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THREAT ASSESSMENT OF AIR TARGETS BASED ON FAHP-ICRITIC COMBINATION WEIGHTING

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Abstract: Aiming at the problem of target threat assessment in air defense operations, a target threat assessment model based on Fuzzy Analytic Hierarchy Process (FAHP) and Improved Criteria Importance Although Intercrieria Correlation (ICRITIC) is proposed. On the basis of establishing the threat assessment index system, the FAHP and ICRITIC methods are used to determine the subjective and objective weights of the threat indicators, the combination weights are based on the principle of maximizing the deviation, and the target threat degree is evaluated based on the TOPSIS method (Technique for Order Preference by Similarity to an Ideal Solution, TOPSIS). The weights and target threat degree obtained by different weighting methods are analyzed to verify the rationality and effectiveness of the proposed method.
Keywords: Air defense operations; Threat assessment; Fuzzy analytic hierarchy process (FAHP); Improved criteria importance though intercrieria correlation (ICRITIC); Combination weighting

INTRODUCTION

The previous information local wars since the Gulf War show that air strikes have become the main form of war initiated by combat opponents. With the continuous development of military theory, military technology and military practice, there are more types of air-raid weapons, with better performance and stronger functions. In the future air defense operations, air strikes and air defense confrontation are more intense, and the "OODA" cycle in the combat process is significantly accelerated, and the complex and changeable battlefield situation requires commanders to make quick, accurate and efficient decisions. Scientific evaluation of the threat degree of various incoming targets is the premise of scientific decision-making, which can provide a basis for the subsequent reasonable allocation of anti-aircraft firepower and maximize the effectiveness of weapons and equipment.

The main contents of target threat assessment include: extraction of threat elements, quantification of threat elements, and determination of threat level[1]. When determining the target threat level, it is necessary to determine the weight of each threat element and rank the degree of the target threat.

A single method or a combination method can be used to determine the weight of threat indicators. Single empowerment method includes both subjective empowerment method and objective empowerment method. Subjective empowerment methods include expert scoring method, Delphi method, hierarchical analysis method, etc. Document [2] determines the weight of threat index of penetrating air combat aircraft, and improves the rationality of the scale method and consistency inspection method of hierarchy analysis to improve the efficiency of target optimization; Document [4] uses the fuzzy consensus matrix in the evaluation to meet the requirements of the relative ambiguity of the evaluation object and overcome the difficulty of consistency inspection. Objective empowerment methods include entropy value method, principal component analysis method, CRITIC method and so on. Literature [5] uses the entropy method to determine the subjective weight value of each attribute of the sea surface target to make the empowerment more objective; literature [6] uses the principal component analysis method to determine the threat index weight to reduce the subjective influence of determining the index weight; literature [7] uses the CRITIC method to determine the attribute weight, considers the data volatility and conflict of each attribute information, and makes the weight allocation more reasonable. The combination empowerment method can consider the subjective preference and the characteristics of evaluation element data, and the common method is linear weighting method[8], Multiplicative synthesis and normalization method[9], The vector similarity method[10]class. The linear weighting method can use the game theory[11], least square method[12]Maximize the difference[13].To determine the combined weight coefficients of the different empowerment methods.

Based on the above analysis, because the CRITIC method underconsiders the correlation coefficient and the degree of data dispersion between the indicators, this paper uses FAHP and improved CRITIC method to determine the subjective and objective weights of the indicators, makes linear weighted combination based on the idea of difference maximization, and uses TOPSIS method to evaluate the threat degree of aerial targets.

1 SELECTION OF THE INDEX SYSTEM

The threat degree of air target generally refers to the possibility of the enemy's successful air strike on our defended targets and the degree of possible damage caused after the successful air strike, which is a reflection of the enemy's air strike intention and the combat ability of air strike weapons. The factors affecting the target threat degree mainly include the target type, flight conditions, flight time, etc. The threat assessment indicators selected in the relevant literature are shown in Table 1.

Table 1 Threat Assessment Indicators Selected from Relevant Literature

Literature number	Selected threat indicators
Literature [14]	S hortcuts to routes ; A ltitude ; T ime of approach ; N umber of targets
Literature [15]	Target type ; S peed ; T ime of approach ; A ltitude ; P arameter update time
Literature [16]	Target type ;Electronic jamming capability ;T ime of approach ; Altitude ; Maneuvering haracteristics ;Shortcuts to routes
Literature [17]	Target type ;Electronic jamming capability ; H eading angle ; A ltitude ; S peed
Literature [18]	Target type ; S peed ; T ime of approach ; Shortcuts to routes ; Electronic jamming capability ;
Literature [19]	S peed ; Characteristics of mobility ; Electronic jamming capability ; A ltitude ; H eading angle ; Distance from own position

Based on relevant research and practical experience, Target type, Altitude, Speed, Time of approach (TOA), Shortcuts to routes (STR), Electronic jamming capability (EJC) and others were selected as threat assessment indicators.

1.1 Target Type

Different target types, their mobility performance, carrying load, attack mode are also different, and the degree of threat to the defended target is also different. The target type threat degree was quantified by the expert scoring method, as shown in Table 2.

Table 2 Threat Affiliation of Target Types

Target type	Bomber	F ighter	A rmed helicopter	Cruise missile	Reconnaissance aircraft
quantified value	0.7	0.6	0.4	0.3	0.2

1.2 Target Height

When the target carries out low altitude and ultra-low altitude mobile penetration, due to the influence of terrain, earth curvature, radar blind area and other factors, the probability of being found by our intelligence reconnaissance system has decreased, and it is easier to achieve the surprise of air attack. Usually, the lower the target height, the greater the threat level. The threat membership function for the target height can be expressed as:

$$y(h)=\begin{cases} 1 & 0\le h\le 1 \\ e^{-k_h(h-1)^2} & 1\le h\le 20 \end{cases} \tag{1}$$

Where h is the target height in k m, $k_h=10^{-2}$.

1.3 Target Speed

The higher the target speed, the easier it is to break through our interception, and the greater the threat degree. The threat membership function of the target speed can be expressed as:

$$y(v)=1-e^{k_v v} \tag{2}$$

Where v is the target speed in m / s, $k_v=-6\times10^{-3}$.

1.4 Fly Time

The shorter the target flight time, the shorter the planning and decision time and the response time of the weapon system, and the greater the threat degree. The threat membership function of flight time can be expressed as:

$$y(t)=e^{-k_t t^2},t\ge 0 \tag{3}$$

Where, t is the flight time and is measured in s, $k_t=2\times10^{-5}$.

1.5 Road Shortcuts

The smaller the shortcut of the target route, the stronger the intention to attack on us, and the greater the threat. The threat membership function of the shortcut can be expressed as:

$$y(d)=e^{-k_d d^2},-30\le d\le 30 \tag{4}$$

Where, d is the air route shortcut, in km, $k_d=8\times10^{-3}$.

1.6 Electronic Interference Capability

Air raid weapons can interfere with and suppress our detection and tracking equipment by carrying an electronic warfare system. The stronger the electronic interference ability of the target, the greater the threat degree. In this paper, the electronic interference ability is quantified as no, weak, weak, strong and strong, and the quantified values are 0,0,0,0 and 0..2.4.6.8

2 TARGET THREAT ASSESSMENT STEPS

2.1 The Subjective Weights were Determined based on the FAHP Method

FAHP determines the relative importance of each index by comparing them separately, establishes the fuzzy complementary matrix and the fuzzy consensus matrix, and then obtains the index weight.

2.1.1 Establish the fuzzy complementary matrix

.1-0.9The "0 scale method" is used to assign the relative importance of the index (the scale significance is shown in Table 3) to establish a fuzzy complementary matrix. Matrix A meets the following conditions: $A=\left(a_{ij}\right)_{m\times m}$

（1） $a_{ii}=0.5, i=1,2,\cdots,m;$

（2） $a_{ij}=1-a_{ji}, i,j=1,2,\cdots,m$

Table 3 Meaning of the "0.1-0.9 Scale"

Relative importance	Meaning	Description
0.5	E qually important	Indicators i and j are equally important
0.6	Slightly important	Indicator i is slightly more important than j
0.7	Significantly important	Indicator i is significantly more important than j
0.8	Strongly important	Indicator i is more strongly important than j
0.9	Extremely important	Extreme importance of indicator i over j
0.1,0.2,0.3,0.4	Anti-comparison	

2.1.2 Establish a fuzzy consensus matrix

The matrix A is converted into a fuzzy consensus matrix according to Equation (5) and (6). $B=\left(b_{ij}\right)_{m\times m}$

$$B=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{bmatrix}$$

$$b_i=\sum_{j=1}^{m} a_{ij} \qquad i=1,2,\cdots,m \tag{5}$$

$$b_{ij}=\frac{b_i-b_j}{2(m-1)}+0.5 \quad i,j=1,2,\cdots,m \tag{6}$$

2.1.3 Calculate the weight of each index

The weight of the i th indexω_iFor[20]:

$$\omega_i=\frac{1}{m}-\frac{1}{2\alpha}+\frac{1}{m\alpha}\sum_{j=1}^{m} b_{ij} \qquad i,j=1,2,\cdots,m \tag{7}$$

$\alpha\alpha$Where, (m-1) / 2, when = (m-1) / 2, the index weight difference is the largest.

2.2 Determine the Objective Weights Based on the I CRITIC Method

CRITIC The method determines the index weight according to the volatility and conflict of the data. Volatility is expressed as the standard deviation of the data under a certain index. On the basis of calculating the conflict degree between a certain index and the other index. According to the volatility and conflict, the information contained in a certain index is found, so as to get the weight of the index. The assignment method has the following deficiencies: (1) when the absolute value of the correlation coefficient of the two indicators is the same but the positive and negative values are different, the correlation reflected is the same; (2) the method mainly considers the volatility and correlation of the data, not the dispersion of the data, so it can be improved in combination with the entropy method[21].

CRITIC The formula for solving the weight method is (data standardization method and solution process, reference [7]):

$$\omega_i = \frac{S_i \sum_{j=1}^{m} \left(1 - r_{ij}\right)}{\sum_{i=1}^{m} S_i \sum_{j=1}^{m} \left(1 - r_{ij}\right)} \tag{8}$$

Where, m represents the number of evaluation indicators, and S_iRepresents the standard deviation of the i th indicator, r_{ij}Represents the correlation coefficient of the two indicators, i and j, using the Pearson correlation coefficient.
There are two main points for the improvement of the CRITIC method: (1) the information entropy value is added to the volatility calculation, and the improved volatility calculation formula is:

$$S_i^{'} = S_i + e_i \tag{9}$$

Where is e_iIs the information entropy of index i (solution process reference [22]).
(2) For the correlation coefficient, r_{ij}Taking the absolute value, the improved conflict calculation formula is:

$$R_i^{'} = \sum_{j=1}^{m} \left(1 - \left|r_{ij}\right|\right) \tag{10}$$

The improved weight calculation formula is:

$$\omega_i = \frac{\left(S_i + e_i\right) \sum_{j=1}^{m} \left(1 - \left|r_{ij}\right|\right)}{\sum_{i=1}^{m} \left(S_i + e_i\right) \sum_{j=1}^{m} \left(1 - \left|r_{ij}\right|\right)} \tag{11}$$

2.3 Determine the Combination Weight Based on the Difference Maximization Idea

The basic idea of difference maximization is that for different evaluation objects, if the evaluation value of each evaluation object is quite different under a certain attribute, then the attribute makes a large contribution to the evaluation results and should be given a large weight; if the difference is small, a small weight should be given.
The subjective weight vector =(was obtained using the F AHP method $\alpha\alpha_1,\alpha_2,\ldots,\alpha_m)^T$, Using the ICRITIC method to obtain the objective weight vector, $\beta = (\beta_1,\beta_2,\ldots,\beta_m)^T$, Combined the two linearly to obtain the combined weight vector, $W = (\omega_1,\omega_2,\ldots,\omega_m)^T$. The W can be expressed as:

$$W = \lambda_1 \alpha + \lambda_2 \beta \tag{12}$$

In the formula,λ_1、λ_2For the combined weight coefficient,$\lambda_1 \geq 0, \lambda_2 \geq 0, \lambda_1^2 + \lambda_2^2 = 1$.
The total deviation of all the evaluated objects can be expressed as:

$$D = \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \omega_j \left|y_{ij} - y_{pj}\right| \tag{13}$$

Where, n is the number of the evaluated objects, and y_{ij}Is the j th index value of the i th evaluation object after the standardized treatment.
Based on the difference maximization idea, the optimization model is constructed, as shown in (14). The combined weight coefficients are solved by constructing the Lagrangian function[23] .

$$\begin{cases} D = \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \omega_j \left|y_{ij} - y_{pj}\right| = \\ \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \left(\lambda_1 \alpha_j + \lambda_2 \beta_j\right) \left|y_{ij} - y_{pj}\right| \\ s.t. \quad \lambda_1^2 + \lambda_2^2 = 1 \\ \lambda_1 \geq 0, \lambda_2 \geq 0 \end{cases} \tag{14}$$

$$\begin{cases} \lambda_1 = \dfrac{\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \alpha_j \left|y_{ij} - y_{pj}\right|}{\sqrt{\left(\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \alpha_j \left|y_{ij} - y_{pj}\right|\right)^2 + \left(\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \beta_j \left|y_{ij} - y_{pj}\right|\right)^2}} \\ \lambda_2 = \dfrac{\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \beta_j \left|y_{ij} - y_{pj}\right|}{\sqrt{\left(\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \alpha_j \left|y_{ij} - y_{pj}\right|\right)^2 + \left(\sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{p=1}^{n} \beta_j \left|y_{ij} - y_{pj}\right|\right)^2}} \end{cases} \tag{15}$$

The final combined weight vector, W, is obtained after substitution of equation (12) and normalized to the combined weight coefficient$_c$=$(\omega_{c1},\omega_{c2},\ldots,\omega_{cm})^T$.

2.4 Evaluate the Target threat Degree Based on the TOPSIS Method

The TOPSIS method is a comprehensive evaluation method of distance. The central idea is to determine the optimal ideal value and the worst ideal value of each evaluation index, and then find the Euclidean distance between each scheme and the positive and negative ideal value, thus obtaining the relative proximity between each scheme and the optimal scheme. The main calculation steps are performed as follows.
(1) Data standardization processing;
(2) Calculate the weighted standardization matrix;
(3) Determine the positive and negative ideal solution;
(4) Calculate the Euclidean distance from the ideal solution;
(5) Calculate the closeness between each scheme and the optimal scheme.

3 EXAMPLE ANALYSIS

It is assumed that in an air defense operation, a batch of air targets are found, and based on the comprehensive analysis of air situation data and various intelligence information, the attribute information of each target is shown in Table 4.

Table 4 Initial attribute values of t argets

Target number	Target type	Altitude	Speed	Time of approach	Shortcuts to routes	Electronic jamming capability
1	Fighter	8	400	170	22	0.8
2	Fighter	3	315	60	20	0.8
3	Cruise missile	0.1	400	150	15	0.6
4	Cruise missile	0.02	600	100	9	0.5
5	Armed helicopter	0.03	120	90	2	0.9
6	Bomber	10	240	140	28	0.5

The raw data was quantified according to the membership function of each threat indicator to obtain the initial decision matrix X:

$$X=\begin{bmatrix}0.6000 & 0.6126 & 0.9093 & 0.5610 & 0.0208 & 0.6000\\0.6000 & 0.9608 & 0.8489 & 0.9305 & 0.0408 & 0.4000\\0.3000 & 1.0000 & 0.9093 & 0.6376 & 0.1653 & 0.0000\\0.3000 & 1.0000 & 0.9727 & 0.8187 & 0.5231 & 0.0000\\0.4000 & 1.0000 & 0.5132 & 0.8504 & 0.9685 & 0.2000\\0.7000 & 0.4449 & 0.7631 & 0.6757 & 0.0019 & 0.4000\end{bmatrix}$$

The X was standardized to obtain the standardized decision matrix Y:

$$Y=\begin{bmatrix}0.7500 & 0.3022 & 0.8620 & 0.0000 & 0.0196 & 1.0000\\0.7500 & 0.9294 & 0.7306 & 1.0000 & 0.0402 & 0.6667\\0.0000 & 1.0000 & 0.8620 & 0.2073 & 0.1691 & 0.0000\\0.0000 & 1.0000 & 1.0000 & 0.6974 & 0.5392 & 0.0000\\0.2500 & 1.0000 & 0.0000 & 0.7833 & 1.0000 & 0.3333\\1.0000 & 0.0000 & 0.5438 & 0.3104 & 0.0000 & 0.6667\end{bmatrix}$$

3.1 Solve the Index Weights Using the FAHP Method

By comparing the threat indicators, the fuzzy complementary matrix A:

$$A=\begin{bmatrix}0.5 & 0.4 & 0.7 & 0.8 & 0.2 & 0.8\\0.6 & 0.5 & 0.8 & 0.9 & 0.4 & 0.8\\0.3 & 0.2 & 0.5 & 0.6 & 0.2 & 0.6\\0.2 & 0.1 & 0.4 & 0.5 & 0.1 & 0.5\\0.8 & 0.6 & 0.8 & 0.9 & 0.5 & 0.9\\0.2 & 0.2 & 0.4 & 0.5 & 0.1 & 0.5\end{bmatrix}$$

Convert the matrix A to a fuzzy consensus matrix:

$$B=\begin{bmatrix}0.5000 & 0.4400 & 0.6000 & 0.6600 & 0.3900 & 0.6500\\ 0.5600 & 0.5000 & 0.6600 & 0.7200 & 0.4500 & 0.7100\\ 0.4000 & 0.3400 & 0.5000 & 0.5600 & 0.2900 & 0.5500\\ 0.3400 & 0.2800 & 0.4400 & 0.5000 & 0.2300 & 0.4900\\ 0.6100 & 0.5500 & 0.7100 & 0.7700 & 0.5000 & 0.7600\\ 0.3500 & 0.2900 & 0.4500 & 0.5100 & 0.2400 & 0.5000\end{bmatrix}$$

A subjective weight vector = $(0.1827,0.2067,0.1427,0.1187,0.2267,0.1227)\alpha^{T}$.

2.3 The weights were Solved Using the ICRITIC Method

In the normalized matrix Y, the separate calculation, the standard deviation and information entropy of each indicator data,
S_j=[0.4306,0.4406,0.3609,0.3849,0.4001,0.4037],e_j=[0.7229,0.8619,0.8876,0.8238,0.5837,0.7376],S_j'=[1.1535,1.3025,1.2485,1.2087,0.9838,1.1413] .
correlation matrix R' For:

$$R'=\begin{bmatrix}1.0000 & 0.8964 & 0.4114 & 0.1068 & 0.7904 & 0.8949\\ 0.8964 & 1.0000 & 0.1968 & 0.4942 & 0.8597 & 0.8124\\ 0.4114 & 0.1968 & 1.0000 & 0.1691 & 0.0338 & 0.3401\\ 0.1068 & 0.4942 & 0.1691 & 1.0000 & 0.4237 & 0.2114\\ 0.7904 & 0.8597 & 0.0338 & 0.4237 & 1.0000 & 0.6323\\ 0.8949 & 0.8124 & 0.3401 & 0.2114 & 0.6323 & 1.0000\end{bmatrix}$$

The objective weight vector is β = $(0.1202,0.1243,0.2634,0.2382,0.1219,0.1320)^{T}$.
The weight of the threat index obtained by each empowerment method is shown in Figure 1.

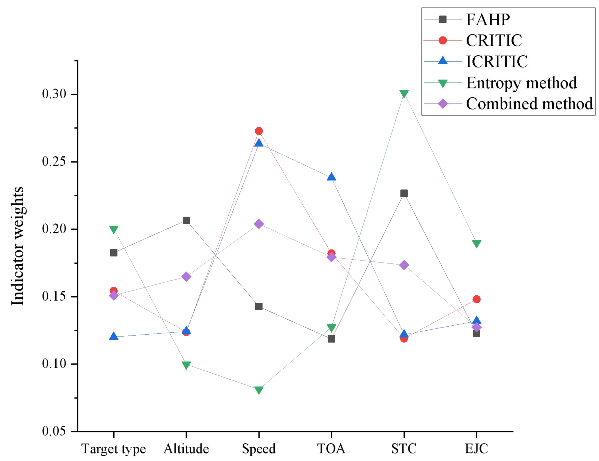

Figure 1 Comparison of Indicator Weights Obtained by Different Weighting Methods

3.3 Combination Empowerment

According to Equation (15) λ_1=0.6967, λ_2.7174=0, obtain the combined weight vector W_c=$(0.1510,0.1649,0.2039,0.1793,0.1735,0.1274)^{T}$.

3.4 Target Threat Level Assessment

The threat degree of each target was evaluated using the TOPSIS method, and the target threat degree under different empowerment methods is shown in Table 5 and Figure 2.

Table 5 Target Threat Level under Different Empowerment Methods

Target Number	FAHP	ICRITIC	Combined Method
1	0.4384	0.4965	0.4746
2	0.5627	0.7045	0.6288
3	0.4451	0.4845	0.4636
4	0.5420	0.6302	0.5813
5	0.6022	0.4678	0.5299

6	0.4000	0.4471	0.4251

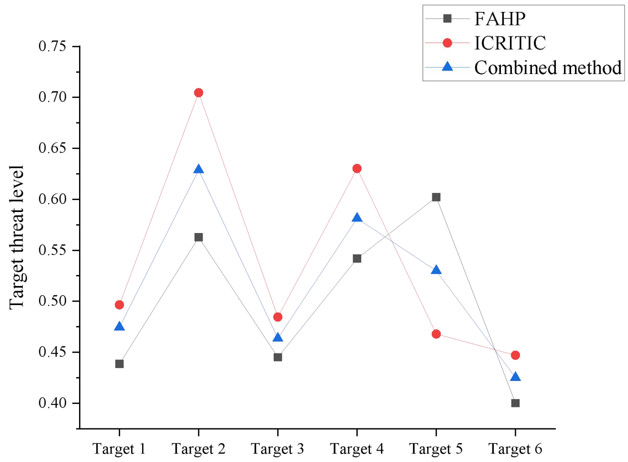

Figure 2 Threat Level of Target under Different Empowerment Methods

3.5 Results Analysis

From the empowerment, using the FAHP method to find the index importance order is: route shortcut, height, type, speed, interference ability, flying time, consistent with the evaluation in the matrix A, reflect decision makers experience and preferences, but the interference ability and flying time weight value is low, failed to fill combined with the actual situation and the use of objective information. CRITIC It is more important to find the target speed and flying time, Mainly because the standard difference of each index is not large, While these both are less correlated with other indicator data, Therefore, give a greater weight; The entropy method considers only the degree of index variation, In the data presented here, Give more weight to the route shortcuts, But if there are more target types, Large differences in indicators such as flight speed, The results are different; ICRITIC Method CRITIC, method with the entropy method, The obtained results were similar to those of the CRITIC, More comprehensive consideration of the volatility, correlation, discreteness of the data, However, the proposed method relies heavily on the data information, It is lacking in considering the purpose of evaluation. Based on the thought of maximizing FAHP method and ICRITIC method, find the objective weight coefficient is slightly larger, get each index importance order: speed, flying time, road shortcut, height, type, interference ability, on the results of the two evaluation methods are complementary, the data is relatively scattered, more easy to decision-making, rationality is stronger.
From the perspective of the target threat degree, using the FAHP method, the ICRITIC method, and the combined empowerment method, the threat degree ranking of the target 1 to 6 is S, respectively$_z$=（5,2,4,3,1,6）、S_k=（3,1,4,2,5,6）、S_c=（4,1,5,2,3,6） .It can be seen that the targets with high threat are low-altitude and ultra-low altitude, but the ranking of target types is different. The evaluation results of the combined empowerment method are more comprehensive considering the decision-making factors and more usable.

4 CONCLUSION

This paper proposes the method of evaluating the air target threat based on FAHP-ICRITIC combination empowerment. Firstly, the FAHP and ICRITIC methods are used to determine the threat index weight, and secondly, the combination weight coefficient of the target threat degree by TOPSIS method. Finally, the threat index weight and target threat degree under different methods are compared and analyzed to verify the effectiveness of the proposed method. The results show that the combined empowerment method can reasonably determine the subjective and objective weight coefficient, comprehensively consider the decision experience and the information provided by the data itself, effectively reduce the uncertainty of the commander in the subjective decision process, and provide a better basis for the command decision.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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