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UAV Selection Using Fuzzy AHP and PROMETHEE Method

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Abstract

UAV (Unmanned Aerial Vehicle) is an aircraft that can fly by remote control or automated system and does not have the capacity to carry people. The optimal selection of UAVs is critical for the successful conduct of operations and the prevention of loss of life and property. The aim of this study is to prioritize the criteria affecting the selection of UAVs and to rank the Strategic UAVs based on these criteria. Thus, it is aimed to improve the UAV selection process of decision makers. As a result of the literature search, there were no studies on the most important criteria affecting the selection of operational, tactical and strategic UAVs. Therefore, Fuzzy AHP and PROMETHEE methods were applied to fulfill these objectives. As a result, it was determined that the most important criteria in the selection of UAVs are realizability, flight stability and payload success rate value.

1. Introduction

UAVs represent a class of unmanned, remotely controlled electro-mechanical flying devices characterized by autonomous or semi-autonomous operation (Mekdad et al. 2023). These vehicles, which vary in take-off weights and dimensions, are generally divided into three different groups as fixed-wing, rotary-wing and hybrid designs according to their rotor configurations (Elmeseiry, Alshaer, and Ismail 2021). UAVs are widely used in military fields due to their critical role in defense technology (Chaturvedi et al. 2019). The use of UAVs in surveillance, tactical reconnaissance and combat operations is becoming increasingly widespread due to their durability, low risk and cost-effectiveness (Hamurcu and Eren 2020). In addition to their single use, UAVs are increasingly used in swarms due to their many advantages (Erkec and Hajiyev 2020). The ability to visit different regions in different conditions is one of the most significant features of UAV (Tadić et al. 2024). UAVs also play important roles in firefighting; avalanche rescue and logistic support missions where traditional methods face difficulties caused by geographical constraints and adverse weather conditions (Mohd Noor, Abdullah, and Hashim 2018). UAVs are now smaller, faster, more competent, more precise, and more dependable than they were in the past due to a combination of rapid developments and technological advancements (Keleş 2024). Although UAVs were first created for military purposes, a wide range of civilian applications have recently surfaced, greatly expanding UAV capabilities at a lower cost (Wang et al. 2023).

As a result of research, Hamurcu and Eren (2020) emphasized the need for a systematic and effective approach for the selection of UAVs. This study proposes an integrated method based on analytical hierarchy process (AHP) and ranking by similarity to ideal solution (TOPSIS) methods, which are multi-criteria decision-making methods. With the use of these methods, UAV alternatives are effectively evaluated in the selection process (Hamurcu and Eren 2020). In Uçar, Adem, and Tanyeri (2022) study, the ideal engine selection problem for UAVs is focused and a solution is proposed for this problem using the Analytic Hierarchy Process (AHP) method. This is the first paper in the literature to address this problem and apply the AHP method to this problem. Furthermore, the proposed mechanism provides a decision support system for UAV manufacturers and users. This system is intended to help UAV users make the right choices by enabling them to evaluate the appropriate brand among performance and different criteria (Uçar, Adem, and Tanyeri 2022). In Ardil (2023) study, it is aimed to determine the most suitable UAV by considering various criteria. For this purpose, standard fuzzy set methodology and decision makers' selection criteria are used. A practical numerical example is presented to demonstrate the applicability of the proposed approach. A comparison was made between UAVs with different missions and the most suitable vehicle was selected (Ardil 2023). In Dagdeviren's study, an integrated approach for multi-criteria equipment selection was proposed and implemented using Analytic Hierarchy Process (AHP) and Preference Ranking Organization Method (PROMETHEE). The proposed method includes steps such as analyzing the equipment selection problem, determining the weights of the criteria and making the final ranking. The decision approach presented in this study involves the use of AHP and PROMETHEE combined decision-making methods to solve equipment selection problems (Dağdeviren 2008).

Therefore, the correct selection of UAVs is important for the successful completion of operations. The aim of this study is to prioritize the criteria affecting the selection of strategic UAVs and to rank the UAVs based on these criteria. Thus, it is aimed to improve the strategic UAV selection process and to help decision makers.

2. Methodology

2.1. Fuzzy AHP

Fuzzy AHP is a method used for decision-making processes in UAV selection by incorporating uncertainty (Sadiq and Tesfamariam 2009). The determination of criteria weights and values under fuzzy logic is the basis of this method. In this way, more effective results are obtained in complex and uncertain decision-making processes. Firstly, the matrix in Equation 1 is created as the numerical equivalent of the experts' evaluations.

$$A = [1 \; \alpha_{12} \cdots \alpha_{1n} \; \alpha_{21} \; 1 \cdots \alpha_{2n} \; \vdots \; \vdots \; \ddots \; \vdots \; \alpha_{n1} \; \alpha_{n2} \cdots 1\,] \tag{1}$$

1. Journal of Aviation, Journal of Aviation. Journal of Matrix A is reciprocal, if $\alpha_{ij} = 1 / \; \alpha_{ij}$ for each $1 \leq i,j \leq n.$
2. Matrix A is consistent if $\alpha_{ij} \cdot \alpha_{jk} = \alpha_{ik}$ for each $1 \leq i,j,k \leq n.$
3. If the condition in Case 2 is not valid, we can say that A is inconsistent.

In the classical AHP method, the consistency of A is measured by the consistency index (CI). In Equation 2, CI is calculated as follows (Ramík and Korviny 2010):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

The consistency of the decision is checked using the formula CR= CI / RI. RI values include the random consistency index listed in Table 1.

Table 1. Random consistency index

Matrix Size	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Random consistency index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The following procedure was used to measure the consistency of the matrices in Equation 3 (Sadiq and Tesfamariam 2009):

$$NI_n^{\sigma}(\hat{\mathrm{A}}) = \gamma_n^{\sigma} \cdot max_{i,j} \left\{ max \left\{ \left| \frac{w_i^L}{w_i^U} - a_{ij}^L \right|, \left| \frac{w_i^M}{w_i^M} - a_{ij}^M \right|, \left| \frac{w_i^U}{w_i^L} - a_{ij}^U \right| \right\} \right\}$$

$$\text{where}$$

$$\gamma_n^{\sigma} \cdot = \{ \frac{1}{max \left\{ \sigma - \sigma^{(2-\frac{2n}{n}}, \sigma^2 \left\{ \left(\frac{2}{n}\right)^{\frac{2}{n-2}} - \left(\frac{2}{n}\right)^{\frac{n}{n-2}} \right\} \right\}} \; \frac{1}{ax \left\{ \sigma - \sigma^{\left(2-\frac{2n}{n}\right)}, \sigma^2 - \sigma \right\}} \qquad otherwise. \tag{3}$$

While the index values are between 0 and 1, a value of 0 indicates that the matrix is completely consistent. Then, the triangular fuzzy numbers, which are the elements of the matrix, are treated with a pairwise comparison matrix. A triangular fuzzy number a is expressed by a triplet of natural numbers:

$$\tilde{\mathrm{A}} = \left((a_{11}^L; a_{11}^M; a_{11}^U) \cdots (a_{1n}^L; a_{1n}^M; a_{1n}^U) \; \vdots \; \ddots \; \vdots \; (a_{m1}^L; a_{m1}^M; a_{m1}^U) \cdots (a_{mn}^L; a_{mn}^M; a_{mn}^U) \right) \tag{4}$$

In particular, let Ã be an n × n matrix with triangular fuzzy elements. We say that A is reciprocal if the following condition is satisfied (Equation 5)

$$\hat{a}_{ij} = (a_{ij}^L; a_{ij}^M; a_{ij}^U) \; implies \; \hat{a}_{ij} = \left(\frac{1}{a_{ij}^U}; \frac{1}{a_{ij}^M}; \frac{1}{a_{ij}^L} \right) \; for \; all \; i,j = 1,2,\ldots,n \tag{5}$$

As in classical AHP, interval scale is used. The range of this scale is {1/9,1/8...,1/2,1, 2,...,8,9}.

Table 2. Linguistic variables

Linguistic Judgement	Value	Triangular Fuzzy Number	Inverse Triangular Fuzzy Correspondence
Equally Important	1	1, 1, 1	1, 1, 1
Medium Important	3	2, 3, 4	1/4, 1/3, 1/2
Strongly Significant	5	4, 5, 6	1/6, 1/5, 1/4
Very Strongly Important	7	6, 7, 8	1/8, 1/7, 1/6
Extremely Important	9	8, 9, 9	1/9, 1/9, 1/8

Fuzzy weights, $w_k = (w_k^L, w_k^M, w_k^U), k = 1,2, \dots, n$ is obtained by utilising Equation 6-8 (Pavel and Talašová 2016):

$$\mathrm{C}_{min} = \left\{ \frac{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{L}\right)^{1/n}} \right\} \text{ while } w_k^L = \mathrm{C}_{min} \cdot \frac{\left(\prod_{j=1}^{n} a_{kj}^{L}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}}, \tag{6}$$

$$w_k^M = \frac{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}, \tag{7}$$

$$\mathrm{C}_{max} = \left\{ \frac{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{U}\right)^{1/n}} \right\} \text{ while } w_k^L = \mathrm{C}_{min} \cdot \frac{\left(\prod_{j=1}^{n} a_{kj}^{U}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}}, \tag{8}$$

2.2. PROMETHEE

PROMETHEE method is used for comparing and ranking different alternatives. PROMETHEE evaluates the performance of UAVs according to specified criteria and determines the advantages and disadvantages of each UAV over the others.

$$max\{f_1(a), f_2(a), \dots, f_n(a) | a \in A| \} \tag{9}$$

Here A is a finite set of possible alternatives and fj denotes the n criteria to be maximized (Equation 9). For each alternative, fj(a) is an evaluation of this alternative. When comparing two alternatives a,b ϵ A, the outcome of these comparisons is expressed in terms of preference (Equation 10). Therefore, P is a preference function. The difference criterion between the evaluations of two alternatives (a and b) with respect to a given alternative becomes a preference function ranging from 0 to 1 (Equation 11).

$$P_{j(a,b)} = G_j\left[f_j(a) - f_j(b)\right], \tag{10}$$

$$0 \leq P_{j(a,b)} \leq 1, \tag{11}$$

Let fj(i) be the preference function associated with criterion i, where Gj is a non-decreasing function of the observed deviation (d) between fj(a) and fj(b) (Equation 10). PROMETHEE requires the calculation of the following values for each alternative a and b (Equations 12-15):

$$\pi(a,b) = \frac{\sum_{j=1}^{n} \omega_j P_{j(a,b)}}{\sum_{j=1}^{n} \omega_j}, \tag{12}$$

$$\phi^{+}(a) = \sum_{x \in A} \pi(a,x), \tag{13}$$

$$\phi^{-}(a) = \sum_{x \in A} \pi(a,x), \tag{14}$$

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{15}$$

For each alternative a belonging to the set of alternatives A, π (a, b) is the overall preference index of a with respect to b (Equation 12). $\phi^{+}(a)$ The outflow expresses how a dominates all other alternatives of A (Equation 13). Symmetrically, the input flow $\phi^{-}(a)$, expresses how a is dominated by all other alternatives of A (Equation 14). ϕ(a) is called the net flow (Equation 15).

3. Findings

3.1. Determination of Criteria

The criteria considered in the selection of strategic UAVs play a critical role in the decision-making process. Based on the recommendations of experts, it has been determined that 9 criteria are decisive in the selection of Strategic UAVs. Table 3 shows these criteria.

Table 3. UAV selection criteria

Code	Criteria
D1	Maximum Take-off Weight
D2	Range
D3	Cost per Hour
D4	Fuel Capacity
D5	Success Rate Value of Load
D6	Maintenance and Repair Requirement
D7	Spare Parts Supply
D8	Realizability
D9	Flight Stability

An explanation of why these criteria are important in UAV selection is given below:

Range refers to the maximum distance the UAV can cover during a single operation and is important for operational flexibility. The cost per hour provides an hourly calculation of the UAV's operation and maintenance costs and helps to evaluate its long-term cost-effectiveness. Fuel capacity determines the amount of fuel that the UAV can carry for the maximum duration and distance that it can fly in a single flight. The payload success rate value expresses the relationship between the amount of payload the UAV can carry and its success rate and determines the importance in completing the mission. Maintenance and repair requirements determines the need for regular maintenance and repair of the UAV and is an important factor affecting operational efficiency. Spare parts procurement ensures that the spare parts required for the UAV to be continuously operational are provided in a timely and appropriate manner. Realizability refers to the ability of the UAV to be produced and developed on site, to meet operational requirements and to be used effectively in real-world conditions. Flight stability refers to the UAV's ability to remain in the air in a stable manner and to successfully perform targeted flights. The values of these criteria on UAVs are shown in the table below (Table 4)

Table 4. Criteria values of strategic UAVs

Alternatives	D1	D2	D3	D4	D5	D6	D7	D8	D9
SUAV1	3300	6500	1278	5000	0.62	0.40	0.70	0.76	0.61
SUAV2	25000	6000	2290	6500	0.76	0.27	0.79	0.43	0.53
SUAV3	20215	4100	3289	3640	0.74	0.39	0.66	0.65	0.43
SUAV4	4200	4000	3800	4782	0.42	0.42	0.74	0.86	0.45
OUAV1	3250	200	1303	3161	0.42	0.24	0.50	0.63	0.22
OUAV2	6000	1000	3573	3296	0.63	0.44	0.59	0.92	0.70
OUAV3	20200	930	2198	7257	0.89	0.32	0.59	0.65	0.45
OUAV4	1633	2575	1050	1081	0.53	0.50	0.39	0.54	0.61
TUAV1	8255	2500	1636	4600	0.79	0.45	0.69	0.46	0.81
TUAV2	21315	3850	5686	8300	0.57	0.69	0.88	0.36	0.42
TUAV3	4860	1852	3500	1800	0.46	0.23	0.66	0.72	0.34
TUAV4	720	3700	1250	300	0.61	0.31	0.53	0.94	0.78

3.2. Creation of Fuzzy Matrix

The experts were asked to compare the 9 Strategic UAV criteria with each other. These experts consisted of academicians and field experts working on UAVs.

Table 5. Comparative fuzzy matrix (average)

	D1	D2	D3	D4	D5	D6	D7	D8	D9
D1	1 1 1	0.488 0.582 0.715	2.491 3.160 3.776	1.149 1.380 1.683	0.218 0.281 0.401	0.574 0.803 1.149	0.574 0.803 1.149	0.201 0.254 0.349	0.218 0.281 0.401
D2	1.398 1.719 2.048	1 1 1	2.491 3.160 3.776	2.000 2.667 3.288	0.330 0.415 0.574	1.149 1.380 1.644	0.660 0.859 1.149	0.280 0.339 0.435	0.435 0.517 0.660
D3	0.265 0.316 0.401	0.265 0.316 0.401	1 1 1	0.574 0.678 0.803	0.265 0.316 0.401	0.530 0.582 0.660	0.530 0.582 0.660	0.185 0.229 0.304	0.196 0.242 0.330
D4	0.597 0.725 0.871	0.305 0.375 0.500	1.246 1.476 1.741	1 1 1	0.244 0.281 0.349	0.530 0.582 0.660	0.561 0.644 0.758	0.244 0.281 0.349	0.175 0.214 0.280
D5	2.491 3.554 4.595	1.741 2.408 3.031	2.491 3.160 3.776	2.862 3.554 4.095	1 1 1	2.169 2.853 3.482	1.398 1.745 2.048	0.758 1.000 1.320	0.660 0.803 1.000
D6	0.871 1.246 1.741	0.611 0.725 0.871	1.516 1.719 1.888	1.516 1.719 1.888	0.287 0.351 0.461	1 1 1	0.758 0.889 1.084	0.218 0.281 0.401	0.287 0.351 0.461
D7	0.871 1.246 1.741	0.871 1.165 1.516	1.516 1.719 1.888	1.320 1.552 1.783	0.488 0.573 0.715	0.922 1.125 1.320	1 1 1	0.379 0.437 0.530	0.287 0.351 0.461
D8	2.862 3.936 4.983	2.297 2.954 3.565	3.288 4.360 5.404	2.862 3.554 4.095	0.758 1.000 1.320	2.491 3.554 4.595	1.888 2.290 2.639	1 1 1	0.871 1.000 1.149
D9	2.491 3.554 4.595	1.516 1.933 2.297	3.288 4.384 5.335	3.565 4.663 5.724	1.000 1.246 1.516	2.169 2.853 3.482	2.169 2.853 3.482	0.871 1.000 1.149	1 1 1

Table 5 shows the comparative fuzzy matrix obtained by taking the geometric mean of the experts' evaluations.

3.3. Determination of Weights

The weights obtained from the fuzzy comparison matrix are shown in Figure 1. Accordingly. it is determined that the most important criterion for strategic UAV selection is the realizability criterion (D8). while the second and third most important criteria are flight stability (D9) and payload success value (D5), respectively.

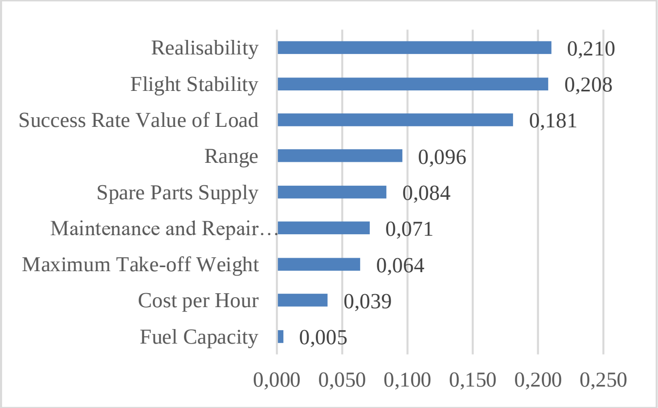

Figure 1. Ranking of UAV selection criteria

The reason why the most important criterion of UAV selection is the realizability criterion is to ensure mission continuity. Even if all other sub-criteria are positive in UAV operations, negative results in the realization of the flight and mission not only affect the entire UAV operation but also cause waste of effort (Erkec and Hajiyev 2020).

Table 6. Promethee flows (SUAV)

	ϕ^+	ϕ^-	ϕ net	Ranking
SUAV1	0.374	0.155	0.219	1
SUAV2	0.393	0.201	0.192	2
SUAV3	0.156	0.325	-0.169	3
SUAV4	0.161	0.402	-0.242	4

Table 6 shows the PROMETHEE flows. Accordingly, it is determined that the Strategic UAV with the highest net flow is SUAV1. Accordingly, it is determined that SUAV1 is the strategic UAV with the highest net flow. The reason for the selection of SUAV1 as the best strategic UAV is that it has significantly better performance in the range and cost per hour criteria compared to other strategic UAVs.

Table 7. Promethee flows (TUAV)

	ϕ^+	ϕ^-	**ϕ net**	**Ranking**
TUAV1	0.344	0.179	0.166	2
TUAV2	0.205	0.368	-0.163	3
TUAV3	0.135	0.408	-0.273	4
TUAV4	0.402	0.132	0.270	1

Table 7 shows the PROMETHEE flows. Accordingly, it is determined that the tactical UAV with the highest net flow is TUAV4. The reason for the selection of TUAV4 as the best tactical UAV is that it has significantly better performance in the range and realizability criteria compared to other tactical UAVs.

Table 8. Promethee flows (OUAV)

	ϕ^+	ϕ^-	**ϕ net**	**Ranking**
OUAV1	0.099	0.424	-0.325	4
OUAV2	0.399	0.132	0.266	1
OUAV3	0.344	0.149	0.195	2
OUAV4	0.188	0.325	-0.137	3

Table 8 shows the PROMETHEE flows. Accordingly, it is determined that the operational UAV with the highest net flow is OUAV1. The reason for the selection of OUAV1 as the best operational UAV is that it has significantly better performance in the realizability criterion compared to other operational UAVs.

4. Conclusion

In this study, the criteria affecting the selection of UAVs were identified, the importance of these criteria for UAVs was determined, and then the UAVs were ranked by making a sample application with the effect of these criteria. Accordingly, it was determined that the most important criteria in UAV selection are realizability, flight stability and success rate value of the payload. The least important criterion was determined to be fuel capacity. This study may contribute to improving and accelerate the decision-making process of decision makers when selecting a UAV.

The reason why range and cost-per-hour criteria stand out in strategic UAV selection is that long range increases operational effectiveness by covering large geographical areas, while low cost-per-hour reduces the total cost of operations and ensures financial sustainability. Long range increases operational flexibility by requiring less refueling and maintenance, while low cost allows for more and wider missions.

For tactical UAVs, range and realizability criteria are important as they enable effectiveness in short- and medium-range missions. Range extends the UAV's mission area, while realizability indicates its ability to be deployed quickly and flexibly. In tactical operations, these criteria assess the UAV's ability to adapt to different scenarios and perform various missions quickly and efficiently. In addition, it increases operational continuity and provides logistical advantages by working smoothly in maintenance and support processes.

In operational UAVs, the realizability criterion refers to the ability to perform various missions (intelligence, surveillance, reconnaissance, target designation) effectively and efficiently. This criterion is critical for the UAV's ability to respond quickly and adapt to different and emergency situations. Realizability refers to the UAV's reliability, low maintenance requirements and durability in long-term and uninterrupted operations. It also optimizes operational costs and resource utilization, enabling missions to be performed economically and efficiently.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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