

# **A HYBRIDIZED IT2FS-DEMATEL-AHP-TOPSIS MULTI-CRITERIA DECISION MAKING APPROACH: CASE STUDY OF SELECTION AND EVALUATION OF CRITERIA FOR DETERMINATION OF AIR TRAFFIC CONTROL RADAR POSITION**

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**Abstract:** *In this paper the criteria for selection of air traffic control (ATC) radar position that provide successfully fulfilled role of radar in air traffic management are determined and evaluated. Using the questionnaire, experts determined the initial criteria for selecting the radar position. Furthermore, the hybridized DEMATEL-AHP-TOPSIS model was modified by using the interval type-2 fuzzy sets (IT2FS). Less important criteria were eliminated by using the IT2FS-DEMATEL method, the prioritization of the final criteria was carried out by using the IT2FS-AHP method and a multi-criteria decision making model was proposed. Of the four ATC radar positions offered, the optimal position was selected by using the IT2FS-TOPSIS method. Validation of model was carried out by using Fuzzy and the IT2FS modified methods: TOPSIS, COPRAS and MABAC. A sensitivity analysis was carried out through 36 scenarios of changes in the criteria's weights.*

**Key words:** *AHP, Air Traffic Control Radar Position, DEMATEL, Interval Type-2 Fuzzy Sets, TOPSIS.*

## **1. Introduction**

The complexity of air traffic arises from the fact that it takes place in the third dimension of space (an air). Furthermore, air traffic's intensity and internationality, complexity of airspace routes and corridors, an organization's complexity and various types of aircrafts with visual flight's rules or instrumental flight's rules have a significant impact on air traffic flow management (Carey, 2019; Fleischer et al., 2019). All over the world, the crucial role in air traffic flow management has an air traffic control, whose functioning is impossible without logistical support in the form of ATC

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radars. In addition to the numerous advantages of this type of traffic, unfortunately, modern age also brings some new security risks for the air traffic (for example 9/11), which has become increasingly vulnerable to asymmetric threats. Some of the potential forms of air traffic violations are the hijacking of aircraft or terrorist attack from the airspace or from the ground (Petrović et al., 2015). In addition, the air traffic control has a very important role in preventing aircraft's accidents related with human mistakes or technical defects in the aircraft. The modern age is characterized by the possibility of using micro unmanned aerial vehicles (drones) whose purpose is to endanger air traffic (Bergen & Tiedemann, 2010). The technological development of modern multifunctional primary-secondary radars based on active phased array antenna system, as well as the active electronically scanned antenna system, provide high frequency radar agility and quick scanning of the airspace. Furthermore, these types of radars have a channel for weather forecast and modern modes of the moving target detector system and the sweeping of ground and airspace clutter due to bad meteorological conditions (Zhao & Yue, 2014). This is the consequence of modern technological solutions (on the radar and on the telecommunication system) based on which radar is collected and sent data, technical staff's abilities, and the selection of ATC radar position on the terrain.

The maximum utilization of all technical performance of the radar system, as well as the minimization of the possibility of attacking asymmetric threats from the airspace, should be ensured by the selection of the optimal radar position. The selection of radar position is especially significant from the aspect of reducing the possibility of using unmanned aerial vehicles for endangering the safety of air traffic, because they mostly fly at low altitudes and have a small radar cross section.

Determination of the radar position implies researching all possible criteria that have an impact on the work of individual radars, as well as entire radar network. Due to the lack of adequate literature, the experts determined the initial criteria for the selection of the ATC radar position. The initial criteria were as follows:

- K1 the quality of providing of continuous radar coverage in accordance with the requirements of air traffic flow management;
- K2 the quality of providing the detection of small radar cross section aircraft at the maximum range of observation;
- K3 reflection coefficient of the terrain of the radar position;
- K4 terrain configuration (the existence of natural obstacles that reduce the range of radar observation);
- K5 the influence of forests on the interference of electromagnetic wave signals;
- K6 the influence of meteorological conditions on the formation of radar beam;
- K7 the accessibility of the radar position from the aspect of realization of logistics functions (supplying spare parts and maintenance of radar system equipment, ensuring optimal conditions for the work of technical personnel, providing a continuous and secure communication system between correspondents on all modes);
- K8 the position in relation to airspace routes and prohibited, restricted and dangerous area.

Taking into consideration the lack of adequate literature, as well as the fact that the small number of experts were participated in the research, for the purpose of multi criteria decision making, IT2FS are applied (Zhang, 2018). This type of fuzzy sets provides valid results in conditions of significant uncertainty, which represented the basic feature of this research (Deveci et al., 2018). Traditional methods of multi-criteria decision making already had significant application in the realization of the research. The DEMATEL (decision-making trial and evaluation laboratory) method is

often applied to prioritize criteria (Stević et al., 2017; Kaya & Yet, 2019; Wang et al., 2019). In this research the DEMATEL was used to eliminate less important criteria (Petrović and Kankaraš, 2018). The prioritization of the final criteria was carried out using the AHP (analytic hierarchy process) method as one of the most appropriate method of subjective determination of the criteria's weights (Kahraman et al., 2014; Singh & Prasher, 2019). The application of this method ensured a significant validity of the research's results, including the application of the TOPSIS (technique for order preference by similarity to ideal solution) method that was used to test the proposed model (Chen et al., 2019). In addition, it should be noted that during the literature analysis, no papers were found which had the methodological approach applied in this paper (the IT2FS-DEMATEL-AHP-TOPSIS approach). Thus, validation of the hybridized model and results was carried out using other multi-criteria decision making methods modified with fuzzy (TOPSIS, MABAC and COPRAS) and IT2F sets (MABAC and COPRAS).

## 2. Methods

The research was carried out in accordance with the algorithm shown in Figure 1. Hybridized IT2FS DEMATEL-AHP-TOPSIS model was carried out in three phases:

- In the first phase, the less-important criteria in relation to other criteria are eliminated using IT2FS-DEMATEL;
- In the second phase, the prioritization of the final criteria was carried out by the IT2FS-AHP method;
- In the third phase, the optimal alternative of the four offered alternatives was selected using the IT2FS-TOPSIS method.

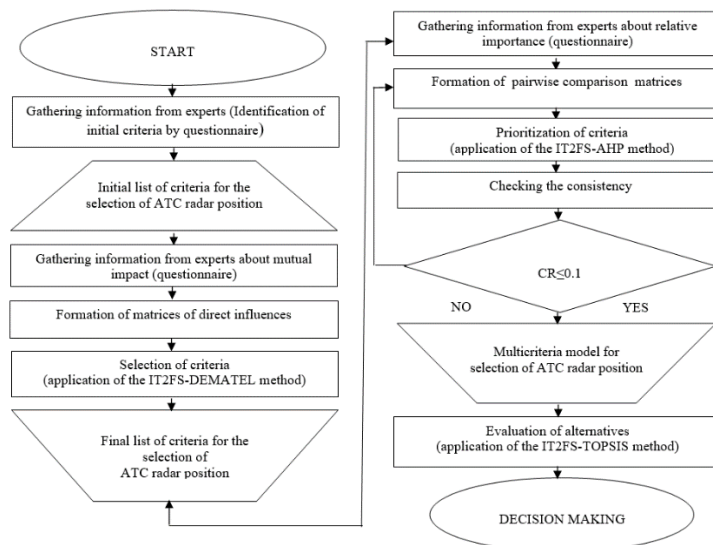


Figure 1. Algorithm of a multi-criteria selection of the ATC radar position

### 2.1. Background of Interval Type-2 Fuzzy Sets

The application of IT2FS, as a special type of Type-2 Fuzzy Sets (T2FS) (Milošević et al., 2019; Haghghi et al., 2019) was caused by the lack of valid research in these

fields. Unlike T2FS, which represent an extended type of T1FS, the IT2FS are easier for calculation and they ensure the validity of the results in the conditions of a high level of uncertainty of the subjective opinion of the experts (Liang et al., 2019).

The T2FS  $\tilde{A}$  in the universe of discourse  $X$  can be presented by the following membership functions:

$$\tilde{A} = \{((x, u), \mu_{\tilde{A}}(x, u)) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1], 0 \leq \mu_{\tilde{A}}(x, u) \leq 1\} \quad (1)$$

Or,

$$\tilde{A} = \iint_{x \in X, u \in J_x} \mu_{\tilde{A}}(x, u) / (x, u) \quad (2)$$

$J_x \subseteq [0,1]$  and  $\iint$  presents union of all  $x$  and  $u$ .

Type T2FS  $\tilde{A}$  for which it is for  $\forall \tilde{A} \Rightarrow \forall \mu_{\tilde{A}}(x, u) = 1$  presents IT2FS, which based on functions 1 and 2 can be represented as (Figure 2):

$$\tilde{A} = \{((x, u), 1) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1], \mu_{\tilde{A}}(x, u) = 1\} \quad (3)$$

Alternatively:

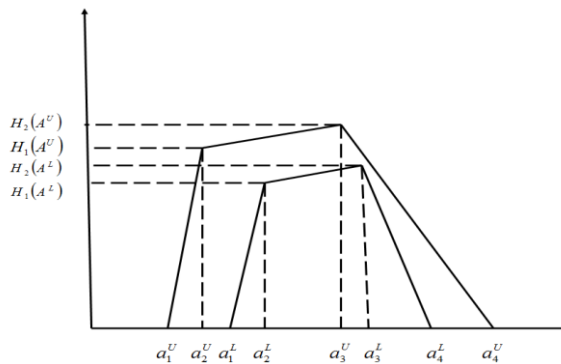
$$\tilde{A} = \iint_{x \in X, u \in J_x} 1 / (x, u), J_x \subseteq [0,1] \quad (4)$$

Bearing in mind that are upper and lower membership functions of the IT2FS are type-1 membership functions, trapezoidal IT2FS  $\tilde{A}_i$  can be presented in the next form (Kahraman et al., 2014):

$$\tilde{A}_i = (A_i^U, A_i^L) = (a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(A_i^U), H_2(A_i^U)), (a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(A_i^L), H_2(A_i^L))) \quad (5)$$

$H_j(A_i^U)$  is the membership value of the element  $a_{i(j+1)}^U$  in the upper trapezoidal function of membership  $A_i^U, 1 \leq j \leq 2$ . And the same is for  $H_j(A_i^L)$  in the lower trapezoidal function of membership  $A_i^L, 1 \leq j \leq 2$ ,

$$H_1(A_i^U) \in [0,1], H_2(A_i^U) \in [0,1], H_1(A_i^L) \in [0,1], H_2(A_i^L) \in [0,1], 1 \leq i \leq n.$$



**Figure 2.** The form of Trapezoidal Interval Type-2 Fuzzy Sets

If are given two IT2FS:

$$\tilde{A}_1 = (A_1^U, A_1^L) = (a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(A_1^U), H_2(A_1^U)), (a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(A_1^L), H_2(A_1^L))$$

$$\tilde{A}_2 = (A_2^U, A_2^L) = (a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(A_2^U), H_2(A_2^U)), (a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(A_2^L), H_2(A_2^L))$$

Their addition operations are defined as follows:

$$\tilde{A}_1 + \tilde{A}_2 = [a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min(H_1(A_1^U), H_1(A_2^U)), \min(H_2(A_1^U), H_2(A_2^U))] \quad (6)$$

$$[a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min(H_1(A_1^L), H_1(A_2^L)), \min(H_2(A_1^L), H_2(A_2^L))]$$

Their subtraction operations are defined as follows:

$$\tilde{A}_1 - \tilde{A}_2 = [a_{11}^U - a_{24}^U, a_{12}^U - a_{23}^U, a_{13}^U - a_{22}^U, a_{14}^U - a_{21}^U; \min(H_1(A_1^U), H_1(A_2^U)), \min(H_2(A_1^U), H_2(A_2^U))] \quad (7)$$

$$[a_{11}^L - a_{24}^L, a_{12}^L - a_{23}^L, a_{13}^L - a_{22}^L, a_{14}^L - a_{21}^L; \min(H_1(A_1^L), H_1(A_2^L)), \min(H_2(A_1^L), H_2(A_2^L))]$$

Their multiplication operations are defined as follows:

$$\tilde{A}_1 \times \tilde{A}_2 = [a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; \min(H_1(A_1^U), H_1(A_2^U)), \min(H_2(A_1^U), H_2(A_2^U))] \quad (8)$$

$$[a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \min(H_1(A_1^L), H_1(A_2^L)), \min(H_2(A_1^L), H_2(A_2^L))]$$

In accordance with calculation rules with fuzzy sets, the division operations between two trapezoidal IT2FS are follows (Kahraman et al., 2014):

$$\frac{\tilde{A}_1}{\tilde{A}_2} = \left[ \frac{a_{11}^U}{a_{24}^U}, \frac{a_{12}^U}{a_{23}^U}, \frac{a_{13}^U}{a_{22}^U}, \frac{a_{14}^U}{a_{21}^U}; \min(H_1(A_1^U), H_1(A_2^U)), \min(H_2(A_1^U), H_2(A_2^U)) \right], \quad (9)$$

$$\left[ \frac{a_{11}^L}{a_{24}^L}, \frac{a_{12}^L}{a_{23}^L}, \frac{a_{13}^L}{a_{22}^L}, \frac{a_{14}^L}{a_{21}^L}; \min(H_1(A_1^L), H_1(A_2^L)), \min(H_2(A_1^L), H_2(A_2^L)) \right],$$

The multiplication and division operations between the trapezoidal IT2FS and scalar  $k$  are defined as follows:

$$k \times \tilde{A}_i = k \times (A_i^U, A_i^L) = (k \times a_{i1}^U, k \times a_{i2}^U, k \times a_{i3}^U, k \times a_{i4}^U; H_1(A_i^U), H_2(A_i^U)), \quad (10)$$

$$(k \times a_{i1}^L, k \times a_{i2}^L, k \times a_{i3}^L, k \times a_{i4}^L; H_1(A_i^L), H_2(A_i^L))$$

$$\frac{\tilde{A}_i}{k} = \left[ \frac{a_{i1}^U}{k}, \frac{a_{i2}^U}{k}, \frac{a_{i3}^U}{k}, \frac{a_{i4}^U}{k}; H_1(A_i^U), H_2(A_i^U) \right], \left[ \frac{a_{i1}^L}{k}, \frac{a_{i2}^L}{k}, \frac{a_{i3}^L}{k}, \frac{a_{i4}^L}{k}; H_1(A_i^L), H_2(A_i^L) \right] \quad (11)$$

The reciprocal of the trapezoidal IT2FS are defined as:

$$\frac{1}{\tilde{A}_i} = \left[ \frac{1}{a_{i4}^U}, \frac{1}{a_{i3}^U}, \frac{1}{a_{i2}^U}, \frac{1}{a_{i1}^U}; H_1(A_i^U), H_2(A_i^U) \right], \left[ \frac{1}{a_{i4}^L}, \frac{1}{a_{i3}^L}, \frac{1}{a_{i2}^L}, \frac{1}{a_{i1}^L}; H_1(A_i^L), H_2(A_i^L) \right] \quad (12)$$

For any trapezoidal IT2FS  $\tilde{A}_i$ ,  $\sqrt[m]{\tilde{A}_i}$  is defined as:

$$\sqrt[m]{\tilde{A}_i} = \left( \left[ \sqrt[m]{a_{i1}^U}, \sqrt[m]{a_{i2}^U}, \sqrt[m]{a_{i3}^U}, \sqrt[m]{a_{i4}^U}; H_1(A_i^U), H_2(A_i^U)} \right], \left[ \sqrt[m]{a_{i1}^L}, \sqrt[m]{a_{i2}^L}, \sqrt[m]{a_{i3}^L}, \sqrt[m]{a_{i4}^L}; H_1(A_i^L), H_2(A_i^L)} \right] \right) \quad (13)$$

The ranking value of the trapezoidal IT2FS  $\tilde{A}_i$  is calculated as follows (Baykasoğlu & Gölcük, 2017):

$$Rank(\tilde{A}_i) = M_1(A_i^U) + M_1(A_i^L) + M_2(A_i^U) + M_{21}(A_i^L) + M_3(A_i^U) + M_3(A_i^L) - \frac{1}{4}(S_1(A_i^U) + S_1(A_i^L) + S_2(A_i^U) + S_2(A_i^L) + S_3(A_i^U) + S_3(A_i^L) + S_4(A_i^U) + S_4(A_i^L)) +$$

$$H_1(A_i^U) + H_1(A_i^L) + H_2(A_i^U) + H_2(A_i^L) \quad (14)$$

$$M_p(A_i^j) = \frac{(a_{ip}^j + a_{i(p+1)}^j)}{2}, 1 \leq p \leq 3 \quad (15)$$

$S_q(A_i^j)$  - The standard deviation of the elements  $a_{iq}^j$  and  $a_{i(q+1)}^j$ :

$$S_q(A_i^j) = \sqrt{\frac{1}{2} \sum_{k=q}^{q+1} \left( a_{ik}^j - \frac{1}{2} \sum_{k=q}^{q+1} a_{ik}^j \right)^2}, 1 \leq q \leq 3 \quad (16)$$

$S_4(A_i^j)$  - The standard deviation of the elements  $a_{ip}^j, 1 \leq q \leq 4$ :

$$S_4(A_i^j) = \sqrt{\frac{1}{4} \sum_{k=1}^4 \left( a_{ik}^j - \frac{1}{4} \sum_{k=1}^4 a_{ik}^j \right)^2} \quad (17)$$

According to Kahraman et al. (2014), defuzzification of the trapezoidal IT2FS  $\tilde{A}_i$  is calculated as follows:

$$DTr\tilde{A}_i = \frac{1}{2} \left\{ \frac{[(a_{i4}^U - a_{i1}^U) + (H_1(\tilde{A}_i^U) a_{i2}^U - a_{i1}^U) + (H_2(\tilde{A}_i^U) a_{i3}^U - a_{i1}^U)] / 4 + a_{i1}^U + [(a_{i4}^L - a_{i1}^L) + (H_1(\tilde{A}_i^L) a_{i2}^L - a_{i1}^L) + (H_2(\tilde{A}_i^L) a_{i3}^L - a_{i1}^L)] / 4 + a_{i1}^L}{2} \right\} \quad (18)$$

These equations are necessary for calculating the DEMATEL, the AHP and the TOPSIS procedures with the trapezoidal IT2FS.

## 2.2. Background of Interval Type-2 Fuzzy Sets-AHP method

The determination of the final criteria's weights was carried out by the IT2FS-AHP method (Celik & Akyuz, 2018). The initial values were gathered by experts in the form of linguistic IT2FS and suited by questionnaire of Satty. The average matrix of pairwise comparisons was obtained using the equations (6), (11) and (12)

$$\tilde{A} = [\tilde{A}_{ij}]_{n \times n} = \begin{bmatrix} \tilde{1} & \tilde{A}_{ij} \\ \frac{1}{\tilde{A}_{ij}} & \tilde{1} \end{bmatrix}$$

$$\tilde{A}_{ij} = (A_{ij}^U, A_{ij}^L) = (a_{ij1}^U, a_{ij2}^U, a_{ij3}^U, a_{ij4}^U; H_1(A_{ij}^U), H_2(A_{ij}^U)), (a_{ij1}^L, a_{ij2}^L, a_{ij3}^L, a_{ij4}^L; H_1(A_{ij}^L), H_2(A_{ij}^L))$$

$$\tilde{1} = (1,1,1,1; H_1(A_{ij}^U), H_2(A_{ij}^U)), (1,1,1,1; H_1(A_{ij}^L), H_2(A_{ij}^L))$$

Using equation (18) defuzzification of the IT2FS elements of the average matrix of pairwise comparisons were carried out and the crisp values for determination of the consistency ratio were calculated.

The consistency ratio was calculated as follows:

$$CR = \frac{CI}{RI} \quad (23)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (24)$$

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \lambda_i \quad (25)$$

$$\lambda_i = \frac{b_i}{w_i} \quad (26)$$

$$\begin{bmatrix} b_1 \\ b_2 \\ b_n \end{bmatrix} = \begin{bmatrix} a_{11} a_{12} a_{1n} \\ a_{21} a_{22} a_{2n} \\ a_{n1} a_{n2} a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_n \end{bmatrix} \quad (27)$$

*RI* - Random index, which depends on the number of rows - columns. If  $CR \leq 0.10$  then the result is consistent.

The prioritization of criteria was carried out by geometric mean method applied to the IT2FS. If  $H_1(A_{ij}^U) = H_2(A_{ij}^U), H_1(A_{ij}^L) = H_2(A_{ij}^L) \Leftrightarrow \forall \tilde{A}_{ij}$  then the IT2FS values of the criteria weights  $\tilde{w}_i$  were derived from the following equations:

$$\tilde{w}_i = \frac{\left[ \left( \prod_{j=1}^n a_{ij1}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij2}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij3}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij4}^U \right)^{1/n}; H_1(A_{ij}^U), H_2(A_{ij}^U) \right], \left[ \left( \prod_{j=1}^n a_{ij1}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij2}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij3}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij4}^L \right)^{1/n}; H_1(A_{ij}^L), H_2(A_{ij}^L) \right]}{\sum_{i=1}^n \left[ \left( \prod_{j=1}^n a_{ij1}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij2}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij3}^U \right)^{1/n}, \left( \prod_{j=1}^n a_{ij4}^U \right)^{1/n}; H_1(A_{ij}^U), H_2(A_{ij}^U) \right], \left[ \left( \prod_{j=1}^n a_{ij1}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij2}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij3}^L \right)^{1/n}, \left( \prod_{j=1}^n a_{ij4}^L \right)^{1/n}; H_1(A_{ij}^L), H_2(A_{ij}^L) \right]} \quad (28)$$

According to equation (9):

$$\tilde{w}_i = \left[ \left( \frac{\left( \prod_{j=1}^n a_{ij1}^U \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij1}^U \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij2}^U \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij2}^U \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij3}^U \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij3}^U \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij4}^U \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij4}^U \right)^{1/n}}; H_1(A_{ij}^U), H_2(A_{ij}^U) \right), \left( \frac{\left( \prod_{j=1}^n a_{ij1}^L \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij1}^L \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij2}^L \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij2}^L \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij3}^L \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij3}^L \right)^{1/n}}, \frac{\left( \prod_{j=1}^n a_{ij4}^L \right)^{1/n}}{\sum_{i=1}^n \left( \prod_{j=1}^n a_{ij4}^L \right)^{1/n}}; H_1(A_{ij}^L), H_2(A_{ij}^L) \right) \right] \quad (29)$$

Using equation (18), the values of  $D\text{Tra}\tilde{W}_i, i = 1, \dots, n$  were calculated, whose aggregations were obtained the weights  $W_i$ .

### 2.3. Background of Interval Type-2 Fuzzy Sets-TOPSIS method

After the criteria's weights were determined, the optimal radar position was selected by the IT2FS-TOPSIS method (Deveci et al., 2018). This method is based on the ranking of alternatives in relation to the ideal and negative ideal solution.

In the first step, individual  $k$  - IT2FS decision matrices was formed from data gathered by six experts ( $k = 6$ ). The average IT2FS decision matrix was derived from the individual IT2FS decision matrices using equation (6) and (11):

$$\tilde{F} = [\tilde{F}_{ij}], 1 \leq i \leq n, 1 \leq j \leq m \quad (30)$$

$n$  - Number of criteria,

$m$  - Number of alternatives.

The normalized IT2FS decision matrix was calculated as follows:

$$\tilde{R} = [\tilde{R}_{ij}] = \left[ \frac{\tilde{F}_{ij}}{\sqrt{\sum_{j=1}^m \tilde{F}_{ij}^2}} \right], 1 \leq i \leq n, 1 \leq j \leq m, \text{ or:}$$

If  $H_1(F_{ij}^U) = H_2(F_{ij}^U), H_1(F_{ij}^L) = H_2(F_{ij}^L) \Leftrightarrow \forall A\tilde{F}_{ij}$  then according to equation (8), (9) and (13) is:

$$\tilde{R}_{ij} = \left[ \left( \frac{f_{ij1}^U}{\sqrt{\sum_{j=1}^m (f_{ij4}^U)^2}}, \frac{f_{ij2}^U}{\sqrt{\sum_{j=1}^m (f_{ij3}^U)^2}}, \frac{f_{ij3}^U}{\sqrt{\sum_{j=1}^m (f_{ij2}^U)^2}}, \frac{f_{ij4}^U}{\sqrt{\sum_{j=1}^m (f_{ij1}^U)^2}}; H_1(F_{ij}^U), H_1(F_{ij}^U) \right), \right. \\ \left. \frac{f_{ij1}^L}{\sqrt{\sum_{j=1}^m (f_{ij4}^L)^2}}, \frac{f_{ij2}^L}{\sqrt{\sum_{j=1}^m (f_{ij3}^L)^2}}, \frac{f_{ij3}^L}{\sqrt{\sum_{j=1}^m (f_{ij2}^L)^2}}, \frac{f_{ij4}^L}{\sqrt{\sum_{j=1}^m (f_{ij1}^L)^2}}; H_1(F_{ij}^L), H_1(F_{ij}^L) \right], \quad (31)$$

In the next step, the weighted IT2FS decision matrix was constructed using equation (32):

$$\tilde{V}_{ij} = \tilde{R}_{ij} W_i \quad (32)$$

Ranking values  $\tilde{V}_{ij} = \tilde{R}_{ij} W_i$  were calculated by equations (14)-(17), and a new matrix was obtained:

$$V = [Rank\tilde{V}_{ij}]$$

In the next step, the positive and negative ideal solutions are respectively calculated using equation (33) and (34):

$$V_j^+ = \left\{ \left( \max Rank\tilde{V}_{ij}, i \in G \right), \left( \min Rank\tilde{V}_{ij}, i \in G^- \right) \right\} = \left\{ Rank\tilde{V}_1^+, Rank\tilde{V}_2^+, \dots, Rank\tilde{V}_n^+ \right\} \quad (33)$$

$$V_j^- = \left\{ \left( \min Rank\tilde{V}_{ij}, i \in G \right), \left( \max Rank\tilde{V}_{ij}, i \in G^- \right) \right\} = \left\{ Rank\tilde{V}_1^-, Rank\tilde{V}_2^-, \dots, Rank\tilde{V}_n^- \right\} \quad (34)$$

$G^+$  - benefit criteria (criteria that are maximized);

$G^-$  - cost criteria (criteria that are minimized).

In the next step, the distance between each alternative, positive, and negative ideal solution was calculated as follows (Hwang & Yoon, 2012):

$$S_j^+ = \sqrt{\sum_{i=1}^n (Rank\tilde{V}_{ij} - Rank\tilde{V}_i^+)^2}, \quad 1 \leq j \leq m \quad (35)$$

$$S_j^- = \sqrt{\sum_{i=1}^n (Rank\tilde{V}_{ij} - Rank\tilde{V}_i^-)^2}, \quad 1 \leq j \leq m \quad (36)$$

In the next step, for each alternative value of the relative degree of closeness to ideal solutions was calculated as follows (Hwang & Yoon, 2012):

$$Q_j^* = \frac{S_j^-}{(S_j^+ + S_j^-)}, \quad 0 \leq Q_j^* \leq 1 \quad (37)$$

Finally, the alternatives are ranked. The optimal alternative is the one that has the largest value of  $Q_j^*$  (Hwang & Yoon, 2012).



### 3. Results

The elimination of less important initial criteria was carried out using the IT2FS-DEMATEL method. At first, six experts carried out the pairwise comparisons of influence between initial criteria. The influence that one criterion can have on other criteria, as well as the influence that same criterion can receive from other criteria is the following: no influence (N), low influence (L), medium influence (M), high influence (H) and very high influence (VH). The linguistic variables of influence expressed by the trapezoidal IT2FS values are shown in Table 1.

**Table 1.** DEMATEL Linguistic variables for causal influence among criteria

Linguistic variable of influence	Trapezoidal IT2FS
No (N)	((0,0,0,0;1,1),(0,0,0,0;0.8,0.8))
Low (L)	((0,0.2,0.2,0.4;1,1),(0,0.1,0.1,0.3;0.8,0.8))
Medium (M)	((0.2,0.4,0.4,0.6;1,1),(0.1,0.3,0.3,0.5;0.8,0.8))
High (H)	((0.4,0.6,0.6,0.8;1,1),(0.3,0.5,0.5,0.7;0.8,0.8))
Very high (VH)	((0.6,0.8,0.8,1;1,1),(0.5,0.7,0.7,0.9;0.8,0.8))

After the average IT2FS matrix of the influence between initial criteria and the normalized direct-relation matrix was calculated, the total relation matrix  $\tilde{T}$  was obtained using the formulas 19, 20 and 21. This matrix was defuzzificated by formula 18 (Table 2).

**Table 2.** Defuzzificated the total relation matrix  $D\text{Tra}\tilde{T}$

K	K1	K2	K3	K4	K5	K6	K7	K8
K1	0.081	0.180	0.190	0.178	0.179	0.171	0.174	0.175
K2	0.140	0.077	0.177	0.156	0.169	0.137	0.140	0.165
K3	0.056	0.066	0.036	0.062	0.055	0.051	0.056	0.061
K4	0.090	0.097	0.124	0.048	0.094	0.066	0.091	0.096
K5	0.066	0.069	0.069	0.069	0.035	0.062	0.059	0.060
K6	0.115	0.120	0.110	0.084	0.073	0.046	0.070	0.083
K7	0.080	0.084	0.125	0.106	0.105	0.114	0.045	0.080
K8	0.121	0.125	0.085	0.102	0.103	0.086	0.123	0.055

The threshold value  $\alpha = 0.099$  was obtained using equation (22).

By subtracting the threshold value from the value of the elements of  $D\text{Tra}\tilde{T}$  was obtained the matrix determines the significance of the criteria.

**Table 3.** Comparison of the elements of the defuzzificated total relation matrix with the threshold values

K	K1	K2	K3	K4	K5	K6	K7	K8
K1	-0.018	0.081	0.091	0.079	0.080	0.072	0.075	0.076
K2	0.041	-0.022	0.078	0.057	0.070	0.038	0.041	0.066
K3*	-0.043	-0.033	-0.063	-0.037	-0.044	-0.048	-0.043	-0.038
K4	-0.009	-0.002	0.025	-0.051	-0.005	-0.033	-0.008	-0.003

K	K1	K2	K3	K4	K5	K6	K7	K8
K5*	-0.033	-0.030	-0.030	-0.030	-0.064	-0.037	-0.040	-0.039
K6	0.016	0.021	0.011	-0.015	-0.026	-0.053	-0.029	-0.016
K7	-0.019	-0.015	0.026	0.007	0.006	0.015	-0.054	-0.019
K8	0.022	0.026	-0.014	0.003	0.004	-0.013	0.024	-0.044

\* Non-significant criteria

Based on Table 3 it can be noted that all values of the criteria K3 and K5 of  $DTra\tilde{T}$  are lower than the threshold value. These two criteria were eliminated.

The final criteria are the following:

- C1 the quality of providing of continuous radar coverage in accordance with the requirements of air traffic flow management;
- C2 the quality of providing the detection of small radar cross section aircraft at the maximum range of observation;
- C3 terrain configuration (the existence of natural obstacles that reduce the range of radar observation);
- C4 the influence of meteorological conditions on the formation of radar beam;
- C5 the accessibility of the radar position from the aspect of realization of logistics functions (supplying spare parts and maintenance of radar system equipment, ensuring optimal conditions for the work of technical personnel, providing a continuous and secure communication system between correspondents on all modes);
- C6 the position in relation to airspace routes and prohibited, restricted and dangerous area.

The linguistic variables and their IT2FS values applied for the pairwise comparisons of criteria in accordance with the procedures of the AHP method are shown in Table 4.

**Table 4.** AHP Linguistic variables of criteria pairwise comparison

Linguistic variables	Trapezoidal IT2FS
Absolutely strong (AS)	((7,8,9,9;1,1),(6,7,8,8;0.8,0.8))
Very strong (VS)	((5,6,7,8;1,1),(4,5,5,6;0.8,0.8))
Fairly strong (FS)	((3,4,4,5;1,1),(2,3,3,4;0.8,0.8))
Slightly strong (SS)	((1,2,3,3;1,1),(1,1,2,2;0.8,0.8))
Equal (E)	((1,1,1,1;1,1),(1,1,1,1;1,1))
Slightly weak (SW)	((0.333,0.333,0.5,1;1,1),(0.5,0.5,1,1;0.8,0.8))
Fairly weak (FW)	((0.2,0.25,0.25,0.333;1,1),(0.25,0.333,0.333,0.5;0.8,0.8))
Very weak (VW)	((0.125,0.143,0.167,0.2;1,1),(0.167,0.2,0.2,0.25;0.8,0.8))
Absolutely weak (AW)	((0.111,0.111,0.125,0.143;1,1),(0.125,0.125,0.143,0.167;0.8,0.8))

After the average IT2FS pairwise comparisons matrix was constructed, the IT2FS values of the criteria weights were obtained using formula 8, 9, 11, 12, 13, 28 and 29. Defuzzification of the IT2FS was carried out by formula 18. By the aggregation of  $DTra\tilde{W}_i$ , the final criteria's weights were obtained  $\tilde{W}_i, i = [1, \dots, 6]$  (Table 5).

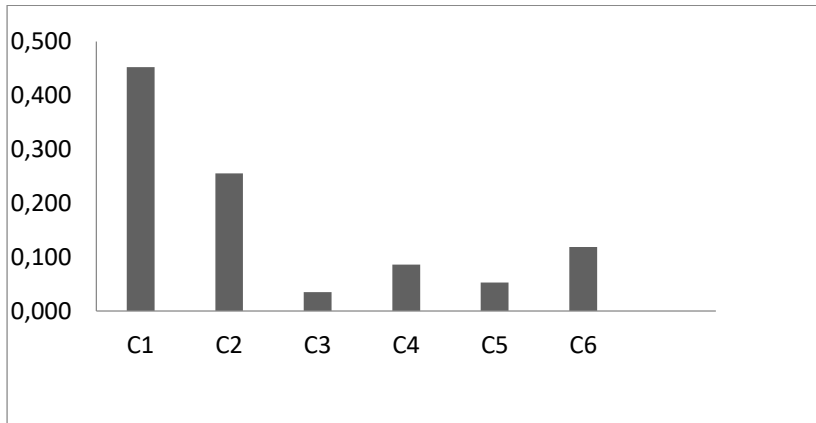
**Table 5.** Criteria's weights  $\tilde{W}_i$

C	Trapezoidal IT2FS	$DTra\tilde{W}_i$	$\tilde{W}_i$
C1	(0.325,0.44,0.514,0.69;1,1),(0.292,0.393,0.481,0.64;0.8,0.8)	0.45	0.452
C2	(0.17,0.235,0.278,0.382;1,1),(0.166,0.234,0.281,0.389;0.8,0.8)	0.254	0.255
C3	(0.021,0.027,0.032,0.046;1,1),(0.028,0.035,0.046,0.06;0.8,0.8)	0.035	0.035
C4	(0.05,0.071,0.091,0.128;1,1),(0.059,0.077,0.105,0.14;0.8,0.8)	0.086	0.086
C5	(0.029,0.037,0.051,0.077;1,1),(0.04,0.048,0.07,0.091;0.8,0.8)	0.053	0.053
C6	(0.07,0.102,0.131,0.178;1,1),(0.078,0.1,0.145,0.189;0.8,0.8)	0.118	0.119

The consistency ratio is obtained as follows:

- 1) Defuzzification of the average IT2FS pairwise comparisons matrix was carried out by formula 18 and  $DTra\tilde{A}_{ij}$  values were obtained.
- 2) Using the formula 23-27 on the elements of  $DTra\tilde{A}_{ij}$  matrix and  $w_i$  (the values of the initial weights determined by the elements of  $DTra\tilde{A}_{ij}$ ), the value of  $CR_1 = 0.011, n = 6 \Rightarrow RI = 1.25$  was obtained.
- 3) Using the formula 23-27 on the elements of  $DTra\tilde{A}_{ij}$  matrix and  $\tilde{W}_i$  the value of  $CR_1 = 0.019, n = 6 \Rightarrow RI = 1.25$  was obtained.
- 4) Bearing in mind that both values of the consistency ratio are less than 0.1, the AHP method was valid for determining the criteria's weights.

Based on the obtained results, the diagram of the criteria's weights was shown in Figure 3.



**Figure 3.** Diagram of the criteria weights

Proposed model of criteria's weights was tested by the IT2FS-TOPSIS method. Using the IT2FS-TOPSIS method, the optimal ATC radar position was selected based on the criteria's weights and the IT2FS value of the linguistic variables of alternatives for each criterion, shown in Table 6.

**Table 6.** Linguistic variables for ranking of alternatives by TOPSIS

Linguistic variables for ranking of alternatives	Trapezoidal IT2FS
Very poor (VP)	$((0,0.1,0.1,0.2;1,1),(0,0,0.1,0.1;0.8,0.8))$
Poor (P)	$((0.1,0.2,0.2,0.4;1,1),(0,0.1,0.1,0.2;0.8,0.8))$
Medium (M)	$((0.2,0.4,0.4,0.6;1,1),(0.1,0.3,0.3,0.5;0.8,0.8))$
Good (G)	$((0.3,0.5,0.6,0.8;1,1),(0.2,0.4,0.4,0.6;0.8,0.8))$
Very good (VG)	$((0.4,0.6,0.8,1;1,1),(0.3,0.5,0.6,0.8;1,1))$

After the average IT2FS decision matrix was constructed (formula 30), the normalized IT2FS decision matrix and the weighted IT2FS decision matrix was calculated by formula 31 and formula 32. Based on formula 14-17, ranking values of the weighted IT2FS decision matrix were calculated (Table 7).

**Table 7.** Ranking values of the weighted IT2FS decision matrix

Rank	A1	A2	A3	A4
C1	4,937	4,717	4,498	3,817
C2	4,006	4,006	4,006	4,006
C3	3,411	3,363	3,363	3,378
C4	3,652	3,557	3,384	3,384
C5	3,523	3,412	3,376	3,412
C6	3,717	3,602	3,423	3,660

Where:

- C1, C2, C5 and C6 are benefit criteria  $G^+$  ;
- C3 and C4 are cost criteria  $G^-$  .

According to formula 33 and 34 were respectively calculated positive and negative ideal solutions.

$$V_j^+ = \{4.937, 4.006, 3.363, 3.384, 3.523, 3.717\},$$

$$V_j^- = \{3.817, 4.006, 3.411, 3.652, 3.376, 3.423\}$$

According to 35 and 36 the distance between each alternative, positive, and negative ideal solution were calculated using formula 35 and 36.

**Table 8.** Ranks of alternatives

Alternatives	A1	A2	A3	A4
$S^+$	0.272	0.322	0.548	1.127
$S^-$	1.167	0.925	0.733	0.361
$Q^*$	0.811	0.742	0.572	0.242
Rank	1	2	3	4

The ranks of the alternatives (Table 8), which depend on values of the relative degree of closeness  $Q^*$ , were calculated using equation (37) (the higher value is the value of the optimal alternative).

#### 4. Discussion

By literature analysis, it is not possible to determine the criteria for the selection of ATC radar positions, which required the engagement of experts for the formation of the initial criteria. After determination the initial criteria, based on the obtained results by the IT2FS-DEMATEL method, the criterion K3 (reflection coefficient of the terrain of the radar position) and criterion K5 (the influence of forests on the interference of electromagnetic wave signals) were eliminated. Based on the obtained results it can be concluded that both criteria were already included in other criteria by experts' opinion. Namely, if reflection coefficient of the terrain of the radar position is low and if the influence of forests on the interference of electromagnetic wave signals is high, it is impossible to provide a quality assurance of continuous radar beam at all flight levels and the high probability of detection of the aircraft of small radar cross section.

In the second phase of the research, using the IT2FS-AHP method, the final criteria were evaluated. Based on Table 5 and Figure 3, it was concluded that the significance of criterion C1 is the highest (the highest weight's value). Furthermore, according to Table 5 and Figure 3, it can be noted that the criteria C2 and C6 have significantly higher weights than the criteria C3, C4 and C5. Similarly, it can be concluded from the values obtained in Tables 2 and 3 (the DEMATEL method is often applied to prioritize the criteria (Stević et al, 2017)).

Bearing in mind that the basic purpose of ATC radars is to ensure the smooth functioning of air traffic, the significance of criterion C1 (the quality of providing of continuous radar coverage in accordance with the requirements of air traffic flow management) could not be specifically explained. Namely, the reliability of the operation of the area control centre, approach control unit and tower control unit on all air routes and corridors depends on the quality of the radar beam's continuity. In the conditions of existence of asymmetric threats, as well as increasingly frequent use of micro unmanned aerial vehicles for various purposes, there is no doubt the possibility of detecting aircraft of low radar cross section is extremely significant. Despite being used for useful purposes (detecting and monitoring major fires or nuclear-chemical accidents, monitoring the situation on the terrain after industrial or other accidents, etc.), the unmanned aerial vehicles can often be used to perform spy or terrorist activities, as well as other forms of airspace violation (Islam et al., 2018; Card, 2018). Therefore, their quick detection is extremely significant for the safety of the functioning of air traffic. Considering aforementioned the criterion C2 is very significant. In the case that the radar position has a great possibility of detecting low cross section aircraft, especially at low altitudes, the safety of air traffic at lower flight levels, as well as below transition level and transition altitude is very appropriate. The significance of the criterion C6 is a consequence of the fact that the radar position must maximize the number of the air routes and the flight levels covered by the radar. This criterion is also significant because of fast detection the airspace violations if the aircraft is in prohibited, restricted or dangerous areas. Based on the obtained results of the weights, the other criteria are less significant. Weight of the criterion C4 is higher than for the criterion C3 (according to experts, and this criterion is the integral part of other criteria) and for the criterion C5. Namely, despite the fact that radar technology is developing exponentially, low ceilings and weather disturbances, such as heavy rain or snow, storms, strong winds, large hail, can still affect the ATC radar coverage. Furthermore, the weather precipitation and low cloudiness have a major influence on the interference of the electromagnetic waves, causing significant clutters reducing radar visibility. The criterion C5 is less significant because of exponential

development of radar's maintenance technology, ensuring optimal conditions for the work of technical personnel and continuous and safe communication system between correspondents. Aforementioned is something what is relatively easy to regulate even in extreme conditions.

Based on the test results obtained by the IT2FS-TOPSIS method, the optimal ATC radar position ensures:

- The high quality of providing of continuous radar coverage in accordance with the requirements of air traffic flow management;
- The detection of small radar cross section aircraft at the maximum range of observation;
- The very good position of covering of airspace routes and prohibited, restricted and dangerous area.

Validation of the hybridized multi-criteria decision making approach was carried out using: TOPSIS, COPRAS and MABAC methods, because of the reliability of the results obtained using these methods (Pamučar et al., 2018a, 2018b; Garg, 2019). These methods were modified using fuzzy (trapezoidal fuzzy sets) and IT2FS (except TOPSIS). At the same time, the validation of the method was used to evaluate the reliability of the obtained results of the hybridized model (Ghorabae et al., 2016). The ranks of alternatives according to modified TOPSIS, COPRAS and MABAC methods are shown in Table 9.

**Table 9.** Comparison of the ranks of alternatives according to modified methods

Alt.	IT2FS-TOPSIS	Fuzzy-TOPSIS	IT2FS-COPRAS	Fuzzy-COPRAS	IT2FS-MABAC	Fuzzy-MABAC
A1	1	1	1	1	1	2
A2	2	2	2	2	2	1
A3	3	3	3	3	3	3
A4	4	4	4	4	4	4

Based on the results in the table, it can be noted that the rank of alternatives was changed only for Fuzzy-MABAC method. Using this method, alternatives A1 and A2 replaced ranks. The correlation of results was tested using Spearman's correlation coefficient of ranks. This statistical technique is extremely useful for ranking a small number of variables (Pamučar et al., 2018a, 2018b; Ghorabae et al., 2016). Using Spearman's correlation coefficient of ranks, it was found that the correlation is less than 1 only in the case of the Fuzzy-MABAC method (Spearman's correlation coefficient is 0.9). The average value of the correlation is 0.98. Based on the average value of Spearman's correlation coefficient of ranks, it can be concluded that the application of the hybridized model is extremely reliable under conditions of the uncertainties.

A sensitivity analysis was carried out through changes in the criteria's weights. The sensitivity analysis carried out through 36 scenarios. In each scenario, the weight of one criterion is increased (reduced) by 25%, 50% and 75%, respectively. The weights of the other criteria are increased (decreased) due to the following condition  $\sum_{i=1}^n W_i = 1$  (Table 10).

The results in the table show that the ranking of alternatives changed through five scenarios. In other scenarios, the ranking of alternatives did not change. Based on Spearman's correlation coefficient, in 31 scenarios, values of correlation is one, while in five scenarios values of correlation is 0.9. Thus, it can be concluded that there is very

high correlation (closeness) of ranks through the scenarios and that the results obtained using hybridized IT2FS-DEMATEL-AHP-TOPSIS approach are credible.

**Table 10.** The sensitivity analysis of results

### 5. Conclusion

In the paper, the criteria for selection of the optimal ATC radar position, which will ensure observation of air traffic at all flight levels (including flights below the altitude transition), were determined and evaluated. Furthermore, radar positions are ranked from the aspect of influence of the radar ability to detect potential air traffic violations, as well as flying through prohibited, restricted or dangerous areas. In the research, special attention is devoted to significance of radar positions in the detection of unmanned aerial vehicles that could be used for endangering safety from the airspace. The IT2FS, which were used in the research, enabled valid decision making in conditions of high level of uncertainty, when partially reliable data (as a consequence of the lack of appropriate literature) was gathered by a small number of experts.

Bearing in mind aforementioned, future research could be focused on:

- 1) The application of other traditional objective and subjective methods of multi-criteria decision making in combination with IT2FS in the determination and evaluation of criteria for the selection of the radar position and for solving other poorly structured problems (for example: CRITIC, BEST-WORST, ANP, ELECTRA, COPRAS, MAIRCA, VIKOR, MABAC, etc.).
- 2) The application of other types of tools that accept uncertainty in decision-making. Such as type 2 fuzzy sets, interval (type 1 or type 2) valued fuzzy sets, (interval valued) intuitionistic fuzzy sets. These types and forms of fuzzy sets can be applied by themselves or in construction with some numbers such as rough numbers or grey theory.

The application of the proposed model in this paper with the geographic information system, which can provide a practical purpose of this model in the selection of the optimal radar position that, ensures maximization of the technical characteristics' utilization of the ATC radar

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### Appendix

**Table A1.** The average linguistic variables matrix of the influence between initial criteria (DEMATEL)

K	K1	K2	K3	K4	K5	K6	K7	K8
K1	N	VH	VH	VH	VH	VH	VH	VH
K2	H	N	VH	1.167×H	VH	H	H	VH
K3	1.17×L	1.5×L	N	1.33×L	L	L	1.17×L	1.33×L
K4	M	1.085×M	H	N	M	L	M	1.085×M
K5	1.5×L	1.5×L	1.33×L	1.5×L	N	1.33×L	1.17×L	1.17×L
K6	H	H	1.167×M	1.5×L	L	N	L	1.5×L
K7	1.5×L	1.5×L	H	1.25×M	1.25×M	H	N	1.5×L
K8	H	H	L	M	M	1.5×L	H	N

**Table A2.** The average linguistic variables pairwise comparisons matrix (AHP)



C	C1	C2	C3	C4	C5	C6
C1	E	FS	AS	VS	$(VS+AS)/2$	$(FS+VS)/2$
C2	1/FS	E	AS	$(4 \times FS + 2 \times VS)$	VS	$(SS+FS)/2$
C3	1/AS	1/AS	E	1/FS	E	$2/(FS+VS)$
C4	1/VS	$1/(4 \times FS + 2 \times VS)$	FS	E	E	E
C5	$2/(VS+AS)$	1/VS	E	E	E	$1/(4 \times SS + 2 \times FS)$
C6	$2/(FS+VS)$	$2/(SS+FS)$	$(FS+VS)/2$	E	$(4 \times SS + 2 \times FS)$	E

**Table A3.** The average IT2FS decision matrix (TOPSIS)

C/A	A1	A2	A3	A4
C1	G	$(M+G)/2$	M	P
C2	$(M+G)/2$	$(P+M)/2$	$(P+M)/2$	$(P+M)/2$
C3	$(G+VG)/2$	M	M	$(P+M)/2$
C4	$(G+VG)/2$	$(P+M)/2$	P	P
C5	$(4 \times M + 2 \times G)/6$	$(4 \times P + 2 \times M)/6$	P	$(4 \times P + 2 \times M)/6$
C6	G	M	P	$(P+M)/2$

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