analysis for Reference Ideal Solution (PARIS). *International Journal of Transport and Vehicle Engineering*, 14(9), 378 - 388.

[15] Ardil, C. (2020). A Comparative Analysis of Multiple Criteria Decision Making Analysis Methods for Strategic, Tactical, and Operational Decisions in Military Fighter Aircraft Selection. *International Journal of Aerospace and Mechanical Engineering*, 14(7), 275 - 288.

[16] Ardil, C. (2020). Trainer Aircraft Selection Using Preference Analysis for Reference Ideal Solution (PARIS). *International Journal of Aerospace and Mechanical Engineering*, 14(5), 195 - 209.

[17] Ardil, C. (2020). Aircraft Selection Process Using Preference Analysis for Reference Ideal Solution (PARIS). *International Journal of Aerospace and Mechanical Engineering*, 14(3), 80 - 93.

[18] Ardil, C. (2019). Aircraft Selection Using Multiple Criteria Decision Making Analysis Method with Different Data Normalization Techniques. *International Journal of Industrial and Systems Engineering*, 13(12), 744 - 756.

[19] Ardil, C. , Pashaev, A. , Sadiqov, R. , Abdullayev, P. (2019). Multiple Criteria Decision Making Analysis for Selecting and Evaluating Fighter Aircraft. *International Journal of Transport and Vehicle Engineering*, 13(11), 683 - 694.

[20] Ardil, C. (2019). Fighter Aircraft Selection Using Technique for Order Preference by Similarity to Ideal Solution with Multiple Criteria Decision Making Analysis. *International Journal of Transport and Vehicle Engineering*, 13(10), 649 - 657.

[21] Ardil, C. (2019). Military Fighter Aircraft Selection Using Multiplicative Multiple Criteria Decision Making Analysis Method. *International Journal of Mathematical and Computational Sciences*, 13(9), 184 - 193.

[22] Sánchez-Lozano, J.M., Correa-Rubio, J., Fernández-Martínez, M. (2022). A double fuzzy multi-criteria analysis to evaluate international high-performance aircrafts for defense purposes. *Engineering Applications of Artificial Intelligence*,Volume 115, October 2022, 105339.

[23] Maêda, S.M., Costa, I.P., Castro Junior, M.A., Fávero, L., Costa, A.P., Corriça, J.V., Gomes, C.F., & Santos, M.D. (2021). Multi-criteria analysis applied to aircraft selection by Brazilian Navy. Production.

[24] Sánchez-Lozano, J.M., Rodríguez, O.N. (2020). Application of Fuzzy Reference Ideal Method (FRIM) to the military advanced training aircraft selection. *Appl. Soft Comput*., 88, 106061.

[25] Kiracı, K., Akan, E. (2020). Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets. *Journal of Air Transport Management*, 89, 101924 - 101924.

[26] Sánchez-Lozano, J.M., Serna, J., Dolón-Payán, A. (2015). Evaluating military training aircrafts through the combination of multi-criteria decision making processes with fuzzy logic. A case study in the Spanish Air Force Academy. *Aerospace Science and Technology*, 42, 58-65.

[27] Saaty, T. L. (1990). How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research, 48(1), 9-26. doi: 10.1016/0377-2217(90)90057-I

[28] Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), 83-98. doi: 10.1504/IJSSCI.2008.017590

[29] Saaty, T.L. (1980). Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York.

[30] Roy, B. (1991). The outranking approach and the foundation of ELECTRE methods. Theory and Decision, 31(1), 49–73.

[31] Fei, L., Xia, J., Feng, Y., Liu, L. (2019) An ELECTRE-Based Multiple Criteria Decision Making Method for Supplier Selection Using Dempster-Shafer Theory. IEEE Access, 7, 84701-84716.

[32] Brans JP., Mareschal B. (2005). Promethee Methods. In: Multiple Criteria Decision Analysis: State of the Art Surveys. International Series in Operations Research & Management Science, vol 78, pp 163-186. Springer, New York, NY. https://doi.org/10.1007/0-387-23081-5_5.

[33] Brans, J., Ph. Vincke. (1985). A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making). Management Science, 31(6), 647-656.

[34] Brans, J.P., Macharis, C., Kunsch, P.L., Chevalier, A., Schwaninger, M., (1998). Combining multicriteria decision aid and system dynamics for the control of socio-economic processes. An iterative real-time procedure. European Journal of Operational Research 109, 428-441.

[35] Brans, J.P., Vincke, Ph., Mareschal, B., (1986). How to select and how to rank projects: the PROMETHEE method. European Journal of Operational Research, 24, 228-238.

[36] Hwang, C.L.; Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. New York: Springer-Verlag.

[37] Chu, T.C. (2002. Facility location selection using fuzzy TOPSIS under group decisions", International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, Vol. 10 No. 6, pp. 687-701.

[38] Choudhary, D. and Shankar, R. (2012. A STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: a case study from India", Energy, Vol. 42 No. 1, pp. 510-521.

[39] Zavadskas, E.K., Mardani, A., Turskis, Z., Jusoh, A., Nor, K.M. (2016) Development of TOPSIS method to solve complicated decision-making problems: An overview on developments from 2000 to 2015. International Journal of Information Technology & Decision Making, 15, 645-682.

[40] Opricovic, S. (1998). Multicriteria Optimization of Civil Engineering Systems. PhD Thesis, Faculty of Civil Engineering, Belgrade (in Serbian).

[41] Opricovic, S. (2007). A fuzzy compromise solution for multicriteria problems. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 15(3), 363–380.

[42] Opricovic, S., Tzeng, G.-H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research, 156(2), 445–455.

[43] Buckley,J.J. (1985). Fuzzy hierarchical analysis, Fuzzy Sets and Systems, 17, 233–247.

[44] Hsu, H.M., Chen, C.T. (1997). Fuzzy credibility relation method for multiple criteria decision-making problems, *Inform. Sci.* 96,79–91.

[45] Hsu, H.M., Chen, C.T. (1996). Aggregation of fuzzy opinions under group decision making, *Fuzzy Sets and Systems*, 79, 279–285.

[46] Chen, C.-T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets Syst.* 114, 1–9.

[47] Bellman, R.E., Zadeh, L.A. (1970). Decision-making in a fuzzy environment. *Management Science*, 17(4), 141–164.

[48] Zadeh L.A., (1965). Fuzzy Sets. *Information and Control*, 8, 338-353.

[49] Zadeh, L.A. (1975). The concept of a linguistic variable and its application to approximate reasoning, *Inform. Sci.* 8, 199–249(I), 301–357(II).

[50] Delgado, M., Verdegay, J.L., Vila, M.A. (1992). Linguistic decision making models, *Int. J. Intelligent System* 7, 479–492.

[51] Herrera, F., Herrera-Viedma, E., Verdegay, J.L. (1996). A model of consensus in group decision making under linguistic assessments, *Fuzzy Sets and Systems*, 78,73–87.

[52] Li, X. G., Wei, X., Huang, Q. (2012). Comprehensive entropy weight observability-controllability risk analysis and its application to water resource decision-making, *Water SA*, vol. 38 (4), 573–579.

[53] Dong, G. H., Shen,J. Q., Jia, Y. Z., Sun, F. H. (2018). Comprehensive evaluation of water resource security: case study from Luoyang City, China, *Water*, 10(8), 1106.