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An Approach Utilizing The Intuitionistic Fuzzy TOPSIS Method To Unmanned Air Vehicle Selection

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Keywords
Intuitionistic Fuzzy Sets,
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TOPSIS,
Unmanned Air Vehicle(UAV)

Abstract — The intuitionistic fuzzy TOPSIS method is one of the popular multi-criteria decision making methods today, as it allows decision makers to reflect their views objectively. In this study, an intuitionistic fuzzy based decision making mechanism was created for the selection of UAVs, which have a very important place in today's military and civil sense. Experts in the field that is decision makers determined the criteria that are important in the selection of UAVs in this method. Afterward, they expressed their opinions about the UAVs to be evaluated according to these criteria, provided that each criterion is independent of each other. The most suitable UAV was selected among the target-oriented UAVs. The method used in the study and the mechanism established will shed light on many studies.

Subject Classification (2020): 03E72,90B50.

1. Introduction

UAV (Unmanned Aerial Vehicle) is air vehicles that are sent by a pilot on the ground and performed with remote control or that are automatically flown by uploading a previously made flight program. Very generally, it is collected in two main classes according to its technical features and usage purposes. According to their technical features; according to their weight, fuel/energy source, wing structure, automatic or remote control, etc. Moreover according to their intended use; military (reconnaissance and surveillance, target and weapon, attack, etc.) and civil (logistics, hobby, scientific and commercial) [19].
UAVs have played an active role in the tasks they have performed in the operational fields and as a developing technology with enormous potential, they have been indispensable in the execution of the duties of the navies. Unmanned aerial vehicles will also find use only if they gain an advantage over manned aircraft. Unmanned aerial vehicles operate in Dull, Dirty, Dangerous environments called 3D without endangering human life [22].

There are many studies on UAV and its selection in the relevant literature, such as UAVs sensors and applications for monitoring, selection of UAV for military fields, selection of UAV by using MCDM, selection

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using fuzzy Choquet integral,UAV selecting under group decision making, drone selection and evaluation using the interval-valued inferential fuzzy TOPSIS, algorithm in UAV formation network, classification of UAV vehicles, UAV landing, UAV history and legal status, electro-optical camera design for UAV, role of UAV, development of UAV, application of MCDM techniques in electro-optics and infrared sensor selection in UAV [1–4, 11, 11, 17, 19, 21–23, 25, 33].

Fuzzy logic, which reveals the feature of expressing the members even better with the rating method rather than just binary logic, was first defined by Zadeh ([40]). Furthermore, Atanassov described and developed intuitionistic fuzzy (IF) sets that are are a generalization of fuzzy sets ([5]). IF sets have shed light on many researchers because of their advantages such as membership degree and nonmembership degree, as well as expressing unstable states with hesitation degree. For a long time, multi-criteria decision making (MCDM) problems have been the focus of attention for all researchers. There are many MCDM methods defined so far ([24]). TOPSIS method is one of the MCDM methods. The TOPSIS method makes a ranking based on the positive ideal and negative ideal relationship [18]. In the IF TOPSIS method, this method is preferred because decision makers are free to express their ideas in linguistic terms. Many researchers have benefited from the TOPSIS method, fuzzy logic and intuitionistic fuzzy sets in theoretically and their application areas such as; supplier selection, renewable energy technologies, topology, algebra, statistics, controlled set, paper quality, education, mobile phone selection, etc. [7–10, 13–16, 20, 26, 27, 29–31, 34–36, 39]

2. Preliminaries

Definition 2.1. [5, 6] Let $X \neq \emptyset$. An intuitionistic fuzzy set A in X;

$$A = \left\{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X \right\},$$

$$\mu_A(x), \nu_A(x), \pi_A(x) : X \to [0, 1]$$

defined membership, nonmembership and hesitation degree of the element $x \in X$ respectively.

$$\mu_A(x) + \nu_A(x) + \pi_A(x) = 1.$$

IF TOPSIS model was presented an introduced by Rouyendegh (2015) ([28]). $A = A_1, A_2, \cdots, A_m$ is set of alternatives, $C = C_1, C_2, \cdots, C_n$ is set of criteria, and $L = l_1, l_2, \cdots, l_l$ is set of decision makers represents. The algorithm consists of seven steps as follows.

Step 1 The contribution of the decision-makers was determined thanks to IF numbers in Table 1 ([37]).

Table 1. Linguistic Terms for Rating DMs

Linguistic Terms	IFNs
Very Important (VI)	(0.80,0.10)
Important (I)	(0.50,0.20)
Medium (M)	(0.50,0.50)
Bad (B)	(0.30,0.50)
Very Bad (VB)	(0.20,0.70)

$Dl = [\mu l, \nu l, \pi l]$ is the IFN for lth DM ranking. As DMs express their opinions, their own weight of importance is assigned. It is expressed by the formula:

$$\lambda l = \frac{[\mu l + \pi l(\frac{\mu l}{\mu l + \nu l})]}{\sum_{l=1}^{k}[\mu l + \pi l(\frac{\mu l}{\mu l + \nu l})]} \tag{2.1}$$

$\lambda 1 \in [0,1]$ and $\sum_{l=1}^{k} \lambda l = 1$.

Step 2 The importance of criterion is represented as linguistic terms in Table 2.

Table 2. Linguistic Terms for Rating the Criterion

Linguistic Terms	IFNs
Very Important (VI)	(0.90,0.10)
Important (I)	(0.75,0.20)
Medium (M)	(0.50,0.45)
Unimportant (U)	(0.35,0.60)
Very Unimportant (VU)	(0.10,0.90)

The IF weighted averaging (IFWA) operator is used to calculate the weights of the criterion. The IFWA operator is developed by Xu (2007)[38]. According to linguistic terms in Table 2, the weight of criteria is calculated as:

$$\begin{aligned} w_j = & IFWAr_\lambda(w_j^{(1)}, w_j^{(2)}, \ldots, w_j^{(l)}) = \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \oplus, \ldots, \lambda_k w_j^{(k)} \\ = & \left[1 - \prod_{l=1}^{k}(1-\mu_{ij}^{(l)})^{\lambda l}, (\prod_{l=1}^{k} \nu_{ij}^{(l)})^{\lambda l}, \prod_{l=1}^{k}(1-\mu_{ij}^{(l)})^{\lambda l} - (\prod_{l=1}^{k} \nu_{ij}^{(l)})^{\lambda l}\right] \end{aligned} \tag{2.2}$$

Step 3 Using the linguistic terms in Table 3, the alternatives are evaluated individually for all criteria by each decision maker. At the end of this evaluation, Intuitionistic Fuzzy Decision Matrix (IFDM) is obtained.

Table 3. Linguistic Terms for Rating the Alternatives

Linguistic Terms	IFNs
Very Good (VG)	(1.00,0.00)
Good (G)	(0.85,0.05)
Medium Good (MG)	(0.70,0.20)
Fair (F)	(0.50,0.50)
Medium Poor (MP)	(0.40,0.50)
Poor (P)	(0.25,0.60)
Very Poor (VP)	(0.00,0.90)

Aggregated Intuitionistic Fuzzy Decision Matrix (AIFDM) is obtained as follows:

$$R^{(l)} = (r_{ij}^{(l)})_{m*n} \text{is the IFDM of each DM.}$$
$$\lambda = \lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_k \text{is the weight of the DM.}$$
$$R = (r_{ij})_{m' \times n'}$$
$$\begin{aligned} r_{ij} &= IFWAr_{\lambda}(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(k)}) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus, \ldots, \lambda_k r_{ij}^{(k)} \\ &= \left[1 - \prod_{l=1}^{k} (1 - \mu_{ij}^{(l)})^{\lambda l}, (\prod_{l=1}^{k} \nu_{ij}^{(l)})^{\lambda l}, \prod_{l=1}^{k} (1 - \mu_{ij}^{(l)})^{\lambda l} - (\prod_{l=1}^{k} \nu_{ij}^{(l)})^{\lambda l} \right] \end{aligned} \tag{2.3}$$

Step 4 S matrix is obtained as follows:

$$S = R \times W \tag{2.4}$$
$$R \otimes W = (\mu'_{ij}, \nu'_{ij}) = \{< x, \mu_{ij} \times \mu_j, \nu_{ij} + \nu_j - \nu_{ij} \times \nu_j >\} \tag{2.5}$$

Step 5 Positive and negative ideal solutions vary according to the criteria and alternatives. The ideal solution approach; the closer an alternative is to the positive, the farther from the negative, which represents the best alternative for the decision-maker. In this step, positive and negative ideal solutions are calculated. The IF positive and negative ideal solutions, A^+ and A^- respectively, in which J_1:benefit and J_2: cost criteria; are determined as follows:

$$A^+ = (r_1'^*, r_2'^*, \ldots, r_n'^*), r_j'^* = (\mu_j'^*, \nu_j'^*, \pi_j'^*), j = 1, 2, \ldots, n \tag{2.6}$$
$$A^- = (r_1'^-, r_2'^-, \ldots, r_n'^-), r_j'^- = (\mu_j'^-, \nu_j'^-, \pi_j'^-), j = 1, 2, \ldots, n \tag{2.7}$$

where

$$\mu_j'^* = \{(\max_i\{\mu'_{ij}\} j \in J_1), (\min_i\{\mu'_{ij}\} j \in J_2)\} \tag{2.8}$$
$$\nu_j'^* = \{(\min_i\{\nu'_{ij}\} j \in J_1), (\max_i\{\nu'_{ij}\} j \in J_2)\} \tag{2.9}$$
$$\mu_j'^- = \{(\min_i\{\mu'_{ij}\} j \in J_1), (\max_i\{\mu'_{ij}\} j \in J_2)\} \tag{2.10}$$
$$\nu_j'^- = \{(\max_i\{\nu'_{ij}\} j \in J_1), (\min_i\{\nu'_{ij}\} j \in J_2)\} \tag{2.11}$$

Step 6 The separation measures between the alternatives are determined. Many distance measures were defined on intuitionistic fuzzy sets ([32],[12]). In this step of the study, unlike other methods, the normalized Hamming measure was used. Studies have shown that the normalized Hamming measure is the most sensitive measure of distance compared to other distance measures. Therefore, in this study, the normalized Hamming distance measure will be used when calculating positive and negative ideal solutions. Through the positive and negative ideal solutions, S_i^+ and S_i^-, respectively, the separation measures of the alternatives are calculated.

$$S_i^+ = \frac{1}{2n}\sum_{i=1}^{n}[| \mu'_{ij} - \mu'^*_{ij} | + | \nu'_{ij} - \nu'^*_{ij} | + | \pi'_{ij} - \pi'^*_{ij} |] \quad (2.12)$$

$$S_i^- = \frac{1}{2n}\sum_{i=1}^{n}[| \mu'_{ij} - \mu'^-_{ij} | + | \nu'_{ij} - \nu'^{*-}_{ij} | + | \pi'_{ij} - \pi'^-_{ij} |] \quad (2.13)$$

Step 7 In the last step, the coefficient of closeness with respect to the positive and negative ideal solutions is calculated by the formula 2.14:

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}, \text{and} 0 \leq C_i^* \leq 1 \quad (2.14)$$

The resulting value is sorted from largest to smallest. A larger C_i^* value indicates better alternative. The hierarchy for the UAV selection decision mechanism is as follows:

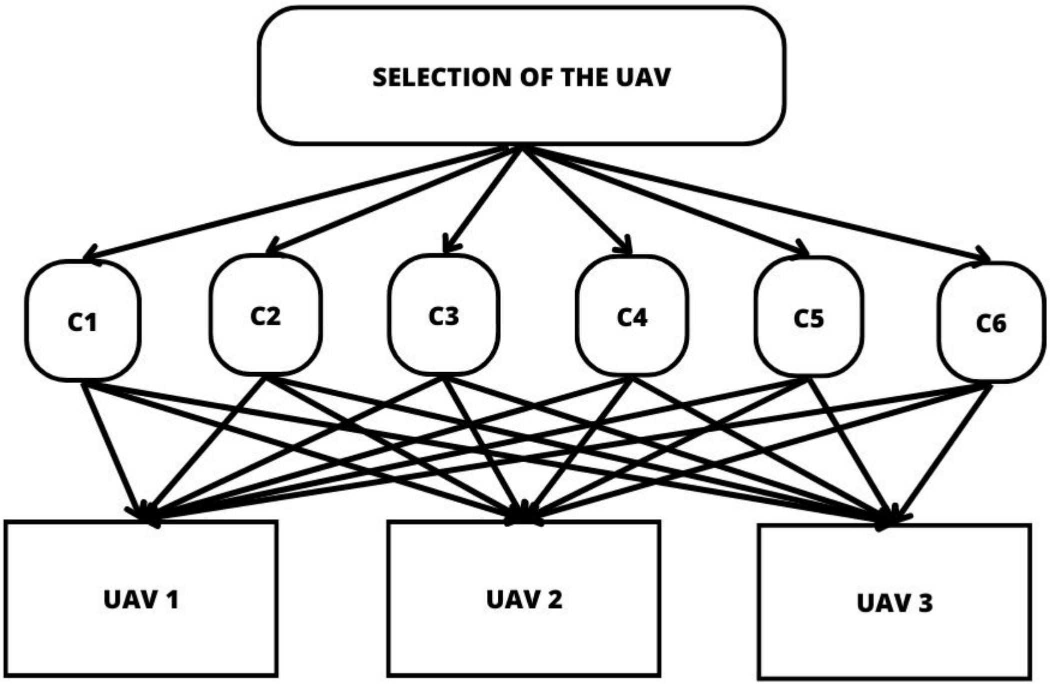

Figure 1. Hierarchy for the UAV selection decision mechanism

3. Selection of UAV Utilizing the Intuitionistic Fuzzy TOPSIS Method

UAVs play a very important role because of their benefits such as low fuel and flight costs, no risk of loss of life, less exposure to weather conditions, working at any time of the day, and scanning more areas. It is very important to determine purpose-oriented criteria when choosing a UAV. The criteria to be considered in the selection of UAVs were determined by the decision makers consisting of experts in the field of UAV. Afterwards, UAVs were evaluated according to the criteria determined by the decision makers. Decision makers first evaluated the criteria using linguistic terms and then evaluated the alternatives one by one independently for all criteria. $U = \{UAV_1, UAV_2, UAV_3\}$ is set of alternatives. Alternatives represent different sensors. $C = \{C_1, C_2, C_3, C_4, C_5, C_6\}$ is set of criteria. All criteria in this study were evaluated independently of each other. The classification of the criteria is as follows:

- C_1 : Performance
- C_2 : Cost
- C_3 : Power
- C_4 : Height
- C_5 : Durability
- C_6 : Weight

In this study, the opinions of 2 decision makers were consulted while using the intuitionistic fuzzy TOPSIS method. The importance of the contribution of decision makers;DM_1 is very important and DM_2 is important according to Table 1. Equation 2.1 is used when calculating the contributions of decision makers. As to; numerical values of DM_1, DM_2's importance weight are 0,554 and 0,446 respectively. Furthermore both decision makers specified the same linguistic terms when determining the importance of the criteria and showed in Table 4.

Table 4. Importance Weights of Criteria as to Decision Makers

Criteria	DM_1	DM_2
C_1	VI	VI
C_2	VI	VI
C_3	I	I
C_4	M	I
C_5	I	I
C_6	I	VI

According to the results obtained by using the values in the Table 4 and Equation 2.2; the weights of the criteria are shown in the Table 5. The importance of the alternatives for each criterion has been determined by the decision makers according to the linguistic expressions in Table 3 and has shown in Table 5.

Table 5. Values of Alternatives for Criteria

	DM_1						DM_2					
	C_1	C_2	C_3	C_4	C_5	C_6	C_1	C_2	C_3	C_4	C_5	C_6
UAV_1	MG	F	P	MG	MP	MP	MP	P	F	MG	MP	P
UAV_2	MG	MP	F	MG	MG	F	MP	F	MP	F	MP	MP
UAV_3	G	G	MG	G	G	MG	MG	MG	G	MG	G	MG

R matrix was created with the help of Equation 2.3. Afterwards, the S matrix was obtained with the help of the Equation 2.4 and the S matrix was shown in Table 6.
The positive ideal A^+ and negative ideal A^- solutions were calculated with the help of Equation 2.6 and shown in Table 7.

Table 6. S Matrix

	C_1	C_2	C_3	C_4	C_5	C_6
UAV_1	(0.532,0.371)	(0.361,0.588)	(0.281,0.643)	(0.443,0.451)	(0.300,0.600)	(0.281,0.609)
UAV_2	(0.532,0.371)	(0.402,0.550)	(0.343,0.600)	(0.394,0.521)	(0.444,0.441)	(0.382,0.573)
UAV_3	(0.716,0.183)	(0.716,0.183)	(0.585,0.286)	(0.504,0.377)	(0.638,0.240)	(0.584,0.317)

Table 7. The IF Positive and Negative Ideal Solution

	C_1	C_2	C_3	C_4	C_5	C_6
A^+	(0.72,0.18)	(0.72,0.18)	(0.58,0.29)	(0.51,0.37)	(0.64,0.24)	(0.58,0.32)
A^-	(0.53,0.37)	(0.36,0.58)	(0.28,0.64)	(0.39,0.52)	(0.30,0.60)	(0.28,0.60)

The separation measures S^+ and S^- of the alternatives calculated using the normalized Hamming measure and the closeness coefficient values were calculated in Table 8. In addition, the graphs of values were shown in Figure 2.

Table 8. Separation Measures and Closeness Coefficient Values

	S^+	S^-	C_i^*
UAV_1	0.2807	0.0115	0.0395
UAV_2	0.2445	0.0606	0.1986
UAV_3	0.0000	0.2923	1.0000

As a result of the evaluation made according to the opinions of the decision makers consisting of experts in the field with the intuitionistic fuzzy TOPSIS method, the ranking among the decision makers from the best to the worst is as follows:UAV_3-UAV_2-UAV_1 According to the result obtained in the decision making mechanism created, the best UAV is the UAV_3. It is recommended to select UAV_3 among the determined UAVs.

4. Conclusion and Suggestions

UAVs, which are non-pilot, remotely controlled by a pilot from the ground, or autonomously flying with various devices depending on the characteristics of the mission, have played an active role in the tasks they have performed in the operational fields and are developing technology with enormous potential. In addition, it has been indispensable in the execution of the duties of the navies. Using the intuitionistic fuzzy sets, membership, non-membership, and sensitivity degrees were all evaluated simultaneously. Thanks to the intuitionistic fuzzy TOPSIS method, the decision makers easily expressed their opinions in linguistic terms, which they had difficulty expressing with numerical values. In the study, 2 decision makers who are experts in their fields shared their views. Intuitionistic fuzzy TOPSIS method based decision making mechanism was created according to 6 criteria determined by the decision makers among a total of 3 UAVs. The most suitable UAV for the target was determined according to the decision making mechanism. Recently, the intuitionistic fuzzy TOPSIS method has attracted the attention of many researchers due to its

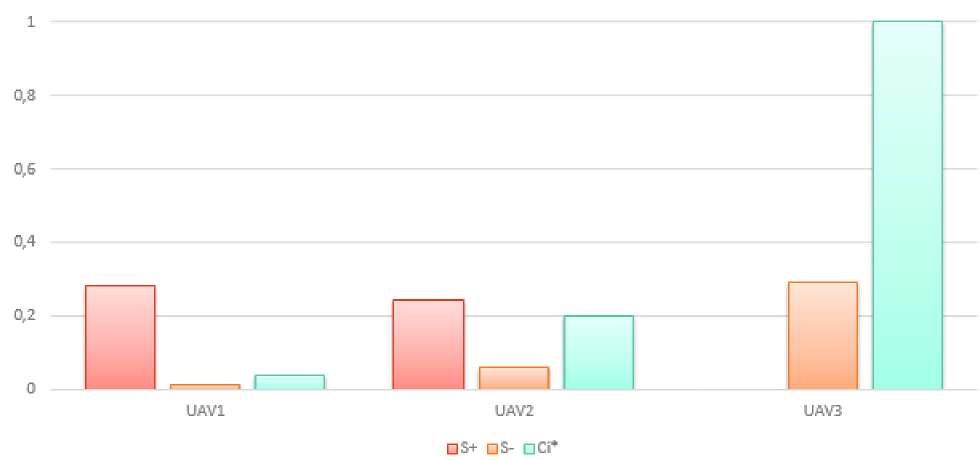

Figure 2. Graphic of values for the UAVs

advantages. UAV selection is a very important issue today. Instead of the intuitionistic fuzzy TOPSIS used in the study, evaluations may be made with different methods. The opinions of different experts may be consulted for the criteria. The range of UAVs to be evaluated may be expanded. This study, which will guide many researchers, has an important place for UAV selection. In addition to contributing to the literature in the future, it will give researchers a new perspective.

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