An evaluation method of synthetic force engineering support capability based on multi-level grey system

Jisong Fan\textsuperscript{1,3}, Jiawei Xu\textsuperscript{1} and Hui Ren\textsuperscript{2}

\textsuperscript{1} Army Engineering University Training Base, Xuzhou Jiangsu 221004, China; \textsuperscript{2} Air Force Logistics University, Xuzhou Jiangsu 221002, China

\textsuperscript{3} Email: pinemothe@126.com

Abstract. Engineering support operations are characterized by diverse tasks, dispersed regions, complex command coordination, many points, long lines and wide areas. It has been difficult to model and evaluate its capability comprehensively. In this paper, according to the characteristics, the index system of support capability of synthetic Force project is constructed, and the support capability of synthetic Force project is analysed and evaluated by combining multi-level grey relational analysis theory and AHP. An evaluation method is put forward and verified by an example. Compared with the past models and methods, they are simple to operate, applicable and scientific in conclusion. It is convenient to analyze and compare the support capacity of multiple units. It can provide support and basis for the development of engineering support capacity construction and scientific assessment of synthetic Force.

1. Introduction

Engineering support is an important military operation that guarantees the concealed security, command stability, movements in battlefield and prevents and delays the movement of enemy forces. The battlefield engineering support itself has the characteristics of multiple points, long lines, and wide areas. Modeling and comprehensive evaluation of its capabilities has always been a difficult issue. In addition, as a unit rebuilt after the military reform, the structure and attributes of engineering support force of the Force have been adjusted. Therefore, it is of great practical significance to model and evaluate the engineering support capability of the synthetic Force, which is a relatively complex work.

The comprehensive evaluation method is a multidisciplinary and trans-disciplinary research field. It mainly studies and analyzes society, economy, 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. The modern comprehensive evaluation method is used to evaluate the engineering support capability model. There are not many research materials in this respect, mainly including: the literature\cite{1} comprehensively and systematically analyzes the generation mode of engineering support capability under the condition of informatization, and uses the "cloud" theory evaluation model to analyze and evaluate the element attributes of engineering support capability; the literature\cite{2} uses the intuitionistic fuzzy comprehensive evaluation method; the literature\cite{3} proposed a method to analyze wartime engineering support capabilities using quantitative simulation models based on comparison of multiple capability analysis methods. In this paper, the grey theory is used to evaluate and analyze the engineering support
capacity of the synthetic Force. The method proposed in this paper has strong applicability and simple operation, which is convenient to analyze and compare the engineering support capacity of multiple units.

2. A design of evaluation system of engineering support capability

Combined with the engineering support tasks of the synthetic Force, divided by the professional functions of engineering support, it can be divided into seven elements: engineering reconnaissance capability, headquarters building capability, engineering camouflage capability, maneuver support capability, obstacles setting capability, obstacle breaking capability, water supply station construction capability, and 28 three-level indicators, as shown in Table 1.

| Table 1. Index system of engineering support capability model. |
|---|---|---|
| target level | Element level | Indicator |
| Engineering support capability (B) | Engineering reconnaissance capability (B1) | B11 |
| | | B12 |
| | | B13 |
| | | B14 |
| | | B15 |
| | Headquarters building capability (B2) | B21 |
| | | B22 |
| | | B23 |
| | | B24 |
| | | B25 |
| | Engineering camouflage capability (B3) | B31 |
| | | B32 |
| | | B33 |
| | Maneuver support capability (B4) | B41 |
| | | B42 |
| | | B43 |
| | | B44 |
| | | B45 |
| | Obstacles setting capability (B5) | B51 |
| | | B52 |
| | | B53 |
| | | B54 |
| | Obstacle breaking capability (B6) | B61 |
| | | B62 |
| | | B63 |
| | | B64 |
| | Water supply station construction capability (B7) | B71 |
| | | B72 |

3. An evaluation model of multi-level grey systems

Relevance analysis is the basis of grey analysis, evaluation, and decision-making. Grey Relational Analysis provides a method for quantitatively analyzing the degree of correlation between two factor sets. Take each index value of the engineering support capacity of the ideal synthetic Force as the entity $X_0$ of the reference sequence $x_{0k}$, and each index of the evaluated Force as the entity $X_I$ of the comparison sequence $x_{ik}$, and calculate the correlation degree $r_i$. The greater the correlation degree is, the more similar the evaluated Force index is to the ideal state, the stronger the engineering support capability is; otherwise, the weaker the support capability is. Therefore, the order of correlation degree
is the order of the support ability of the evaluated Force project. The evaluation steps are as follows[4, 5].

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:

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

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:

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

The selected reference sequence is:

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

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 Initialization processing methods:

\[ x_{ik} = \frac{v_{ik}}{v_{i1}} = (x_{i1}, x_{i2}, \cdots, x_{in}) \tag{2} \]

After normalization, the following results are obtained:

\[ X = (x_{ik})_{m \times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{3} \]

Step 3. Calculation of correlation coefficient
Take the normalized sequence \( X_0 = (x_{01}, x_{02}, \cdots, x_{0n}) \) as the reference sequence and \( X_i = (x_{i1}, x_{i2}, \cdots, x_{in}) \) (i = 1,2,⋯ m) as the comparison sequence. The calculation formula of the correlation coefficient is as follows:

\[ \xi_{ik} = \frac{\min_{i} \min_{k} |x_{ok} - x_{ik}| + \rho \max_{i} \max_{k} |x_{ok} - x_{ik}|}{|x_{ok} - x_{ik}| + \rho \max_{i} \max_{k} |x_{ok} - x_{ik}|} \tag{4} \]

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:

\[ E = (\xi_{ik})_{m \times n} = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{m1} & \xi_{m2} & \cdots & \xi_{mn} \end{bmatrix} \tag{5} \]

Where: \( \xi_{ik} \) is the correlation coefficient between the ith index of the kth evaluation unit and the kth 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:

\[ W = (\omega_1, \omega_2, \cdots, \omega_n) \]

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:

\[ R = (r_1)_{1 \times m} = (r_1, r_2, \cdots, r_n) = WE^T \tag{6} \]
Step 5. Calculating the final relevance of multi-level evaluation system
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 \( r_i(i = 1, 2, \cdots m) \) size, the order of the magnitude of the correlation is the order of the strength of the engineering support capability.

4. Analysis of an example
As mentioned above, the composite force engineering support capability indicator system (Table 1) is composed of three levels of indicators, the target level, and the engineering support capability (B); the second level: the element level, including engineering reconnaissance capability, headquarters building capability, engineering camouflage capability, maneuver support capability, obstacles setting capability, obstacle breaking capability, water supply station construction capability; third layer: indicator layer, 28 indicators at all.

4.1. Determine the weight of each level and comprehensive weight
Using expert survey method and AHP empowerment, the process of specific AHP method is omitted here, and the results are given directly. The weight of each layer is:
- Engineering support capacity, \( W_B = (0.0670, 0.1386, 0.0710, 0.2450, 0.2596, 0.1255, 0.0932) \)
- Engineering reconnaissance capability, \( W_{B1} = (0.4598, 0.1384, 0.1249, 0.1384, 0.1384) \)
- Build command post capabilities, \( W_{B2} = (0.4587, 0.0725, 0.0725, 0.2410, 0.1552) \)
- Engineering camouflage capability, \( W_{B3} = (0.6370, 0.2583, 0.1047) \)
- Mobile support capability, \( W_{B4} = (0.1392, 0.3714, 0.2692, 0.1392, 0.0810) \)
- Barrier-breaking ability, \( W_{B5} = (0.3750, 0.3750, 0.1250, 0.1250) \)
- Barrier setting ability, \( W_{B6} = (0.1667, 0.3333, 0.3333, 0.1667) \)
- Build water supply station capacity, \( W_{B7} = (0.5000, 0.5000) \)

Therefore, the comprehensive weight of the underlying indicators is shown in Table 2 and Figure 1. It can also be intuitively seen from Figure 1 that the index weights in the "engineering reconnaissance capability" are relatively low, while the index weights in the "mobile support capability" and "barrier-breaking capability" are relatively high.

4.2. Determine the values of the evaluation index
The types of indicators for the engineering support capability model are more complex. Among the three-level indicators, for indicators that can be more easily quantified, for example, "acquisition data acquisition", "construction work", "road operations", "mining operations", etc., select the operation capacity or operation time in their typical operations as The quantized values are shown in Table 3 [6]. If the system index \( V_i \) has a negative correlation with the main behavior \( V_0 \), such as the operation time, it can be reversed or counted down for standardized processing. For indicators that are difficult to quantify, the indicator scores are obtained by combining the evaluation and evaluation of special exercises, such as dividing the indicators into "excellent", "great", "pass"", "Failed" four-level system, [9, 10] is divided into" excellent ", [7, 9) is divided into "great ", [6, 7) is divided into" pass", [0, 6) is divided into "failed".
Table 2. Comprehensive weight table.

| Indicator | Indicator 1 | Indicator 2 | Indicator 3 | Indicator 4 | Indicator 5 |
|-----------|-------------|-------------|-------------|-------------|-------------|
| B1        | 0.0308      | 0.0093      | 0.0084      | 0.0093      | 0.0093      |
| B2        | 0.0636      | 0.0100      | 0.0100      | 0.0334      | 0.0215      |
| B3        | 0.0452      | 0.0183      | 0.0074      | 0        | 0          |
| B4        | 0.0341      | 0.0910      | 0.0660      | 0.0341      | 0.0198      |
| B5        | 0.0974      | 0.0974      | 0.0324      | 0.0324      | 0.0209      |
| B6        | 0.0418      | 0.0418      | 0.0418      | 0.0209      | 0          |
| B7        | 0.0466      | 0.0466      | 0          | 0          | 0          |

Figure 1. Comprehensive weight distributions.

Table 3. Road constructing capacity.

| Operation item | Operating conditions | Operational efficiency | Operational force |
|----------------|----------------------|------------------------|-------------------|
| To build a military road | Medium undulations | \( \times \times \text{km/(platoon \cdot day)} \) | Engineering platoon | operation platoon |

The process of specific evaluation index value is omitted. In order to facilitate the unified measurement in the later stage, the index value is standardized to 0-10, as in literature [7, 8, 9].

Taking the engineering support capability simulation data \((V_1, V_2, V_3, V_4)\) of 4 synthetic Forces as an example, as shown in Table 4, the synthetic Force \(V_1\) is characterized by high reconnaissance and physical fitness, so the values of indicators \(B_{11}, B_{14}\) and \(B_{71}\) are higher; the characteristics of the synthetic Force \(V_2\) it has a strong engineering operation ability, and the values of indicators \(B_{21}, B_{31}\), and \(B_{42}\) are high. The characteristics of the synthetic Force \(V_3\) are relatively balanced in all aspects, there are no too prominent indicators, and there are no shortcomings; the characteristic of the synthetic Force \(V_4\) is its relatively strong support capabilities. But the ability to work is weak, the values of indicators \(B_{25}, B_{33}, B_{45}\) are high. Take \(v_{0k} = \text{Optimum}(v_{ik})\) as the reference sequence, as shown in Table 4.

4.3. Calculate single-level correlations

According to the formula (4) in the previous section, take the resolution coefficient \(\rho = 0.5\), and calculate the correlation coefficient \(\xi_{ik}(i = 1,2,\ldots ; k = 1,2,\ldots n)\) values of each index and the reference number series as shown in Table 5.
Table 4. Simulation value and ideal value of each index of engineering support capability.

|       | V1 | V2 | V3 | V4 | Optimum value |
|-------|----|----|----|----|---------------|
| B11   | 9  | 6  | 7  | 6  | 9             |
| B12   | 7  | 5  | 8  | 6  | 8             |
| B13   | 7  | 6  | 7  | 6  | 7             |
| B14   | 9  | 6  | 7  | 5  | 9             |
| B15   | 6  | 5  | 8  | 6  | 8             |
| B21   | 6  | 8  | 8  | 6  | 8             |
| B22   | 6  | 7  | 7  | 6  | 7             |
| B23   | 6  | 7  | 7  | 7  | 7             |
| B24   | 6  | 6  | 6  | 6  | 6             |
| B25   | 5  | 5  | 8  | 9  | 9             |
| B31   | 6  | 8  | 6  | 6  | 8             |
| B32   | 6  | 5  | 8  | 7  | 8             |
| B33   | 5  | 6  | 7  | 9  | 9             |
| B41   | 6  | 7  | 7  | 6  | 7             |
| B42   | 6  | 8  | 8  | 6  | 8             |
| B43   | 6  | 7  | 8  | 6  | 8             |
| B44   | 6  | 6  | 8  | 6  | 8             |
| B45   | 5  | 5  | 7  | 9  | 9             |
| B51   | 6  | 7  | 7  | 6  | 7             |
| B52   | 6  | 7  | 7  | 6  | 7             |
| B53   | 7  | 5  | 8  | 6  | 8             |
| B54   | 5  | 5  | 8  | 9  | 9             |
| B61   | 7  | 6  | 7  | 6  | 7             |
| B62   | 6  | 7  | 8  | 5  | 8             |
| B63   | 7  | 7  | 8  | 6  | 8             |
| B64   | 6  | 5  | 7  | 9  | 9             |
| B71   | 9  | 6  | 7  | 6  | 9             |
| B72   | 7  | 7  | 7  | 6  | 7             |

4.4. Multi-structure correlation degree synthesis

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

\[
R_{Bx} = W_{Bx}E_{Bx}^T = \begin{bmatrix}
0.89 & 0.43 & 0.70 & 0.45 \\
0.62 & 0.90 & 0.95 & 0.75 \\
0.48 & 0.78 & 0.63 & 0.60 \\
0.51 & 0.79 & 0.96 & 0.56 \\
0.63 & 0.84 & 0.96 & 0.69 \\
0.62 & 0.61 & 0.92 & 0.58 \\
1 & 0.7 & 0.75 & 0.54 \\
\end{bmatrix}
\]

Radar chart of second level index correlation is shown in Figure 2. Furthermore, the correlation degree of the highest level indicator B can be obtained by multiplying the first level weight \( W_B \) matrix by the second level correlation degree \( R_{Bx} \) matrix.

\[
R_B = W_B R_{Bx} = (0.588, 0.618, 0.694, 0.585)
\]

Sequence of engineering support capacity: according to the correlation degree in \( R_B \), the sequence of \( V_i \) is \( V_3 > V_2 > V_1 > V_4 \). The conclusion shows that \( V_3 \) which is balanced in all aspects, is superior to \( V_2 \) with strong engineering operation ability, \( V_1 \) with high reconnaissance and physical quality, and \( V_4 \) with strong support ability and weak operation ability.
Table 5. Correlation coefficient ($\xi_{ik}$) of each index and reference series.

|     | V1  | V2  | V3  | V4  |
|-----|-----|-----|-----|-----|
| B11 | 1   | 0.4 | 0.5 | 0.4 |
| B12 | 0.67| 0.4 | 1   | 0.5 |
| B13 | 1   | 0.67| 1   | 0.67|
| B14 | 1   | 0.4 | 0.5 | 0.33|
| B15 | 0.5 | 0.4 | 1   | 0.5 |
| B21 | 0.5 | 1   | 1   | 0.5 |
| B22 | 0.67| 1   | 1   | 0.67|
| B23 | 0.67| 1   | 1   | 1   |
| B24 | 1   | 1   | 1   | 1   |
| B25 | 0.33| 0.33| 0.67| 1   |
| B31 | 0.5 | 1   | 0.5 | 0.5 |
| B32 | 0.5 | 0.4 | 1   | 0.67|
| B33 | 0.33| 0.4 | 0.5 | 1   |
| B41 | 0.67| 1   | 1   | 0.67|
| B42 | 0.5 | 1   | 1   | 0.5 |
| B43 | 0.5 | 0.67| 1   | 0.5 |
| B44 | 0.5 | 0.5 | 1   | 0.5 |
| B45 | 0.33| 0.33| 0.5 | 1   |
| B51 | 0.67| 1   | 1   | 0.67|
| B52 | 0.67| 1   | 1   | 0.67|
| B53 | 0.67| 0.4 | 1   | 0.5 |
| B54 | 0.33| 0.33| 0.67| 1   |
| B61 | 1   | 0.67| 1   | 0.67|
| B62 | 0.5 | 0.67| 1   | 0.4 |
| B63 | 0.67| 0.67| 1   | 0.5 |
| B64 | 0.4 | 0.33| 0.5 | 1   |
| B71 | 1   | 0.4 | 0.5 | 0.4 |
| B72 | 1   | 1   | 1   | 0.67|

Figure 2. Radar chart of second level index correlation.
5. Conclusions
In this paper, according to the characteristics of the synthetic Force engineering support capability, the index system of engineering support capability is constructed, and the efficiency of engineering support capability is evaluated by combining grey theory and AHP. It can provide support and basis for the evaluation and assessment of the support capacity of synthetic engineering. In the next step, it will further improve the system of the support capacity of engineering and improve the comprehensive assessment method according to the assessment conclusion data, so as to make the assessment conclusion more consistent with the actual situation.

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