Air Attack Target Threat Assessment Based on Combination Weighting

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***Abstract*—Threat assessment is an important process of quantifying the threat of enemy attacking targets. It is also one of the main basis for commanders to make control decisions in air defense operations. Target threat assessment needs to obtain a large amount of air attack target information from various reconnaissance equipment and battlefield sensors, fuse these information, and get the ranking of the threat degree of air attack targets to our side. In view of the unbalanced distribution of index weight in threat assessment in air defense operations, a target threat assessment model based on combined weight is proposed in this paper. Firstly, according to the index system of air raid target threat assessment, the subjective and objective weights of the indexes are determined by analytic hierarchy process and critical method respectively, and the combined weights are calculated by multiplication synthesis method; Then the threat ranking of targets is obtained by TOPSIS method; Finally, the model is verified by an example. The simulation results show that the air target threat assessment model is reasonable.**

Keywords- Threat Assessment; Air Raid Targets; Combination Weighting; CRITIC; Multiplication Synthesis Method; TOPSIS

I. INTRODUCTION

In modern war air defense operations, with the wide application of various new technologies in the military field, the performance of air attack targets is higher and higher, and the mode of air attack has undergone qualitative changes, which makes modern air defense face more threats. Therefore, in the process of air defense battle command, the commander must analyze and evaluate the battlefield situation and threat of the enemy and ours according to air intelligence, and make decisions quickly and accurately in order to obtain the initiative. For the possible complex war environment and different threat factors of multiple incoming targets, it is very difficult to evaluate and judge them and establish a scientific and accurate evaluation model. Research on more accurate and credible threat assessment methods has become an important development trend in this field.

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At present, there is no accurate definition of threat assessment. In the mid-1980s, the C3 Technical Committee under the joint directors of laboratories (JDL) established an information fusion expert group and developed a general information fusion processing model - JDL model. The model is mainly divided into five levels: information preprocessing, object refinement, situation assessment, threat assessment and excellent process. Its structure is shown in figure 1.

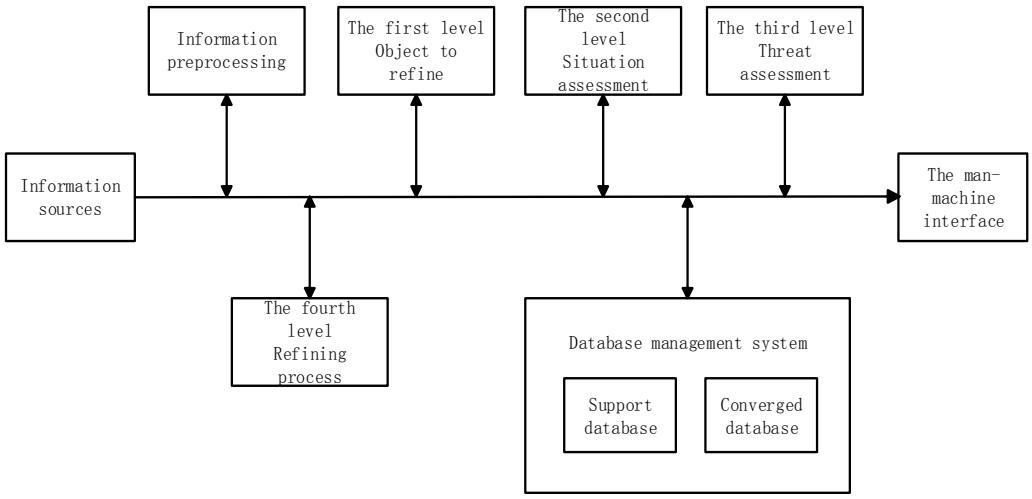

Figure 1. JDL model

Threat estimation is an important content of information fusion decision-making level. It is located in the third level in the model proposed by JDL. It is an important process to quantify the threat of enemy attacking targets. It is also one of the main basis for commanders to make control decisions in air defense operations. In the rapidly changing battlefield environment of information war, it is a very important work to quickly identify the original data of enemy targets obtained from a variety of complex sensors, obtain key information such as target type, position and speed through data preprocessing, judge the threat degree of incoming targets to our side, and provide data support for battlefield commanders to take corresponding combat deployment decisions. Many exploratory studies have been carried out on threat assessment at home and abroad. The main theories and methods are: multi-attribute decision-making method, fuzzy comprehensive evaluation method, grey correlation method and so on. Using these methods to evaluate the threat of air raid targets and determine the attribute weight of targets is a very important work, which is related to the reliability and correctness of target threat assessment results. The attribute weight of the target can be divided into subjective weighting method and objective weighting method according to its source. Subjective weighting method, such as analytic hierarchy process [2], whose index weight is flexibly determined by experts or commanders according to their own experience and battlefield situation, has great subjective randomness, and is also vulnerable to the lack of expert knowledge; Objective weighting method, such as entropy weight method, determines the weight according to the amount of information and correlation degree of indicators, which has a strong mathematical theoretical basis, but often ignores the subjective intention of decision-makers, and both of them have certain limitations.

For the threat assessment of air raid targets, there have been many assessment methods, but there are some problems in determining the index weight, such as over reliance on expert experience, unreasonable index weight distribution and too one-sided assessment results. Therefore, this paper proposes an air raid target threat assessment model based on combined weighting and TOPSIS method [14], which uses analytic hierarchy process and critical method to determine the subjective and objective weights of indicators respectively, taking into account both the subjective factors of experts and the correlation between indicators; The combination weight is

obtained by multiplication synthesis method; Using TOPSIS method to rank the threat of air raid targets [15]; Finally, an example of target threat assessment in air defense operation shows that the method is feasible and effective.

II. DETERMINE THE INDICATORS OF THREAT ASSESSMENT

In air defense operations, the threat target is an air attack target with the intention of attacking, threatening or even destroying our army's position. The threat assessment indicators affecting the target mainly include: target type, flight speed, flight altitude, arrival time, route shortcut, weapon type, penetration capability, jamming capability, etc. These indicators are not independent of each other, and they are more or less related to each other [1]. For example, the penetration ability, jamming ability and the number and type of weapons carried by the target are often determined by the target type. Moreover, since the threat assessment model is based on the fusion of target information collected by sensors, the assessment indicators should be operable in quantification. For the same batch of air raid targets, the fixed defense location will not affect the judgment of target threat [9]. As shown in Figure.2, the threat evaluation model can be established under the premise of fully identifying the target type of the paper.

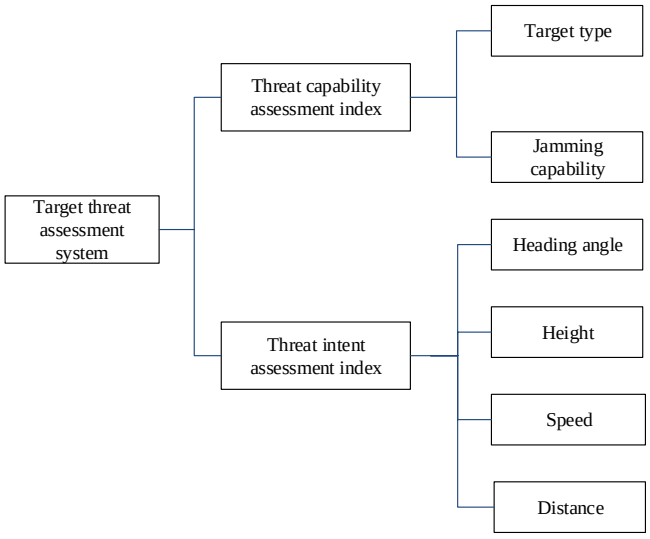

Figure 2. target threat assessment index system

Threat assessment indicators are divided into qualitative indicators and quantitative indicators. From the established threat assessment indicator system, it can be seen that threat capability assessment indicators belong to qualitative indicators, and the target height in threat intention assessment indicators is regarded as qualitative indicators. Here, G.A. Miller's 9-level quantitative theory is used to quantify three qualitative indicators: target type, target interference ability and target height. The incoming weapons for air defense operations in important places are mainly divided into missiles and aircraft. Among them, tactical ballistic missiles are a special kind of missiles, which will not be considered here. According to the actual air defense operations in the current naval key areas, the incoming targets are divided into large targets, small targets and armed helicopters in combination with the operational capability and reflection area of the incoming weapons, which are assigned as 8, 5 and 3 in turn. Among them, large targets can be divided into bombers, fighter bombers, assault aircraft; Small targets can be divided into cruise missiles, air to ground missiles, airborne missiles, stealth aircraft, etc. generally, the speed of such targets is relatively fast, and the maximum flight speed of airborne missiles and stealth aircraft can usually reach Mach 4 ~ 7 [3]; According to the target interference ability, it is divided into four levels: strong, medium, weak and none, with values of 9, 7, 5 and 3 respectively. According to the height of the incoming target, it is divided into high altitude, hollow altitude, low altitude and ultra-low altitude, which are quantified as 3, 5, 7 and 9 in turn.

III. AIR ATTACK TARGET THREAT ASSESSMENT MODEL BASED ON COMBINATION WEIGHTING

A. Determine subjective weight

Among the determination of subjective weight, the most common is analytic hierarchy process. Analytic hierarchy process (AHP) introduces Saaty's 9-level scoring system [13], uses human experience and judgment to quantify the influencing factors of the system hierarchically, constructs the judgment matrix through pairwise comparison, and calculates the relative weight of

the lower level elements of the adjacent level to the upper level elements according to the weight solution method. The specific calculation steps are as follows:

1) Consult experts to get the expert's judgment on the importance of each index and the expert judgment matrix u. The expert's judgment on the importance of each index is shown in Table I.

TABLE I. INDEX IMPORTANCE JUDGMENT

Equally important	Slightly important	Strong importance	Strongly important	Extremely important
1	3	5	7	9

2) Conduct consistency inspection. Test the consistency of U's thinking.

3) The weight of judgment matrix U is solved by analytic hierarchy process and normalized.

Punctuate equations with commas or periods when they are part of a sentence, as in

$$W_j = \sqrt[n]{\prod_{i=1}^{n} u_{ji}} \quad j = 1, 2, \cdots, n \tag{1}$$

$$\alpha = W \Big/ \sum_{j=1}^{n} W_j \quad j = 1, 2, \cdots, n \tag{2}$$

B. Determine objective weight

The common method to determine the objective weight is the information entropy method [6], but this method only considers the amount of information of the index value and ignores the correlation between the indexes. Therefore, this paper introduces the critical method to determine the objective weight of the index [12]. Critical method comprehensively determines the index weight according to the contrast strength and conflict between the evaluation indexes. At the same time, considering the difference and correlation between the indexes, critical method has the advantages of high reliability and independent of expert knowledge background. It is a more scientific objective weighting method. The calculation steps are as follows:

1) Determine the contrast strength S_i is

$$S_j = \sqrt{\frac{1}{m} \sum_{i=1}^{m} \left(d_{ij} - \bar{d}_j \right)^2} \quad j = 1, 2, \cdots, n \tag{3}$$

Conflict *correlation coefficient* r_{ki} *is*

$$r_{kj} = \operatorname{cov}\left(D_k, D_j \right) \Big/ \left(s_k, s_j \right) \quad \text{k,j=1,2,}\cdots,n \tag{4}$$

2) Determine the comprehensive information content of each index

$$G_j = s_j \sum_{k=1}^{n} \left(1 - r_{kj} \right) \quad \text{j=1,2,}\cdots,\text{n} \tag{5}$$

3) The weight coefficient between indicators is determined by the comprehensive information of each indicator, Represented by β

$$\begin{cases} \omega = \left(\omega_1, \omega_2, \cdots, \omega_n \right) \\ \beta = \omega_j = \dfrac{G_j}{\sum_{j=1}^{n} G_j} \quad \text{j=1,2,}\cdots,\text{n} \end{cases} \tag{6}$$

C. Determine the combination weigh

Many experts usually use subjective weighting method or objective weighting method to determine the weight of the index system of the main attack direction of the enemy's incoming target. The subjective method mainly relies on the battlefield experience of battlefield experts to give a certain weight to the relevant battlefield indicators. This method relies too much on expert experience, which will lead to errors due to the lack of knowledge in the field of experts; Objective method refers to collecting relevant battlefield data according to various types of sensors to determine the weight of relevant battlefield indicators, ignoring expert experience and violating the principle of people-oriented in the battlefield.

In order to simultaneously consider the objective information obtained by the sensor and the experience judgment ability of the commander,

and make up for the defect of single subjective and objective weighting, this paper uses the multiplication synthesis method in literature [4] to determine the comprehensive coefficient of subjective and objective weighting, so as to ensure that under the premise of data analysis and excavation, combined weighting can be carried out according to expert criteria and the specific actual situation of air combat. The specific calculation is as follows.

$$\varepsilon_j = \frac{\alpha_j \times \beta_j}{\sum_{j=1}^{n} \alpha_j \times \beta_j}, j = 1, 2, \cdots, n \tag{7}$$

Inside, and β_j are the subjective and objective weights of air raid targets respectively, and ε_j are the weights of the ε_j index.

D. Threat assessment based on TOPSIS

The multi-attribute decision-making theory comprehensively considers multiple factors in the target threat, and can comprehensively reflect the impact of multiple factors on the evaluation. TOPSIS is a relatively mature multi-attribute decision-making method. TOPSIS theory normalizes the original data matrix, sorts and compares the decision-making schemes by calculating the weighted standardization matrix, finds out the optimal scheme (positive ideal scheme) and the worst scheme (negative ideal scheme) among the alternatives, and then calculates the distance between a scheme and the optimal scheme and the worst scheme, so as to obtain the proximity between the scheme and the optimal scheme, And take it as the basis for evaluating the advantages and disadvantages of each scheme [5]. The specific steps are as follows:

1) Construct objective decision matrix $D_{m\times n}$.

2) Determine the combination weight of each threat assessment index W.

3) Determine weighted decision matrix $\bar{A} = \left(\bar{a}_{ij}\right)_{m\times n}, \bar{a}_{ij} = D_{ij} W_j$.

4) Determine the ideal solution $\bar{a}_j^+$ *and negative ideal solution* $\bar{a}_j^-$.

$$\begin{cases} \bar{a}_j^+ = \max\limits_{1\le i\le n}\left(\bar{a}_{ij}\right) \\ \bar{a}_j^- = \min\limits_{1\le i\le n}\left(\bar{a}_{ij}\right) \end{cases} \tag{8}$$

5) Calculate the distance from each target to the ideal solution and negative ideal Solution d_i^+、d_i^-.

$$\begin{cases} d_i^+ = \sum\limits_{j=1}^{m} \left\| \bar{a}_{ij} - \bar{a}_j^+ \right\| \\ d_i^- = \sum\limits_{j=1}^{m} \left\| \bar{a}_{ij} - \bar{a}_j^- \right\| \end{cases} \tag{9}$$

6) Calculate the closeness between each target and the ideal solution T_i^+ *and rank the threats.*

$$T_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} \tag{10}$$

Judge the target threat according to the calculated proximity T_i^+ .The greater the comprehensive evaluation Index T_i^+ , the greater the target threat; The smaller the comprehensive evaluation index T_i^+ ,the smaller the target threat [16].

IV. EXAMPLE SIMULATION

In terms of data selection, on the one hand, it should conform to the reality of air defense operations in important places, on the other hand, the data selection should not lose generality, and the importance of evaluation index factors should be highlighted, so as to fully verify the effectiveness of the method. Therefore, the initial simulation data of literature [8] is used for simulation analysis. Suppose that in an air defense battle, there are the following 6 groups of air attack targets. The target threat degree constitutes the evaluation index system according to the target type, speed, heading angle, jamming ability, air

raid altitude and distance. We obtained the threat evaluation index parameters of these six batches of targets through various sensors, as shown in Table II.

According to the calculation method in Section 1, the attribute values of the six incoming target threats are quantified, and the threat values are shown in Table III.

1) Determine subjective weights. According to AHP subjective weighting method, the calculated subjective weight is:

α=(0.2594, 0.2227, 0.0238, 0.1225, 0.0909, 0.0663)

2) Determine objective weights. First, normalize the threat attribute values, as shown in Table IV

TABLE II. THREAT INFORMATION OF AIR ATTACK TARGET

	Target type	**Speed(m/s)**	**Heading angle（° ）**	**Jamming capability**	**Air raid altitude**	**Distance（km）**
target 1	large	400	5	strong	hollow altitude	100
target 2	large	720	8	strong	hollow altitude	150
target 3	small-scale	1600	3	none	low altitude	300
target 4	small-scale	1200	5	none	low altitude	260
target 5	large	280	10	weak	ultra-low altitude	140
target 6	helicopter	100	15	medium	ultra-low altitude	120

TABLE III. TARGET ATTRIBUTE THREAT VALUE

	Target type	**Speed(m/s)**	**Heading angle（° ）**	**Jamming capability**	**Air raid altitude**	**Distance（km）**
target 1	5	400	5	8	4	100
target 2	5	720	8	8	4	150
target 3	8	1600	3	2	6	300
target 4	8	1200	5	2	6	260
target 5	5	280	10	4	8	140
target 6	3	100	15	6	8	120

TABLE IV. STANDARDIZATION DECISION TABLE

	Target type	**Speed(m/s)**	**Heading angle（° ）**	**Jamming capability**	**Air raid altitude**	**Distance（km）**
target 1	0.4	0.2	0.8333	1	0	1
target 2	0.4	0.4133	0.5833	1	0	0.75
target 3	1	1	1	0	0.5	0
target 4	1	0.7333	0.8333	0	0.5	0.2
target 5	0.4	0.12	0.4167	0.3333	1	0.8
target 6	0	0	0	0.6667	1	0.9

According to equation (3) ~ equation (6), the objective weight is calculated as:

$$\beta = (0.1836, 0.1294, 0.2706, 0.1753, 0.1144, 0.1267)$$

3) Determine the combination weight. According to equation (7), the combination weight is calculated as:

$$W = [0.1813, 0.2100, 0.0993, 0.1561, 0.2400, 0.1133]$$

4) The weighted normalized decision matrix can be obtained from the combination weight as follows:

$$\bar{A} = \begin{Bmatrix} 0.0725 & 0.042 & 0.0827 & 0.1561 & 0 & 0.1133 \\ 0.0725 & 0.0868 & 0.0579 & 0.1561 & 0 & 0.0850 \\ 0.1813 & 0.2100 & 0.0993 & 0 & 0.1200 & 0 \\ 0.1813 & 0.1540 & 0.0827 & 0 & 0.1200 & 0.0227 \\ 0.0725 & 0.0252 & 0.0414 & 0.0520 & 0.2400 & 0.0904 \\ 0 & 0 & 0 & 0.1041 & 0.2400 & 0.1020 \end{Bmatrix}$$

5) According to equation (8) and equation (10) of TOPSIS method, the relative closeness of target threat is , It can be seen from this that the ranking results of the threat size of the six groups of air raid targets are as follows: target3> target 4> target 2> target 1> target 5> target 6.

Figure 3. Comparison of simulation decision and sample decision results

It can be seen from Figure.3 that the ranking results are basically consistent with the decision results of the original samples in document [10], which shows the feasibility and effectiveness of this threat assessment method. It can be seen intuitively from the figure that when using this method for threat assessment, there is a large gap between the threat degree of each target, so the decision-maker can get the threat ranking of air raid targets more quickly.

V. USING THE TEMPLATE

For the threat assessment of air raid targets, in order to make good use of the objective information obtained by sensors in the threat assessment model and integrate the subjective experience and command preference of command decision-makers, this paper uses the method of combined weighted TOPSIS to establish the threat assessment model. Due to the impact of different weighting methods on threat assessment indicators, the target threat degree is also different. In the process of threat assessment, commanders flexibly use the combined weighting method combining analytic hierarchy process and critic method according to the battlefield situation to reasonably determine the weight of assessment indicators, use the ranking method approaching the ideal solution to quickly and accurately assess the threat of air raid targets, and quickly implement fire attack on targets with high threat, which has a certain auxiliary decision-making function. When the sensor detection ability is limited, the commander's experience judgment ability should be appropriately added in order to further improve the threat assessment method. The proposed method of determining the subjective weight has strong operability, and the commander's decision-making opinions are easy to quantify. However, when calculating the combination weight, the multiplication formula is easy to amplify the difference, which makes the evaluation result not objective enough. In the future research, we should further improve the above deficiencies.

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