Neutrosophic TOPSIS Method for Technology Evaluation of Unmanned Aerial Vehicles (UAVs)

Ali Karaşan[1], İhsan Kaya[2]

[1]Institute of Natural and Applied Sciences, Yildiz Technical University, Davutpaşa, Istanbul, Turkey

[2]Department of Industrial Engineering, Yildiz Technical University, Yıldız, Beşiktaş, Istanbul, Turkey

akarasan@yildiz.edu.tr, ihkaya@yildiz.edu.tr

Abstract. The utilizations of Unmanned Aerial Vehicles (UAVs) have become increasingly more popular today and been successfully demonstrated for various civil and military applications. In these applications, one of the most critical issue is networking between UAVs and ground control points due to requirements of efficient control and sustainable path for data transmission. Since UAV nodes are extremely dynamic and provide a vast range of applications, selection process of the most appropriate network controller technology is extremely complex and can be considered as a multi-criteria decision making (MCDM) problem. In this paper, a neutrosophic TOPSIS method has been suggested to evaluate the network controllers and relays of the UAV alternatives. The proposed methodology is applied for the evaluation of the most appropriate control technology for UAVs.

Keywords: Neutrosophic sets, neutrosophic TOPSIS, unmanned aerial vehicles, decision making.

1 Introduction

In the literature, published papers that have concentered for Unmanned Aerial Vehicles (UAVs) especially in control and navigation has enormously seen in recently [1-8]. There are several systems for the control and navigation such as visual control system, the tracking algorithm, and the fuzzy controllers [9]. These systems aim to give a quick response to the vehicles and greater mobility during a route planning or under manual control to execute assigned tasks. Since there have been numerous kinds of UAVs and controlling systems, compatibility between each other to get maximum efficiency is important.

In military, UAVs are used in extremely important missions and give a significant advantage over the enemy. These tasks can be summarized as surveillance, discovery, bombardment and destruction. While performing these tasks, the performances of the vehicles are evaluated within the limits of the vehicles and within the capacity limits. Also, there is a great deal of risk to those who have an active role during tasks. For example, if the enemy captures the vehicle, your greatest advantage may turn into your enemy's weapon with the reverse engineering. The capturing is connected with the unauthorized access by the enemy to the control system of the UAV. This yields how important the control systems are for the safety as well as the impact on the efficiency of the vehicle.

In this study, control technology evaluation of unmanned aerial vehicles (UAVs) is studied by applying one of the most important MCDM techniques named TOPSIS based on neutrosophic sets. For this aim, the TOPSIS method, the most used distance based multi criteria decision making (MCDM) method in the literature, is extended by neutrosophic sets to represent not only vagueness of the data but also the hesitancy of the decision maker consensus. To the best of our knowledge, neutrosophic TOPSIS method (N-TOPSIS) is the first time applied for the control technology evaluation of UAVs. The advantages of the applied method can be summarized as below:

- The method represents the both uncertainty and indeterminacy.
- This study can be explanatory work for the researchers who intends to research on this topic.
- The application can be extended by adding stakeholders from the defense industries for further studies to support decision making processes.

The rest of this paper has been organized as follows: In Section 2, a brief information about UAVs and the importance for military is briefly introduced. In Section 3, preliminaries of neutrosophic sets are briefly summarized. By the way interval-valued neutrosophic sets are presented. In Section 4, interval-valued neutrosophic TOPSIS and its steps are detailed. In Section 5, application is carried out and results are analyzed. The obtained results and further research suggestion for researchers have been indicated into Section 6.

2 Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs) defined as the vehicles that has not a pilot by the Global Air Traffic Management Operational Concept. UAVs are the aircrafts that are used for many purposes in civil and military aviation with many different shapes, sizes, configurations and characteristics. These purposes can be summarized as search and rescue missions, border surveillance, aerial mapping, agricultural imaging, and so on [10]. From this perspective, growing attention is being paid to the necessity of UAVs' autonomy in terms of navigation as well as in terms of energy, especially when acting in complex environments that consist of indoors and outdoors [11]. In spite of object detection and tracking are basic problems in vision systems for UAVs, there are some benefits of them such as increasing the inspection area size, covering a bigger area, detection and tracking [12]. To make use of them with the most advantageous way, controlling systems for UAVs are vital. There are several approaches in the literature for the controlling such as adaptive systems [13], artificial neural networks [14], evolutionary algorithms [15], fuzzy logic and fuzzy inference systems [12, 16].

3 Neutrosophic Sets

3.1. Preliminaries: Neutrosophic Sets

Definition 1. Let E be a universe. A single valued neutrosophic set $\tilde{\ddot{A}}$ in E is defined as in Eq. (1) [23]:

$$\tilde{\ddot{A}} = \{< x, (T_{\tilde{\ddot{A}}}(x), I_{\tilde{\ddot{A}}}(x), F_{\tilde{\ddot{A}}}(x)) >: x \in E, (T_{\tilde{\ddot{A}}}(x), I_{\tilde{\ddot{A}}}(x), F_{\tilde{\ddot{A}}}(x) \in [0,1]\} \quad (1)$$

where $T_{\tilde{\ddot{A}}}$ is a truth-membership function; $I_{\tilde{\ddot{A}}}$ is an indeterminacy-membership function, and $F_{\tilde{\ddot{A}}}$ is a falsity-membership function, and $T_{\tilde{\ddot{A}}}(x); I_{\tilde{\ddot{A}}}(x)$ and $F_{\tilde{\ddot{A}}}(x) \in [0,1]$. The sum of these elements is as follows:

$$0 \leq T_{\tilde{\ddot{A}}}(x) + I_{\tilde{\ddot{A}}}(x) + F_{\tilde{\ddot{A}}}(x) \leq 3.$$

3.2. Preliminaries: Interval-Valued Neutrosophic Sets

Definition 2. $\tilde{\ddot{x}}_j = \langle [T_j^L, T_j^U], [I_j^L, I_j^U], [F_j^L, F_j^U] \rangle$ is a collection of interval-valued neutrosophic numbers where $j = 1,2,\dots,n$ [17].

Definition 3. The deneutrosophication function for an interval-valued neutrosophic number (IVNNs) is given in Eq. (2) [17]:

$$\mathfrak{D}(\tilde{\ddot{x}}_j) = \frac{(T_j^L + T_j^U + (1-F_j^L) + (1-F_j^U))}{4} * \left(\frac{(1-I_j^L) + (1-I_j^U)}{2}\right) \quad (2)$$

where $\tilde{\ddot{x}}_j = \langle [T_j^L, T_j^U], [I_j^L, I_j^U], [F_j^L, F_j^U] \rangle$.

Definition 4. Let $\tilde{\ddot{a}} = \langle [T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U] \rangle$ and $\tilde{\ddot{b}} = \langle [T_b^L, T_b^U], [I_b^L, I_b^U], [F_b^L, F_b^U] \rangle$ be two IVNNs. Addition and multiplication operations can be defined as follows [18]:

$$\tilde{\ddot{a}} \oplus \tilde{\ddot{b}} = \langle [T_a^L + T_b^L - T_a^L T_b^L, T_a^U + T_b^U - T_a^U T_b^U], [I_a^L I_b^L, I_a^U I_b^U], [F_a^L F_b^L, F_a^U F_b^U] \rangle \quad (3)$$

$$\tilde{\ddot{a}} \otimes \tilde{\ddot{b}} = \langle [T_a^L T_b^L, T_a^U T_b^U], [I_a^L + I_b^L - I_a^L I_b^L, I_a^U + I_b^U - I_a^U I_b^U], [F_a^L + F_b^L - F_a^L F_b^L, F_a^U + F_b^U - F_a^U F_b^U] \rangle \quad (4)$$

Definition 5. Let $\tilde{\ddot{a}} = \langle [T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U] \rangle$ and $\tilde{\ddot{b}} = \langle [T_b^L, T_b^U], [I_b^L, I_b^U], [F_b^L, F_b^U] \rangle$ be two interval-valued neutrosophic numbers. Subtraction operation for these numbers is defined by Eq. (5) [19]:

$$\tilde{\ddot{a}} \ominus \tilde{\ddot{b}} = \langle [T_a^L - T_b^U, T_a^U - T_b^L], [\mathrm{Max}(I_a^L, I_b^L), \mathrm{Max}(I_a^U, I_b^U)], [F_a^L - F_b^U, F_a^U - F_b^L] \rangle \quad (5)$$

Definition 6. The interval neutrosophic number weighted averaging operator (INNWA) is defined as in Eq. (6) [24]:

$$\mathrm{INNWA}A_w(A_1, A_2, \dots, A_n) = \begin{pmatrix} [1 - \prod_{i=1}^n (1 - infT_{A_i})^{w_i}, 1 - \prod_{i=1}^n (1 - supT_{A_i})^{w_i}], \\ [\prod_{i=1}^n Inf\ I_{A_i}^{w_i}, \prod_{i=1}^n Sup\ I_{A_i}^{w_i},], [\prod_{i=1}^n Inf\ F_{A_i}^{w_i}, \prod_{i=1}^n Sup\ F_{A_i}^{w_i},] \end{pmatrix} \quad (6)$$

where $W = (w_1, w_2, \cdots, w_n)$ is the weight vector of A_j $(j = 1,2,\dots,n)$ with $w_j \in [0,1]$ and $\sum_{j=1}^n w_j = 1$.

Definition 7. Let $\tilde{\tilde{a}} = \langle [T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U] \rangle$ and $\tilde{\tilde{b}} = \langle [T_b^L, T_b^U], [I_b^L, I_b^U], [F_b^L, F_b^U] \rangle$ be two IVNNs. The distance between two interval-valued neutrosophic numbers can be calculated as follows:

$$D\left(\tilde{\tilde{a}}, \tilde{\tilde{b}}\right) = \frac{1}{6}(|T_a^L - T_b^L| + |T_a^U - T_b^U| + |I_a^L - I_b^L| + |I_a^U - I_b^U| + |F_a^L - F_b^L| + |F_a^U - F_b^U|) \quad (7)$$

4 Neutrosophic TOPSIS

In this paper, a TOPSIS method based on neutrosophic sets have been suggested to determine the most appropriate control technology for UAVs. The method is introduced by integrating two neutrosophic TOPSIS methods [20, 21]. The details of the proposed method are as follows:

Step 1. Construct the neutrosophic decision-making matrix $(\tilde{\tilde{X}}_l)$ for decision makers as shown in Eq. (8):

$$\tilde{\tilde{X}}_l[\tilde{\tilde{x}}_{ijl}]_{n\times m} = \begin{bmatrix} \tilde{\tilde{x}}_{11l} & \cdots & \tilde{\tilde{x}}_{1ml} \\ \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{n1l} & \cdots & \tilde{\tilde{x}}_{nml} \end{bmatrix} \quad (8)$$

where $\tilde{\tilde{x}}_{ijl} = \langle [T_{ijl}^L, T_{ijl}^U], [I_{ijl}^L, I_{ijl}^U], [F_{ijl}^L, F_{ijl}^U] \rangle$ denotes the neutrosophic evaluation score of i^{th} $(i \in \{1,2,\dots,n\})$ alternative with respect to j^{th} criterion $(j \in \{1,2,\dots,m\})$ and l^{th} $(l \in \{1,2,\dots,q\})$ decision maker.

Step 2. Compute the aggregated neutrosophic decision matrix $(\tilde{\tilde{X}})$ by using Definition 6 as in Eq. (6):

$$\tilde{\tilde{X}}[\tilde{\tilde{x}}_{ij}]_{n\times m} = \begin{bmatrix} \tilde{\tilde{x}}_{11} & \cdots & \tilde{\tilde{x}}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{n1} & \cdots & \tilde{\tilde{x}}_{nm} \end{bmatrix} \quad (9)$$

where $\tilde{\tilde{x}}_{ij} = \langle [T_{ij}^L, T_{ij}^U], [I_{ij}^L, I_{ij}^U], [F_{ij}^L, F_{ij}^U] \rangle$ shows the aggregated neutrosophic score of i^{th} alternative with respect to j^{th} criterion.

Step 3. Obtain the neutrosophic weight of each criterion $(\tilde{w}_j)$ from each decision maker:

$$\tilde{\tilde{W}}_l = [\tilde{\tilde{w}}_{jl}]_{1\times m} \quad (10)$$

where $\tilde{\tilde{w}}_{jl}$ denotes the neutrosophic weight of j^{th} criterion $(j \in \{1,2,\dots,m\})$ with respect to l^{th} decision maker $(l \in \{1,2,\dots,q\})$,

Step 4. Compute the aggregated neutrosophic decision matrix $(\tilde{\tilde{W}})$ by using Definition 6 as in Eq. (6):

$$\tilde{\tilde{W}} = [\tilde{\tilde{w}}_j]_{1\times m} \quad (11)$$

where $\tilde{\tilde{w}}_j$ shows the average neutrosophic weight of j^{th} criterion.

Step 5. Calculate the neutrosophic weighted normalized decision matrix $(\tilde{R})$:

$$\tilde{\tilde{R}} = [\tilde{\tilde{r}}_{ij}]_{n\times m} \quad (12)$$

$$\tilde{\tilde{r}}_{ij} = \tilde{\tilde{w}}_j \otimes \tilde{\tilde{n}}_{ij} \quad (13)$$

Step 6. Obtain the interval-valued neutrosophic positive ideal solution (IVNPIS) $\tilde{\tilde{S}}^+$ and interval-valued neutrosophic negative ideal solution (IVNNIS) $\tilde{\tilde{S}}^-$ by using Eqs. (14) and (15):

$$\tilde{\ddot{S}}_i^{+} = [\max_i(T_i^L), \max_i(T_i^U)], [\min_i(I_i^L), \min_i(I_i^L)], [\min_i(F_i^L), \min_i(F_i^L)] \quad (14)$$

$$\tilde{\ddot{S}}_i^{-} = [\min_i(T_i^L), \min_i(T_i^U)], [\max_i(I_i^L), \max_i(I_i^L)], [\max_i(F_i^L), \max_i(F_i^L)] \quad (15)$$

Step 7. Calculate the distances by using Eq. (7) to obtain distances to IVNPIS (D_{PIS}) and IVNNIS (D_{NIS}) with respect to alternatives.

Step 8. Obtain the final scores by using Eq. (16) as follows (greater is better):

$$Score = \frac{D_{NIS}}{(D_{NIS}+D_{PIS})} \quad (16)$$

5 Application

In recent years, the usage of UAVs in different application areas has considerably increased, with a corresponding increase in the expectations from their autopilot systems. Capabilities of autopilot systems are important to successfully complete the mission of an UAV. A number of different autonomous capabilities may be required to be exhibited during a flight, like autonomous take off, navigation and autonomous landing [22]. In this paper, a MCDM methodology based on N-TOPSIS has been constructed for evaluation of the most appropriate control technology for UAVs. For this aim, firstly a Delphi method and literature review have been applied to determine criteria and alternatives. As a result, 6 criteria are determined and are listed as follows:

C1 – Effect on maximum distance
C2 – Weight
C3 – Effect on maximum altitude
C4 – Effect on velocity
C5 – Cyber security
C6 – Flexibility

By the way, 4 possible alternatives are determined for the evaluation process. The scales for alternatives and criteria are given in Tables 1 and 2, respectively.

Table 1. Linguistic table for scoring the alternatives

AL - Absolutely Low	<[0.05,0.2],[0.4,0.6],[0.85,1]>
VL - Very Low	<[0.15,0.3],[0.3,0.5],[0.75,0.9]>
L - Low	<[0.25,0.4],[0.2,0.4],[0.65,0.8]>
UA - Under Average	<[0.35,0.5],[0.1,0.3],[0.55,0.7]>
A - Average	<[0.45,0.6],[0,0.2],[0.45,0.6]>
AA - Above Average	<[0.55,0.7],[0.1,0.3],[0.35,0.5]>
H - High	<[0.65,0.8],[0.2,0.4],[0.25,0.4]>
VH - Very High	<[0.75,0.9],[0.3,0.5],[0.15,0.3]>
AH - Absolutely High	<[0.85,1],[0.4,0.6],[0.05,0.2]>

Table 2. Linguistic table for weighting the criteria

ALI - Absolutely Low Importance	<[0.05,0.25],[0.67,0.78],[0.75,0.95]>
VLI - Very Low Importance	<[0.15,0.35],[0.56,0.67],[0.65,0.85]>

LI - Low Importance	<[0.25,0.45],[0.44,0.56],[0.55,0.75]>
UAI - Under Average Importance	<[0.35,0.55],[0.33,0.44],[0.45,0.65]>
AI - Average Importance	<[0.4,0.6],[0.11,0.22],[0.4,0.6]>
AAI - Above Average Importance	<[0.45,0.65],[0.33,0.44],[0.35,0.55]>
HI - High Importance	<[0.55,0.75],[0.44,0.56],[0.25,0.45]>
VHI - Very High Importance	<[0.65,0.85],[0.56,0.67],[0.15,0.35]>
AHI - Absolutely High Importance	<[0.75,0.95],[0.67,0.78],[0.05,0.25]>

The decision matrices based on 3 decision makers who are experts on topic are constructed as shown in Table 3.

Table 3. Decision matrices based on experts' evaluation

		DM1 Weight			0.42	DM2 Weight			0.30	DM3 Weight			0.28
	Type	AL1	AL2	AL3	AL4	AL1	AL2	AL3	AL4	AL1	AL2	AL3	AL4
C1	Benefit	L	AH	AH	UA	AH	AA	AA	VL	H	UA	H	H
C2	Cost	L	UA	AH	VL	VH	VH	VH	L	L	A	UA	UA
C3	Benefit	UA	H	UA	H	AL	A	VL	A	VL	AH	A	VH
C4	Benefit	VL	VH	UA	L	VL	AL	UA	L	L	VH	A	VH
C5	Benefit	L	AL	L	UA	H	A	AL	L	AL	VL	L	AH
C6	Benefit	L	VH	A	L	L	H	L	VH	AL	UA	VL	AA

The weights of the criteria are calculated based on experts' judgments as shown in Table 4.

Table 4. Criteria Weights

	DM1	DM2	DM3
C1	AI	VLI	ALI
C2	VHI	AAI	LI
C3	VLI	AAI	AI
C4	LI	AI	AI
C5	HI	AAI	VLI
C6	AAI	UAI	HI

Through the calculations, the obtained results are presented in Table 5.

Table 5. Results of the application

	AL1	AL2	AL3	AL4
$\tilde{\tilde{S}}_i^{+}$	0.84	0.43	0.74	0.31
$\tilde{\tilde{S}}_i^{-}$	0.63	0.61	0.47	0.58
$Score$	0.43	0.59	0.39	0.65
Rank	3	2	4	1

According to Table 5, the alternative AL4 is determined as the most appropriate alternative for the controller technology of UAV with respect to selected criteria based on experts' judgments.

6 Conclusions

Today, unmanned aerial vehicles (UAVs) have a great potential in the arm industry for both defensive and attack aims. When UAVs' characteristics is analyzed, controlling of an UAV is counted as one of the most important aspect of these vehicles. In this paper, we investigated the several control technologies for UAVs with respect to determined criteria based on experts' evaluations by using interval-valued neutrosophic TOPSIS method. The criteria weights and decision matrices are determined by using linguistic scales. After that, these weights and matrices are converted to corresponded interval-valued neutrosophic numbers. Through the application the alternative AL4 is determined as the best alternative. To the best of our knowledge, this is the first study that compares the control technologies with the context of multi-criteria decision making (MCDM) methods. For further studies, this study can be a roadmap for the researchers who intends to work in this area with MCDM methods. Also, the study can be extended by adding stakeholders from the market and can be compared with different decision making techniques such as other MCDM methods, fuzzy inference system, and neural networks methods. By the way, a sensitivity analysis to check the robustness of the given decisions based on main criteria' weights changes can be managed.

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