

Aircraft Selection Problem Using Decision Uncertainty Distance in Fuzzy Multiple Criteria Decision Making Analysis

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Abstract—Aircraft have different capabilities and specifications according to the required strategic goals and objectives in operations. With various types on the market with different aircraft characteristics, it becomes difficult to select a suitable aircraft for certain operations and requirements. The entropy weighting method (EWM) is a useful, highly consistent, and reliable method for obtaining the weights of the criteria and is worth integrating with the decision uncertainty distance (DUD) method, which is more applicable and requires less computation than other methods. An illustrative example is presented to demonstrate the validity and usability of the proposed methodology. Comparing the ranking results matches the distance-based approach, which is the technique for order preference by similarity to ideal solution (TOPSIS) method, which shows the robustness of the entropy DUD hybrid method. Validity analysis shows that the proposed hybrid multiple criteria decision-making analysis (MCDMA) methodology is quantitatively stable and reliable.

Keywords—aircraft selection, decision uncertainty distance (DUD), multiple criteria decision making analysis, MCDMA, TOPSIS.

I. INTRODUCTION

THE massive use of aircraft in the aviation industry is due to extensive progress in engineering and information technology. Commercial aircraft have many features, specifications, and capabilities to operate correctly compared to other existing classical transportation systems. An aircraft is a multipurpose vessel capable of performing a variety of tasks in a variety of civil, military, and industrial applications.

The use of aircraft has increased the productivity and profitability of aviation organizations. With the use and application of modern technology in aviation organizations, speed of operation, quality, reliable transportation process, logistics, etc. factors are developed.

In addition, due to the wide global competitive market, it becomes very difficult for aviation companies and organizations to choose the most suitable aircraft for their requirements. The key point in the selection process of an aircraft is the determination of evaluation attributes according to the needs of the work.

These attributes are divided into two categories beneficial and non-beneficial, utility attributes must be of high value, and conversely, non-beneficial attributes must have low values, e.g., cost provides non-benefit, thus requiring the least value, and reliability is the benefit attribute, thus requiring the highest value.

In decision making environment, there are many MCDMA methodologies for selecting suitable commercial aircraft. A number of MCDMA techniques and evaluation criteria were applied in aircraft type selection problems. Various MCDMA methods were proposed to deal with complex decision problems, such as Additive Weighted Model (AWM)[1-5], Multiplicative Weighted Model (MWM)[6], Analytical Hierarchy Process (AHP)[7-9], Composite Programming[10-11], Compromise Programming [11-14], Entropic Programming [15], Preference Analysis for Reference Ideal Solution (PARIS) [16-20], ELimination Et Choix Traduisant la REALité (ELECTRE) [21-22], Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) [23-27], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)[28-34], VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [35-37]. Uncertainty in decision making processes is often modeled using fuzzy [38-47], intuitionistic [48], neutrosophic [50], and plithogenic [51-52] decision analysis methods. In addition, the importance weights of criteria are objectively computed using the entropy method in multiple criteria decision analysis processes [53].

In this paper, decision uncertainty distance (DUD) is proposed as a multiple criteria decision making analysis (MCDMA) method for the classification and selection of aircraft. DUD is a compensatory method in which the criteria are independent, the qualitative attributes are converted into quantities for evaluation by the DUD, the decision matrix identifies the input information and using this method an aircraft is selected for a civil aviation company. DUD was developed as an aircraft selection methodology, taking into account the uncertainty of the distance value of several alternatives being evaluated simultaneously.

The DUD method stands out because its solution is obtained from the distance solution, which eliminates the risk of unfairness to an alternative by the experts. Simplicity and the need for less computation are the most important features of the DUD method. The entropy weighting method (EWM) has had great success in practice because of its consistency and solid results. Similarly, the application of the DUD method is also very advantageous due to its simplicity and robustness. Therefore, it is advantageous to integrate EWM with DUD method as EWM is more applicable and more consistent for weight calculation and DUD method provides more stable results with lower computational cost.

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In this paper, the hybrid entropic DUD method is proposed for commercial aircraft selection. The purpose of this article is to provide a simple, reliable, and robust MCDMA methodology for commercial aircraft selection with less computational cost.

This is the original integrated EWM with the DUD method for the aircraft selection problem. The EWM method for weight calculations has three advantages: i) EWM gives consistent results, ii) requires less computation than other MCDMA methods, iii) it is reliable and logical to select the decision criteria and compare them with other criteria.

The DUD method is proposed and chosen for the aircraft selection problem because it is a new original method and requires a low computational cost compared to other MCDMA methods. The ranking results are compared with the TOPSIS method. Validity analysis shows that DUD and TOPSIS are more important for the aircraft selection process.

The presentation of the work is structured as follows: Section 2 introduces the representation of the decision uncertainty distance method, Section 3 presents the application of the MCDMA model, and finally, Section 4 concludes with recommendations.

II. METHODOLOGY

A. Fuzzy Logic and Fuzzy Set Theory

Fuzzy set theory is an extension of classical set theory in which elements have a certain degree of membership. In real life, human thought and reasoning (analysis, logic, interpretation) often contain fuzzy information (i.e. vague, uncertain, imprecise, etc.). Fuzzy logic emerged in the context of the theory of fuzzy sets, which was introduced by Lotfi Zadeh [54]. A fuzzy set assigns a degree of membership, typically a real number from the interval [0,1], to elements of a universe. Fuzzy logic arises by assigning degrees of truth to propositions.

A fuzzy set X on the universe of discourse $U = \{u_1, u_2, u_3, \dots, u_i\}$ is defined as follows:

$$X = \left\{ \langle u_i, \mu_X(u_i) \rangle / u_i \in U, 0 \leq \mu_X(u_i) \leq 1 \right\} \quad (1)$$

where

- $\mu_X(u_i) : X \rightarrow [0,1]$ is the membership function;
- U is a universal set or a set of considerations based on which a fuzzy set X is defined;
- $\mu_X(u_i)$ is a membership function of the element $u (u \in U)$ to the set X .

Fuzzy logic is used to convert qualitative measures into quantitative measures. Fuzzy set theory was first associated with fuzzy set theory and decision-making problems [55]. Uncertainty, vague and imprecise information about fuzzy MCDMA were combined using many robust and efficient techniques. Conversion of linguistic terms to fuzzy numbers first and then fuzzy numbers to crisp scores was proposed to effectively handle the decision-making process [56].

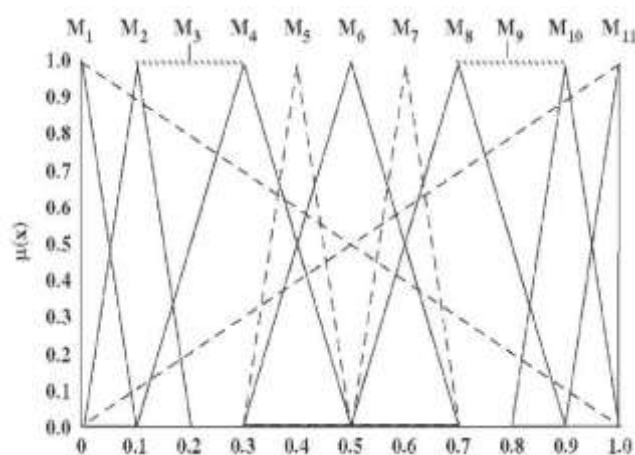


Fig. 1 Linguistic term into their corresponding fuzzy numbers (11-point scale)

Table 1. Conversion of linguistic terms into fuzzy scores (11-point scale)

Linguistic term	Fuzzy number	Crisp number
Exceptionally low	M1	0,045
Extremely low	M2	0,135
Very low	M3	0,255
Low	M4	0,335
Below average	M5	0,41
Average	M6	0,5
Above average	M7	0,59
High	M8	0,665
Very high	M9	0,745
Extremely high	M10	0,865
Exceptionally high	M11	0,955

In this paper, an 11-point scale was used to map the corresponding fuzzy numbers for the linguistic terms is shown in Fig. 1, and the fuzzy crisp score is shown in Table 1.

B. Entropy Weighting Method (EWM)

The entropy of the j th evaluation attribute is determined by the following algorithm:

Step 1. Calculation of the attribute's entropy

$$H_j = \frac{\sum_{i=1}^I f_{ij} \ln f_{ij}}{\ln I}, (i = 1, \dots, I; j = 1, \dots, J) \quad (2)$$

wherein;

$$f_{ij} = \frac{x_{ij}}{\sum_{i=1}^I x_{ij}}, (i = 1, \dots, I; j = 1, \dots, J) \quad (3)$$

Step 2. Calculation of the attribute's entropy weight

$$\omega_j = \frac{1 - H_j}{\sum_{j=1}^J (1 - H_j)}, \sum_{j=1}^J \omega_j = 1, (j = 1, \dots, J) \quad (4)$$

In information theory, the entropy weight (ω_j) represents useful information of the evaluation attribute. Therefore, the greater the entropy weight of the attribute, the more useful the information of the attribute is. The reverse is the same.

C. Decision Uncertainty Distance (DUD) Method

In the DUD method, the positive distance solution d_i^+ and the negative distance solution d_i^- are calculated, the optimal alternative d_i has a higher distance than the nadir solution and the lowest distance from the ideal solution. This method is useful for conflicting criteria and is valuable because it requires less computation.

Suppose that, given a set of alternatives I , $a_i = (a_{i1}, \dots, a_{ij})$, $i \in \{i = 1, \dots, I\}$, a set of criteria J , $g_j = (g_{j1}, \dots, g_{jI})$, $j \in \{j = 1, \dots, J\}$, and the importance weight of each criterion (ω_j , $j \in \{j = 1, \dots, J\}$) is known. The DUD method consists of the following steps.

Step 1. Selection of the most important criteria for the alternatives

Step 2. Construction of the decision matrix, $X = (x_{ij})_{ixj}$

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \\ \vdots \\ a_j \end{pmatrix} \begin{pmatrix} g_1 & \cdots & g_j \\ x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \quad (5)$$

where x_{ij} determines the performance value of i th alternative with respect to j th criterion.

Step 3. Determination of the mean solution and standard deviation to all criteria

$$\mu_j = \frac{1}{I} \sum_{i=1}^I x_{ij} \quad (6)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^I (x_{ij} - \mu_j)^2}{I}} \quad (7)$$

where μ_j determines the mean solution of j th criterion, and σ_j determines the standard deviation of j th criterion.

Step 4. The matrix d_{ij}^+ and d_{ij}^- are calculated according to the benefit and cost criteria as follows:

if j th criterion is beneficial,

$$d_{ij}^+ = \max \left(0, \frac{(x_{ij} - \mu_j)}{\sigma_j} \right) \quad (8)$$

$$d_{ij}^- = \max \left(0, 1 - \frac{(x_{ij} - \mu_j)}{\sigma_j} \right) \quad (9)$$

if j th criterion is cost,

$$d_{ij}^+ = \max \left(0, \frac{(\mu_j - x_{ij})}{\sigma_j} \right) \quad (10)$$

$$d_{ij}^- = \max \left(0, 1 - \frac{(\mu_j - x_{ij})}{\sigma_j} \right) \quad (11)$$

where d_{ij}^+ and d_{ij}^- denote the positive distance and the negative distance of i th alternative from mean solution in terms of j th criterion, respectively.

Step 5. Determination of the weighted sum of d_i^+ and d_i^-

$$d_i^+ = \sum_{j=1}^J \omega_j d_{ij}^+ \quad (12)$$

$$d_i^- = \sum_{j=1}^J \omega_j d_{ij}^- \quad (13)$$

Step 6. Calculation of the relative degree of approximation

$$d_i = \frac{d_i^+}{d_i^+ + d_i^-}, (0 \leq d_i \leq 1, i = 1, \dots, I) \quad (14)$$

The decision uncertainty distance (DUD) method requires that the evaluation alternative is ranked by the value of its relative degree of approximation. The larger the value, the better the evaluation alternative.

In this paper, the EWM technique is integrated with DUD and TOPSIS methods. Weights derived using EWM are used to make priority ranking of aircraft using DUD and TOPSIS methods.

D. TOPSIS Method

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

Step 1. The construction of a decision matrix

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \\ \vdots \\ a_I \end{pmatrix} \begin{pmatrix} g_1 & \cdots & g_j \\ x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \\ \vdots & \ddots & \vdots \\ x_{I1} & \cdots & x_{Ij} \end{pmatrix}_{ixj} \quad (15)$$

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 .

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

For benefit criteria

$$r_{ij} = \frac{x_{ij}}{x_j^{\max}}, \quad i = 1, \dots, I, j = 1, \dots, J \quad (16)$$

For cost criteria

$$r_{ij} = \frac{x_j^{\min}}{x_{ij}}, \quad i = 1, \dots, I, j = 1, \dots, J \quad (17)$$

Step 3. Calculation of the weighted normalized values

$$v_{ij} = \omega_j r_{ij} \quad (18)$$

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

$$a_i^+ = \{v_1^+, \dots, v_j^+\} = \{(max_i v_{ij} | j \in B), (\min_i v_{ij} | j \in C)\} \quad (19)$$

$$a_i^- = \{v_1^-, \dots, v_j^-\} = \{(max_i v_{ij} | j \in B), (\min_i v_{ij} | j \in C)\} \quad (20)$$

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

$$d_i^+ = \sqrt{\sum_{j=1}^J (v_{ij} - v_j^+)^2} \quad (21)$$

$$d_i^- = \sqrt{\sum_{j=1}^J (v_{ij} - v_j^-)^2} \quad (22)$$

Step 6. Calculation of the closeness coefficient d_i of each alternative

$$d_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (23)$$

Step 7. Rank the alternatives in decreasing order of the closeness coefficient values d_i

III. APPLICATION

In this section, the selection of commercial aircraft is quantitatively carried out using DUD and TOPSIS methods.

i) By DUD algorithm:

Step 1. The objective is ranking of aircraft based on seven attributes (Aircraft price (g_1), Environmental cost (g_2), Cost per available seat mile CASM (g_3), Seat capacity (g_4), Baggage capacity (g_5), Aircraft Speed (g_6), Maximum take-off weight MTOW (g_7). Aircraft price, Environmental Cost, and CASM attributes are the nonbeneficial attributes, i.e. lower values are desired. Seat capacity, Baggage capacity, Aircraft Speed, MTOW attributes are the beneficial attributes, i.e. higher values are desired.

Table 2. Initial decision matrix

a_i	DM	g_1	g_2	g_3	g_4	g_5	g_6	g_7
	1	0,665	0,745	0,59	0,865	0,745	0,665	0,865
a_1	2	0,745	0,41	0,5	0,745	0,865	0,665	0,745
	3	0,59	0,335	0,665	0,59	0,59	0,745	0,745
	1	0,865	0,255	0,41	0,745	0,335	0,745	0,665
a_2	2	0,41	0,41	0,865	0,745	0,59	0,665	0,41
	3	0,335	0,335	0,255	0,665	0,745	0,745	0,59
	1	0,59	0,955	0,335	0,335	0,665	0,5	0,865
a_3	2	0,665	0,045	0,255	0,59	0,59	0,59	0,59
	3	0,335	0,135	0,135	0,41	0,335	0,41	0,665
	1	0,955	0,255	0,665	0,745	0,865	0,745	0,59
a_4	2	0,665	0,135	0,5	0,665	0,59	0,665	0,41
	3	0,335	0,045	0,745	0,41	0,665	0,59	0,745
	1	0,955	0,745	0,255	0,745	0,955	0,865	0,955
a_5	2	0,745	0,665	0,59	0,41	0,59	0,745	0,865
	3	0,335	0,135	0,745	0,59	0,335	0,665	0,59

Step 2. Convert qualitative attributes to their corresponding fuzzy number and then converted them to the crisp scores. The quantitative values of attributes are, given in fuzzy crisp

values, given in Table 2. The expert committee (decision makers (DMs), consisting of three people, evaluated 5 alternative aircraft according to 7 attributes.

Table 3. Combined ratings of DMs

a_i	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,218	0,266	0,234	0,238	0,233	0,211	0,229
a_2	0,175	0,178	0,204	0,233	0,177	0,219	0,162
a_3	0,173	0,202	0,097	0,144	0,168	0,152	0,206
a_4	0,213	0,078	0,254	0,197	0,224	0,203	0,169
a_5	0,221	0,276	0,212	0,189	0,199	0,215	0,234

Step 3. Calculate the mean solution μ_j and standard deviation σ_j of attributes.

Table 4. Calculated the mean solution μ_j and standard deviation σ_j of attributes.

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
μ_j	0,613	0,374	0,501	0,617	0,631	0,656	0,686
σ_j	0,073	0,149	0,153	0,117	0,089	0,089	0,114

Step 4. Objective importance weights of evaluation attributes are calculated by the entropy weighting method

Table 5. Calculated objective entropic criteria weights

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
H_j	0,996	0,955	0,973	0,991	0,995	0,995	0,993
$1-H_j$	0,004	0,045	0,027	0,009	0,005	0,005	0,007
ω_j	0,035	0,445	0,263	0,091	0,049	0,048	0,068

Step 5. Determine the weighted sums of d_i^+ and d_i^- , and relative degree of approximation d_i , and ranking R_i values

Table 6. Calculated values of d_i^+ , d_i^- , d_i and R_i

a_i	d_i^+	d_i^-	d_i	R_i
a_1	0,431	1,767	0,196	4
a_2	0,996	2,703	0,269	3
a_3	1,226	2,469	0,332	1
a_4	1,220	2,497	0,328	2
a_5	0,336	1,648	0,169	5

Step 6. Calculation of the relative degree of approximation

$$0 \leq d_i \leq 1 : R_i \rightarrow \{a_3 \succ a_4 \succ a_2 \succ a_1 \succ a_5\}$$

ii) By TOPSIS algorithm:

Step 1. Determine the normalized matrix

Table 7. Normalized decision matrix

a_i	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,795	0,292	0,413	1,000	1,000	0,963	0,977
a_2	0,988	0,435	0,474	0,980	0,759	1,000	0,691
a_3	1,000	0,383	1,000	0,607	0,723	0,696	0,880
a_4	0,813	1,000	0,380	0,827	0,964	0,928	0,724
a_5	0,781	0,282	0,456	0,793	0,855	0,981	1,000

Step 2. Determine the weighted normalized matrix

Table 8. Weighted normalized decision matrix

a_i	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a_1	0,028	0,130	0,109	0,091	0,049	0,047	0,067
a_2	0,035	0,193	0,125	0,089	0,037	0,048	0,047
a_3	0,035	0,170	0,263	0,055	0,036	0,034	0,060
a_4	0,029	0,445	0,100	0,075	0,047	0,045	0,050
a_5	0,028	0,125	0,120	0,072	0,042	0,047	0,068

Step 3. Calculate the ideal and anti-ideal solutions

Table 9. Calculated the ideal and anti-ideal solutions

	g_1	g_2	g_3	g_4	g_5	g_6	g_7
a^+	0,035	0,445	0,263	0,091	0,049	0,048	0,068
a^-	0,028	0,125	0,100	0,055	0,036	0,034	0,047

Step 4. Determine the Euclidean distance of alternatives from the ideal d_i^+ and anti-ideal d_i^- solutions, and relative degree of approximation, d_i and ranking Q_i values

Table 10. Calculated values of d_i^+ , d_i^- , d_i and Q_i

a_i	d_i^+	d_i^-	d_i	Q_i
a_1	0,480	0,096	0,166	4
a_2	0,425	0,151	0,262	3
a_3	0,347	0,229	0,398	1
a_4	0,210	0,366	0,636	2
a_5	0,497	0,078	0,136	5

Step 5. Calculation of the relative degree of approximation

$$0 \leq d_i \leq 1 : Q_i \rightarrow \{a_3 \succ a_4 \succ a_2 \succ a_1 \succ a_5\}$$

iii) Result and discussion:

Aircraft performance is affected by a variety of performance measures. The present study is considered quite important for aviation industries in evaluating aircraft performance, as it is highly recommended to perform in fierce competition, especially for the survival of an industry. A comparative study of MCDMA approaches such as a new original DUD integrated with EWM and TOPSIS for prioritizing performance measures in the aircraft selection process with linguistic qualitative data is discussed.

EWM is used to determine the weights of the performance measures in the DUD and TOPSIS approaches, to prioritize the performance criteria and to enable the management to make decisions about the aircraft evaluation. Here, fuzzy logic is used to transform qualitative measures into quantitative measures. The methodologies discussed here are useful for breakthrough improvement as well as for continuous improvement in organizations. First, qualitative measures are converted to corresponding fuzzy numbers and then converted to crisp values. Then, with the help of EWS methodology, the global weights of different conflicting measures are determined according to the objective, then DUD and TOPSIS are used.

Here, the measures affecting the performance of an aircraft selection problem are grouped into three categories: 'economic', 'environmental' and 'technical'. The DUD and TOPSIS methodologies reveal that evaluation measures have a significant impact on aircraft selection process. The methodologies presented in this paper can be used to aid in developing an appropriate strategy for evaluating aircraft performance based on the effectiveness of different categories of measures.

This will help decision makers infer the assessments they need in aircraft selection processes, as they evaluate the performance of aircraft in changing market conditions. The scores obtained with DUD and TOPSIS are shown in Table 10, and their comparative ranking prioritizations are shown in Table 11.

Finally, the comparative validity analysis shows that both the DUD and TOPSIS method have the same ranking patterns. This validity analysis confirms the robustness and effectiveness of the new original DUD method in the MCDMA environment.

Table 11. Comparison of DUD and TOPSIS ranking results

	DUD (R_i)	TOPSIS (Q_i)
a_1	4	4
a_2	3	3
a_3	1	1
a_4	2	2
a_5	5	5

IV. CONCLUSION

As unique contribution of this paper, a new original MCDMA 'decision uncertainty distance' (DUD) method was

introduced to select the best aircraft in the aircraft selection process. The performance of the aircraft selection problem is affected by various performance evaluation measures. It is therefore necessary to measure the impact of these measures on aircraft evaluation performance and to know the exact nature of these measures. The present work helps achieve these goals and objectives significantly. Various factors affecting the performance of the aircraft selection problem were identified and analyzed.

As theoretical and industrial managerial implications, the methodologies discussed here can be used to aid in developing an appropriate strategy for improving the performance of aircraft selection problems based on the effectiveness of different categories of measures. The procedure also helps to compare different industries in terms of their performance. The findings of this study have important industrial managerial significance. Management can gain better insights and guidelines to identify various decisions regarding the improvement of processes and operations to improve the performance of the aircraft selection process.

It is an effective tool for evaluating, classifying, comparing, and ranking aircraft performance. This will help aviation industrial managers understand the improvements they need in their aircraft selection processes if they want to improve performance considering changing market conditions.

As limitation of the work, aircraft performance is expressed in global composite score. This value also depends on the inheritance of the main measures that depend on its sub-measures. Therefore, the appropriate combination of measures and their sub-measures should be selected for the assessment of aircraft performance.

Understanding future research directions is crucial as the intense competition in the aviation industry leaves no room for decision inefficiencies, as the performance of the aircraft selection process plays a vital role in the survival of organizations in the global market.

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