An Evaluation Method of Combined Forces Electronic Countermeasure Capability based on Grey Relational Analysis

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Abstract: Electronic warfare in battle is a dynamic game process with incomplete information, in which there are not only complex technical factors, but also a lot of uncertain factors, fuzzy factors or human factors, so it is difficult to model and evaluate its capability. In this paper, the index system of the electronic countermeasure capability of the synthetic army is established, and a method of multi-level grey relational analysis and AHP is used to analyse and evaluate the electronic countermeasure capability of the synthetic army. A complete set of evaluation method steps is put forward and verified by an example. Compared with the past models and methods, they are easy to operate, applicable and scientific in conclusion, which is convenient to analyse and evaluate the electronic countermeasures capability of multiple units. It is of great theoretical significance and practical value for the development of electronic countermeasure capability construction and scientific assessment and evaluation of synthetic forces.

1. Introduction
Electronic countermeasures are technical operations that use electromagnetic energy and other technical means to control the electromagnetic spectrum, weaken and destroy the operational effectiveness of enemy electronic information equipment, systems, and networks, and at the same time protect their own electronic information equipment, systems, and other operational effectiveness. Battlefield contract operations electronic countermeasures support operations have complex patterns, and modeling and comprehensive evaluation of their capabilities is a difficult problem. After the military reform, the combined forces under the jurisdiction of the first support electronic counterattack force, its strength structure and attributes have also been adjusted. Therefore, modeling and evaluating the electronic countermeasures capabilities of synthetic troops has strong practical significance and is a relatively complex system engineering.

The comprehensive evaluation method is a multidisciplinary and trans-disciplinary research field. It mainly studies and analyzes social, economic, military and other issues from the perspective of statistics, system engineering or specific specialty. At present, the comprehensive evaluation methods are widely used, including analytic hierarchy process, fuzzy comprehensive evaluation, data envelopment analysis, artificial neural network, grey system and other methods. Using modern comprehensive evaluation methods to evaluate electronic countermeasure equipment and operational capability models, the main research data in this area are: Literature[1] A mathematical model was established using the analytic hierarchy process to evaluate and analyze airborne electronic
countermeasure capabilities; Literature[2] Establish and standardize the evaluation indicators of the electronic countermeasures action plan, convert the linguistic evaluation information into triangular fuzzy numbers, and then obtain the comprehensive evaluation value of the plan; Literature[3] established the use of grey analytic method to evaluate the effectiveness of the underwater acoustic countermeasure system Literature[4] focused on the three major aspects of evaluation methods, evaluation criteria, and evaluation index systems around the operational performance and operational effectiveness of electronic equipment and systems such as radar, communications, and optoelectronics. However, the field of electronic countermeasure assessment has not yet formed a set of recognized theoretical systems and implementation standards. In addition, with the rapid development of electronic countermeasure technology and equipment, especially the emergence of new systems and equipment, the application of new tactics, and the increasing complexity of the electromagnetic environment, the field of electronic countermeasures is facing new challenges.

Presently, the Army's electronic countermeasure evaluation researches are still weak. This article use the grey theory to evaluate and analyze the electronic countermeasures capabilities of the combined forces from the perspective of the content of the operations. The proposed method has strong applicability and simple operation, which is convenient to analyze and compare the electronic countermeasures capabilities of multiple units.

2. A design of the EW capability evaluation system

Combined with the electronic countermeasures mission of the combined forces, they are divided according to the content of electronic countermeasures. They can be divided into three elements: electronic countermeasure reconnaissance, electronic jamming, and electronic defense [5], and 12 three-level indicators, as shown in Figure 1.

![Index System of Electronic Countermeasure Capability Model of Synthetic Force](image)

Figure 1. Index System of Electronic Countermeasure Capability Model of Synthetic Force
3. Multi-level grey correlation analysis model

The theory of grey system was proposed by the famous scholar Professor Deng Ju-long in 1982. The object of his research is the "poor information" uncertainty system with "some information is known and some information is unknown", and he realizes the exact description and understanding of the real world by generating and developing some known information. The grey system theory mainly uses known information to determine the unknown information of the system, so that the system changes from "grey" to "white". Its biggest feature is that it does not have strict requirements on the sample size and does not require any distribution.

Step 1. Select reference sequence

Set i as the serial number of each evaluation unit i, i = 1, 2, ..., m; k as the serial number of each evaluation index k, k = 1, 2, ..., n; v_{ik} as the evaluation value of the first index i of each evaluation unit k. Take the best value of each index v_{0k} to refer to the entity of series V_0, so there is:

\[ V_0 = (v_{01}, v_{02}, ..., v_{0n}) \]

Where: v_{0k} = Optimum(v_{ik}), i = 1, 2, ..., m; k = 1, 2, ..., n

For a system consisting of m evaluation units and n evaluation indexes, there is the following matrix:

\[ V = (v_{ik})_{m \times n} = \begin{bmatrix} v_{i1} & v_{i2} & \cdots & v_{in} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \]

The selected reference sequence is:

Step 2. Standardized treatment of index value

In order to make the indicators comparable, the values of each indicator need to be standardized. The goal of processing is to make the values dimensionless. There are generally three processing methods:

a. Initialization

\[ x_{ik} = \frac{v_{ik}}{v_{i1}} = (x_{i1}, x_{i2}, ..., x_{in}) \]  \hspace{1cm} (1)

The initial value method is suitable for dimensionless with certain trend phenomena, for example, a series that shows a steady growth (down) trend. Through the initial value processing, the growth (down) trend can be more obvious.

b. Averaging

\[ x_{ik} = \frac{v_{ik}}{v_{i1}}, \quad \bar{v}_i = \frac{1}{n} \sum_{k=1}^{n} v_{ik} \]  \hspace{1cm} (2)

Generally speaking, the average method is more suitable for data processing without obvious up and down trend.

c. Intervalization

\[ x_{ik} = \frac{v_{ik} - \min v_{ik}}{\max v_{ik} - \min v_{ik}} \]  \hspace{1cm} (3)

The three methods should not be mixed or overlapped. One of them can be selected according to the actual situation when analyzing the system factors.

After normalization, the following results are obtained:

\[ X = (x_{ik})_{m \times n} = \begin{bmatrix} x_{i1} & x_{i2} & \cdots & x_{in} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \]

Step 3. Calculation of correlation coefficient

Take the normalized sequence \( X_0 = (x_{01}, x_{02}, ..., x_{0n}) \) as the reference sequence and \( X_i = (x_{i1}, x_{i2}, ..., x_{in})(i = 1, 2, ..., m) \) as the comparison sequence. The calculation formula of the correlation coefficient is as follows:

\[ \xi_{ik} = \frac{\min_k |x_{0k} - x_{ik}| + \rho \max_k |x_{0k} - x_{ik}|}{|x_{0k} - x_{ik}| + \rho \max_k |x_{0k} - x_{ik}|} \]  \hspace{1cm} (4)
\[ i = 1,2,\ldots m; \ k = 1,2,\ldots n \]

Where \( \rho \) is the resolution coefficient, \( \rho \in [0,1] \).

Using the formula to calculate the correlation coefficient \( X \), the following correlation coefficient matrix is obtained:

\[ E = (\xi_{ik})_{m \times n} = \begin{bmatrix}
\xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\
\xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\xi_{m1} & \xi_{m2} & \cdots & \xi_{mn}
\end{bmatrix} \]

Where: \( \xi_{ik} \) is the correlation coefficient between the \( i \)th index of the \( k \)th evaluation unit and the \( k \)th best index.

Step 4. Calculate the association degree of a single level

Considering that the importance of each index is different, the calculation method of correlation degree adopts weight times correlation coefficient. According to the expert method, the priority weight of each index of a certain level relative to the target of the upper level is:

\[ W = (\omega_1, \omega_2, \ldots, \omega_t) \]

Where: \( \sum_{k=1}^{t} \omega_k = 1 \), \( t \) indicates the number of indicators in the layer. Then the calculation formula of correlation degree is:

\[ R = (r_i)_{1 \times m} = (r_1, r_2, \ldots, r_n) = WE^T \]  

Step 5. Calculating the final relevance of multi-level evaluation system

For a multi-layer evaluation system composed of \( L \) layers, the calculation method of the final correlation degree is as follows: the correlation coefficient of each index in \( k \) layer is synthesized to obtain the correlation degree of each index in \( k-1 \) layer, which is the upper layer to which they belong; then the correlation degree obtained in this layer is taken as the original data, and the correlation degree of each index in \( K-2 \) is synthesized continuously, and so on until the highest level index is obtained. Until the correlation degree of the subject matter.

Step 6. Sorting of engineering support capacity

Sort according to the degree of correlation \( r_i (i = 1,2,\ldots m) \) size, the order of the magnitude of the correlation is the order of the strength of the engineering support capability.

4. Example analysis

As mentioned above, the electronic countermeasure capability index system of the synthetic force (Figure 1) consists of three levels of indexes: target level and electronic countermeasure capability (b); the second level: element level, including electronic countermeasure reconnaissance capability (B1), electronic jamming capability (B2) and electronic defense capability (B3); the third level: index level, a total of 12 indexes.

4.1 Determine the weight of each level and comprehensive weight of the index system

The indicators of each level of the electronic countermeasure ability have different weights according to different tasks. Considering the use of expert survey method and analytic hierarchy process (AHP) empowerment in general contract battles, after the consistency check, the CR values of the four judgment matrices are 0.008, 0.02, 0.02, and 0.0004, all satisfying \( CR <0.1 \), and the judgment matrix has consistency. The process of the specific analytic method is omitted here, and the results are directly given. The single-layer weights at each level are:

Next level index weight of electronic countermeasure capability of synthetic force

\[ W_B = (0.2970, 0.5396, 0.1634) \]

The weight of the next level of electronic countermeasure reconnaissance capability

\[ W_{B1} = (0.4287, 0.1472, 0.2303, 0.1937) \]

Electronic interference capability next level indicator weight

\[ W_{B2} = (0.4287, 0.1472, 0.2303, 0.1937) \]
Electronic defense capability next level indicator weight

\[ W_{B4} = (0.2627, 0.1413, 0.4550, 0.1411) \]

Therefore, the comprehensive weight of the underlying indicators is shown in Table 1 and Figure 2. From Figure 2, it can also be seen intuitively that the comprehensive weight "electronic jamming" has a relatively high weight and "electronic defense" is relatively low. For the combined force's electronic countermeasures capability, in the three-level indicator, "communication jamming" has the largest weight.

| Table 1. Comprehensive weight table |
|-------------------------------------|
| Indicator 1 | Indicator 2 | Indicator 3 | Indicator 4 |
| B_1 | 0.1273 | 0.0437 | 0.0684 | 0.0575 |
| B_2 | 0.2313 | 0.0794 | 0.1243 | 0.1045 |
| B_3 | 0.0429 | 0.0231 | 0.0743 | 0.0231 |

Figure 2. Comprehensive Weight Distributions

4.2 Determine the value of the evaluation index

The types of indicators of the electronic countermeasure capability model are complex and quantified. Taking the "communication interference" performance index as an example, we can collect the node interference rate in the confrontation exercise to represent the "communication interference" performance. Node interference rate refers to the degree to which enemy tactical Internet nodes are interfered by us within a certain period of time. The greater the node interference rate, the better the interference effect. The specific index is the ratio of the number of interfered nodes to the number of deployed working nodes.

Assuming that the number of interfered nodes is \( N_i \) and the number of nodes performing work is \( N_r \), the node interference rate can be expressed as:

\[ R_n = \frac{N_i}{N_r} \] (6)

According to the interference rate of nodes, dimensionless processing is carried out. For indicators that are difficult to quantify, such as "command and control", "mobile performance", etc., the indicator score is obtained by combining the evaluation and scoring of special training data, such as dividing the indicators into "excellent", "good", and "passing". Failed "four-level system, [9,10] is classified as" excellent", [7,9) is classified as" good", [6,7) is classified as" passed", and [0,6) is classified as "failed". The process of its specific evaluation index value is omitted. In order to facilitate the unified measurement in the later period, the index value is standardized to be between 0 and 10.

Take the mock data \((V_1, V_2, V_3, V_4)\) of the electronic countermeasures of the four combined forces as an example. As shown in Table 2, \( V_1 \) is characterized by a high level of communication countermeasure training, so the values of indicators \( B_{11}, B_{21}, B_{31} \) are high. The characteristics of \( V_2 \) are radar countermeasures have a strong capability, and the values of indicators \( B_{12}, B_{22}, B_{32} \)
are relatively high. The characteristics of $V_3$ have outstanding photoelectric countermeasures and the values of indicators $B_{31}$, $B_{32}$ and $B_{33}$ are relatively high. The characteristics of $V_4$ are relatively balanced in all aspects, and are no shortcomings. Take the reference sequence $v_{0k} = \text{Optimum}(v_{ik})$, as shown in the table 2.

| Index | $V_1$ | $V_2$ | $V_3$ | $V_4$ | Reference index value |
|-------|-------|-------|-------|-------|-----------------------|
| $B_{11}$ | 8     | 5     | 5     | 6     | 8                     |
| $B_{12}$ | 5     | 8     | 5     | 6     | 8                     |
| $B_{13}$ | 5     | 5     | 8     | 6     | 8                     |
| $B_{14}$ | 5     | 5     | 5     | 5     | 5                     |
| $B_{21}$ | 8     | 5     | 5     | 6     | 8                     |
| $B_{22}$ | 5     | 8     | 5     | 6     | 8                     |
| $B_{23}$ | 5     | 5     | 8     | 6     | 8                     |
| $B_{24}$ | 5     | 5     | 5     | 7     | 7                     |
| $B_{31}$ | 8     | 5     | 5     | 6     | 8                     |
| $B_{32}$ | 5     | 8     | 5     | 6     | 8                     |
| $B_{33}$ | 5     | 5     | 8     | 7     | 8                     |
| $B_{34}$ | 5     | 5     | 5     | 6     | 6                     |

4.3 Calculate single-level correlation

According to the formula (4) in the previous section, take the resolution coefficient $\rho = 0.5$, and calculate the correlation coefficient $\xi_{ik}(i = 1, 2, \cdots, m; k = 1, 2, \cdots, n)$ values of each index and the reference number series as shown in Table 3.

| Index | $V_1$ | $V_2$ | $V_3$ | $V_4$ |
|-------|-------|-------|-------|-------|
| $B_{11}$ | 1     | 0.33  | 0.33  | 0.43  |
| $B_{12}$ | 0.33  | 1     | 0.33  | 0.43  |
| $B_{13}$ | 0.33  | 0.33  | 1     | 0.43  |
| $B_{14}$ | 1     | 1     | 1     | 1     |
| $B_{21}$ | 1     | 0.33  | 0.33  | 0.43  |
| $B_{22}$ | 0.33  | 0.33  | 1     | 0.43  |
| $B_{23}$ | 0.33  | 0.33  | 1     | 0.43  |
| $B_{24}$ | 0.43  | 0.43  | 0.43  | 1     |
| $B_{31}$ | 1     | 0.33  | 0.33  | 0.43  |
| $B_{32}$ | 0.33  | 1     | 0.33  | 0.43  |
| $B_{33}$ | 0.33  | 0.33  | 1     | 0.6   |
| $B_{34}$ | 0.6   | 0.6   | 0.6   | 1     |

Using formula (5) $R = WE^T$, we can get the correlation matrix of the second level index:

$$R_{BX} = W_{BX}E_{BX}^T = \begin{bmatrix} 0.75 & 0.56 & 0.62 & 0.54 \\ 0.64 & 0.45 & 0.51 & 0.54 \\ 0.55 & 0.46 & 0.67 & 0.59 \end{bmatrix}$$

Furthermore, the correlation degree of the indicator B can be obtained by multiplying the first level weight $W_B$ matrix by the second level correlation degree $R_{BX}$ matrix.

$$R_B = W_BR_{BX} = (0.65, 0.485, 0.566, 0.547)$$
Figure 3. Radar chart of the second level index correlation degree

Ranking of electronic countermeasure capabilities: Generally, the correlations of the four forces are not much different. According to the final correlation degree in $R_B$, it can be obtained that the combined forces $V_1, V_2, V_3, V_4$'s electronic countermeasures are in the order of $V_1 > V_3 > V_4 > V_2$. The conclusion shows that under this evaluation system, $V_1$ with a higher level of communication confrontation is better than $V_3$ with a more prominent optoelectronic countermeasure capability, better than $V_4$ with a more balanced comprehensive index, and better than $V_2$ with high radar countermeasure capability.

5. Conclusions
According to the characteristics of the electronic countermeasure capability of the Army synthetic force, this paper constructs an electronic countermeasure capability index system of the ground battlefield, and combines the grey theory and the analytic hierarchy process (AHP) to give weights to evaluate the effectiveness of the electronic countermeasure capability. It can provide theoretical support and basis for the evaluation and assessment of the electronic countermeasure capability of the combined forces. The next step will further improve the electronic countermeasures capability index system and improve the comprehensive evaluation method for specific actions based on practical data.

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