Grey Evaluation Method of Radar Equipment Supportability Based on G1

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Abstract. A comprehensive evaluation method combining grey system theory and order relation analysis (G1) is proposed to solve the problems of various and uncertain factors affecting the supportability of radar equipment. Firstly, according to the requirement of radar equipment supportability, the evaluation index system of radar equipment supportability is constructed. Secondly, order relation analysis (G1) is used to determine the weight coefficient of each evaluation index. Finally, the grey scale and whitening weight function are determined by expert scoring value and grading standard, and the guarantee grade of radar equipment is obtained by using grey evaluation model. The accuracy of this method is verified by an example, which provides a new idea for the supportability evaluation of radar equipment.

1. Introduction
Because there are many factors affecting the supportability of radar equipment, some of them are not completely clear, and the relationship between the factors is not completely clear, which leads to the incompleteness and uncertainty of its information. Grey system theory focuses on the study of “small data”, “poor information” and uncertain systems. By using grey system method and model technology, through the generation of “part” known information, the important information contained in the system observation data is developed and excavated to realize the correct description and understanding of the real world [1]. Grey evaluation method has no special requirement for sample size and does not need to obey the typical probability distribution. It is an effective method to deal with uncertainties because of its simplicity and convenience in calculation. But at the same time, there are also some shortcomings. First, there is no objective evaluation index system for the evaluation object. Second, there is no reasonable explanation for the weight of each evaluation index.

Order relation is a way of expressing the degree of mutual importance [2]. Order relation analysis (G1) is a subjective weighting method, each step of which can fully reflect the wishes of experts, the process is clear and definite, the method is simple and practical, there is no need for judgment matrix, nor need for consistency test [3]. This method has no restriction on the number of elements or indicators, and has the property of keeping order, which reduces the difficulty of determining the weight of factors [4].

Combining grey evaluation method with order relation analysis method can make up for their shortcomings and give full play to their advantages. The order relation analysis method is used to solve the problem of determining the index weight in the grey evaluation of radar equipment supportability,
and to get a more accurate supportability grade, which can provide an auxiliary decision-making basis for the product upgrade of the developer and the equipment purchase of the user.

2. Establishment of Radar Equipment Supportability Evaluation Index System

According to the definition of supportability of radar equipment, supportability requirements are divided into comprehensive supportability requirements, design requirements related to supportability and supportability resource requirements [5]. Therefore, the evaluation index of supportability of radar equipment can be divided into three parts [6]: comprehensive supportability (B1), design supportability (B2) and resource supportability (B3).

Comprehensive supportability is proposed based on the capability of the equipment to complete and maintain specified tasks in the expected peacetime and wartime use conditions, which reflects the overall expectation of the military for the equipment supportability, and its indexes mainly include readiness (C11), availability (C12), mission sustainability (C13), life cycle cost (C14), etc.

Design supportability reflects the characteristics of radar equipment related to supportability, which directly affects the design of radar equipment and is an important requirement for the radar equipment to be easily support. Its indexes mainly include reliability (C21), maintainability (C22), testability (C23), security (C24) and electromagnetic compatibility (C25), etc.

Resource supportability refers to the resource requirements planned for the smooth implementation of equipment use and support in peacetime and wartime. It determines the variety and quantity of support resources, involving support personnel (C31), support spare parts (C32), support equipment (C33), technical data (C34), etc.

3. Grey Evaluation Model Based on G1

3.1 Determination of Weight of Evaluation Indexes

In this paper, the weight coefficients of each evaluation index of radar equipment supportability are determined by the method of ordinal relation analysis. The steps are as follows [7].

1) Determine the order relation: If the importance of the evaluation index $x_i$ is greater than $x_j$, denoted as $x_i \succ x_j$ (symbol "\succ" indicates the superior relationship). If the evaluation indexes $x_1, x_2, \cdots, x_n$ have $x_1' \succ x_2' \succ \cdots \succ x_n'$ based on an evaluation criterion, then order relationship between the evaluation indexes $x_1, x_2, \cdots, x_n$ is established according to "\succ". $x_i'$ is the evaluation index of item $i(i = 1, 2, \cdots, n)$ after \{x\} is sorted in order relationship "\succ".

The decision-maker selects the most important index from the indexes set \{x_1, x_2, \cdots, x_n\} and marks it as $x_1'$.

From the remaining $n-1$ indexes set, the decision-maker selects the most important one and marks it as $x_2'$.

From the remaining $n-(k-1)$ indexes set, the decision-maker selects the most important one and marks it as $x_k'$.

After $n-1$ selections, the last index is called $x_n'$. Thus, an order relation $x_1' \succ x_2' \succ \cdots \succ x_n'$ is uniquely determined for the evaluation index set \{x_1, x_2, \cdots, x_n\} according to its importance.

2) Compare and evaluate indexes: The ratio of importance between the evaluation indexes $x_{k-1}$ and $x_k$ is given as $w_{k-1}/w_k$, denoted as $r_k$:

$$r_k = w_{k-1}/w_k, k = n, n-1, \cdots, 3, 2$$ (1)

3) Calculate weight coefficient: If $r_k$ given by the experts meets the following conditions:

$$r_{k-1} > 1/r_k, k = n, n-1, \cdots, 3, 2$$ (2)

Then the weight $w_n$ is:
\[ w_n = \left( 1 + \sum_{i=2}^{n} \prod_{r=1}^{i} r \right)^{-1} \quad (3) \]

\[ w_{k-1} = w_k r_k, k = n, n-1, \cdots, 3, 2 \quad (4) \]

### 3.2 Determination of Evaluation Indexes Sample Matrix

According to the grading standard in reference [8], the grade of radar equipment supportability evaluation is divided into five grades of I-V. The grading standards of each grade are: grade I \((0.8,1]\) is excellent, grade II \((0.6,0.8]\) is good, grade III \((0.4,0.6]\) is average, grade IV \((0.2,0.4]\) is poor, grade V \([0,0.2]\) is extremely poor.

Assuming that \(p\) experts participate in the evaluation of the index \(C_y\) in the supportability evaluation index system of radar equipment, and the scoring value given by the \(s\)-th \((s = 1, 2, \cdots, p)\) expert according to the scoring standard is \(d_{ys}^i\), then the evaluation sample matrix \(D\) of the index is as follows.

\[
D = \begin{bmatrix}
  d_{11}^1 & d_{11}^2 & \cdots & d_{11}^p \\
  d_{21}^1 & d_{21}^2 & \cdots & d_{21}^p \\
  \vdots & \vdots & \ddots & \vdots \\
  d_{y1}^1 & d_{y1}^2 & \cdots & d_{y1}^p \\
\end{bmatrix} \quad (5)
\]

### 3.3 Determination of Evaluation Grey Class

To determine the evaluation grey class is to determine the grade number, grey number and whitening weight function of the evaluation grey class [9]. According to the grading standard of radar equipment supportability, the whitening weight function is set for five grey classes: excellent, good, general, poor and extremely poor. The whitening weight function is set as follows.

1) The first kind of “excellent” \((e = 1)\): Grey number is \(\Theta_1 \in [0.9, +\infty)\), the whitening weight function is \(f_1(d_{ys}^i)\).

\[
f_1(d_{ys}^i) = \begin{cases} 
  d_{ys}^i, & d_{ys}^i \in [0,0.9] \\
  1, & d_{ys}^i \in [0.9, +\infty) \\
  0, & d_{ys}^i \in [0,1.4] 
\end{cases} \quad (6)
\]

2) The second kind of “good” \((e = 2)\): Grey number is \(\Theta_2 \in [0,0.7,1.4]\), the whitening weight function is \(f_2(d_{ys}^i)\).

\[
f_2(d_{ys}^i) = \begin{cases} 
  d_{ys}^i, & d_{ys}^i \in [0,0.7] \\
  2 - \frac{d_{ys}^i}{0.7}, & d_{ys}^i \in [0.7,1.4] \\
  0, & d_{ys}^i \in [1.4, +\infty) 
\end{cases} \quad (7)
\]

3) The third kind of “general” \((e = 3)\): Grey number is \(\Theta_3 \in [0,0.5,1.0]\), the whitening weight function is \(f_3(d_{ys}^i)\).
4) **The fourth kind of “poor” (e = 4):** Grey number is $\mathbb{G}_e \in [0,0.3,0.6]$, the whitening weight function is $f_4(d'_y)$.

\[
f_4(d'_y) = \begin{cases} 
\frac{d'_y}{0.5}, & d'_y \in [0,0.5] \\
2 - \frac{d'_y}{0.5}, & d'_y \in [0.5,1.0] \\
0, & d'_y \notin [0,1.0]
\end{cases}
\] (8)

5) **The fifth kind of “extremely poor” (e = 5):** Grey number is $\mathbb{G}_e \in [0,0.1,0.2]$, the whitening weight function is $f_5(d'_y)$.

\[
f_5(d'_y) = \begin{cases} 
\frac{d'_y}{0.3}, & d'_y \in [0,0.3] \\
2 - \frac{d'_y}{0.3}, & d'_y \in [0.3,0.6] \\
0, & d'_y \notin [0,0.6]
\end{cases}
\] (9)

### 3.4 Calculation of Grey Evaluation Coefficient

After field investigation and consultation with experts, the scores of experts on Supportability Evaluation Index of certain radar equipment are collected. For the supportability evaluation index $C_y$ of radar equipment, the gray evaluation coefficient of the e-th ($e = 1,2,\cdots,5$) grey class is denoted as $x_{yge}$, and the total gray evaluation coefficient is denoted as $X_y$.

\[
x_{yge} = \sum_{e=1}^{5} f_e(d'_y)
\] (11)

\[
X_y = \sum_{e=1}^{5} x_{yge}
\] (12)

### 3.5 Calculation of Grey Evaluation Weight Vector and Weight Matrix

The grey evaluation right of the e-th grey grade of the supportability evaluation index $C_y$ of radar equipment can be calculated by $x_{yge}$ and $X_y$.

\[
r_{yge} = \frac{x_{yge}}{X_y}
\] (13)

Considering $e = 1,2,\cdots,5$, the grey evaluation vector of radar equipment supportability evaluation index $C_y$ is $r_y$.

\[
r_y' = \begin{bmatrix} r_{y1},r_{y2},\cdots,r_{y5} \end{bmatrix}
\] (14)

Then, the grey evaluation matrix is obtained as $R_y$.
3.6 Calculation and Normalization of Comprehensive Evaluation Results

According to the weight value of each second-level index \( C_{ij} \) relative to the first-level index \( B_i \), the first-level index \( B_i \) is comprehensively evaluated, and the evaluation result is denoted as \( F_i \).

\[
F_i = W_{B_i} \cdot R
\]

Then, the grey evaluation matrix of each first-level index \( B_i \) to each evaluation gray class is \( J = (F_1, F_2, \ldots, F_j)^T \).

The supportability of radar equipment is comprehensively evaluated, and the evaluation result is recorded as follows.

\[
F = W_A \cdot J
\]

The result \( F \) of the comprehensive evaluation is normalized, and the grade of each gray class is assigned by the whitening value, and the vector \( E = (0.9, 0.7, 0.5, 0.3, 0.1)^T \) of each gray class value can be obtained, and then the comprehensive evaluation value of radar equipment supposition after normalization is \( Z \).

\[
Z = F \cdot E
\]

According to the standard range of rating grade \( Z \) falls into, the level of supportability of radar equipment can be obtained.

4. Example Analysis

Taking a certain type of radar equipment as an example, according to the index system built in Fig.1 and grey evaluation model of radar equipment supportability, the supportability of radar equipment is calculated and analyzed as follows.

4.1 Determine Weight of Evaluation Index

According to the ordinal relation analysis (G1), the weights of indexes at each level are determined as follows:

\[
W_A = (0.2481, 0.3750, 0.3409) ;
W_{B_1} = (0.3358, 0.2399, 0.2399, 0.1845) ;
W_{B_2} = (0.2360, 0.2145, 0.1773, 0.1950, 0.1773) ;
W_{B_3} = (0.2868, 0.2370, 0.2155, 0.2607) .
\]

4.2 Calculate Grey Matrix

After field investigation and consulting with seven experts, the scores of each evaluation index for the supportability of a certain type of radar equipment given by the experts are collected, as shown in table I.

| Expert Number | Evaluation indexes Score |
|---------------|-------------------------|
|               | \( C_{11} \) | \( C_{12} \) | \( C_{13} \) | \( C_{14} \) | \( C_{21} \) | \( C_{22} \) | \( C_{23} \) |
| 1             | 0.90      | 0.85      | 0.80      | 0.60      | 0.79      | 0.65      | 0.55      |
| 2             | 0.80      | 0.85      | 0.70      | 0.52      | 0.80      | 0.70      | 0.60      |
| 3             | 0.85      | 0.84      | 0.75      | 0.50      | 0.85      | 0.60      | 0.60      |
| 4             | 0.70      | 0.80      | 0.85      | 0.55      | 0.70      | 0.65      | 0.50      |
According to formula (6) - (14), the grey evaluation matrix of each first-level index $B_i$ is obtained as follows.

$$
R_1 = \begin{bmatrix}
0.4652 & 0.3870 & 0.1478 & 0 & 0 \\
0.4545 & 0.3896 & 0.1559 & 0 & 0 \\
0.3684 & 0.4105 & 0.2211 & 0 & 0 \\
0.2294 & 0.2949 & 0.3698 & 0.1059 & 0 \\
0.4047 & 0.4017 & 0.1936 & 0 & 0 \\
0.3072 & 0.3950 & 0.2978 & 0 & 0 \\
0.2481 & 0.3189 & 0.3654 & 0.0677 & 0 \\
0.4441 & 0.3922 & 0.1637 & 0 & 0 \\
0.3953 & 0.4040 & 0.2007 & 0 & 0 \\
0.3431 & 0.4167 & 0.2402 & 0 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0 \\
0.2338 & 0.3005 & 0.3731 & 0.0926 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0
\end{bmatrix}
$$

$$
R_2 = \begin{bmatrix}
0.4047 & 0.4017 & 0.1936 & 0 & 0 \\
0.3072 & 0.3950 & 0.2978 & 0 & 0 \\
0.2481 & 0.3189 & 0.3654 & 0.0677 & 0 \\
0.4441 & 0.3922 & 0.1637 & 0 & 0 \\
0.3953 & 0.4040 & 0.2007 & 0 & 0 \\
0.3431 & 0.4167 & 0.2402 & 0 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0 \\
0.2338 & 0.3005 & 0.3731 & 0.0926 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0
\end{bmatrix}
$$

$$
R_3 = \begin{bmatrix}
0.4652 & 0.3870 & 0.1478 & 0 & 0 \\
0.4545 & 0.3896 & 0.1559 & 0 & 0 \\
0.3684 & 0.4105 & 0.2211 & 0 & 0 \\
0.2294 & 0.2949 & 0.3698 & 0.1059 & 0 \\
0.3431 & 0.4167 & 0.2402 & 0 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0 \\
0.2338 & 0.3005 & 0.3731 & 0.0926 & 0 \\
0.3772 & 0.4084 & 0.2144 & 0 & 0
\end{bmatrix}
$$

4.3 Comprehensive Evaluation

According to formula (15), the comprehensive evaluation results of the first-level indexes $B_i$ of radar equipment supportability are as follows.

$$
F_1 = W_B \cdot R_1 = (0.3960, 0.3763, 0.2083, 0.0195, 0); \\
F_2 = W_B \cdot R_2 = (0.3621, 0.3842, 0.2419, 0.0120, 0); \\
F_3 = W_B \cdot R_3 = (0.3365, 0.3875, 0.2560, 0.0200, 0).
$$

According to formula (16), the comprehensive evaluation result of radar equipment supportability can be obtained as $F = W_A \cdot J = (0.3630, 0.3831, 0.2372, 0.0169, 0)$. According to formula (17), it can be concluded that the comprehensive evaluation result of the supportability of radar equipment after normalization is $Z = F \cdot E = 0.7185$.

According to the grading standard, the comprehensive evaluation result is 0.7185 falling into the range (0.6, 0.8], so the level of supportability of this radar equipment is grade II, that is “good”. This conclusion is consistent with the conclusions of extension evaluation method [10], catastrophe progression method [11] and cloud evaluation method [12], and conforms to the objective reality.

5. Conclusion

According to the requirement of the definition of radar equipment supportability, this paper establishes a multi-level evaluation index system of radar equipment supportability, empowers the indexes by the method of ordinal relation analysis, and constructs a grey evaluation model of radar equipment...
supportability by using grey theory, which solves the incomplete and uncertain problems that are difficult to deal with in the evaluation of radar equipment supportability. The example proves that the evaluation method is simple, easy to understand and easy to calculate, which provides a new method for the supportability evaluation of radar equipment.

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