Supportability Evaluation of Radar Equipment Based on Cloud Model and Improved RS-G1

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Abstract. In the context that factors affecting the supportability of radar equipment are numerous and of diverse dimensions, the existing index systems of supportability evaluation of radar equipment can hardly satisfy the continuously improving requirements of radar equipment support. First, aiming at the problem of transformation between quantitative description and qualitative concept, this paper converts the evaluation index set into an evaluation cloud model based on the cloud theory, generates the digital characteristics of the cloud model of the expert scoring by using the reverse cloud generator and the supportable comprehensive evaluation cloud drop chart of radar equipment by using forward cloud generator. Second, to make up for the shortcomings of the existing single weighting method, the Rough Set (RS) weighting method is improved with the introduction of the Order Relationship Analysis method (G1). Then this paper proposes the RS-G1 synthetic weighting method, and designs radar equipment supportability cloud evaluation based on this method. In the end, example shows that this method can evaluate the supportability level of radar equipment scientifically and effectively.

1. Introduction
The supportability of radar equipment refers to the capability that the design characteristics and planned support resources of radar equipment can meet the requirements of peacetime combat readiness and wartime use [1]. At present, evaluation methods of radar equipment supportability mainly include set pair analysis method [2], fuzzy evaluation method [3], grey correlation theory [4], etc. However, these methods consider the fuzziness and randomness of evaluation indexes separately, or quantify the fuzziness by using the fuzzy set method, or quantify the randomness by using the probability method, without taking these two uncertainties into comprehensive consideration. Cloud model [5] can use the form of cloud droplets to directly reflect the level of supportability evaluation of radar equipment, which is an effective method to study the supportability evaluation of radar equipment. However, in the cloud model, how to reasonably calculate the index weight is a very important issue.

At present, the calculation methods of weight coefficient can be divided into two basic categories according to their characteristics: subjective weighting methods and objective weighting methods [6]. But both of them have their own advantages and disadvantages. It is an effective way to solve the defects of single weighting method by combining the two weighting methods, making use of the advantages of them and drawing on each other's strength to realize synthetic weighting.
In this paper, combining the cloud theory with the improved RS-G1 comprehensive weighting method, this paper gives full play to the advantages of the two methods, and uses the comprehensive weighting method to settle the issue of determination of the index weight value in the supportability evaluation of radar equipment based on cloud model. A more accurate supportability level can be obtained through the cloud model, which can provide an auxiliary decision-making basis for the product upgrade of the developer and the equipment procurement of the user.

2. Construction 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 [7]. Therefore, the evaluation index of supportability of radar equipment can be divided into three parts: comprehensive supportability, design supportability and resource supportability.

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, availability, mission sustainability, life cycle cost, 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, maintainability, testability, security and electromagnetic compatibility, 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, support spare parts, support equipment, technical data, etc.

3. Algorithm Introduction

3.1 The improved RS-G1 comprehensive weighting method

3.1.1 The improved RS weighting method. In rough set theory, when the evaluation problem is expressed as a decision table, the weight of the index is the attribute importance, and the index weight can be determined by calculating the attribute importance. To calculate the importance degree of an index, you need to remove it from the table and examine how classification changes after the attribute is removed. If this attribute is removed, the classification will be changed accordingly, indicating that the importance of this attribute is high, otherwise the importance is low [8]. The information system decision table and attribute importance are defined as follows in [8,9].

Definition 1: The decision table of the comprehensive evaluation information system [9] is $S = \{U, R, V, f\}$, in which $U$ represents the collected importance rating score data of each index given by several experts, called the theory domain. $R$ represents a set of attributes; $V = \bigcup_{r \in R} V_r$, represents a set of attribute values; $V_r$ represents the range of attribute value; $f : U \times R \rightarrow V$ represents an information function that specifies the various attribute values of each object $x$ in $U$, the specific expression is $\forall r \in R, x \in U, f(x, r) \in V_r$.

Definition 2 [9]: For the decision table $S = \{U, R, V, f\}$, $R = C \cup D$ . condition attribute $c_i \in C(i = 1, 2, \ldots, n)$, the $C$ positive domain of $D$ is $pos_c(D)$, and the importance degree of $c_i$ to decision attribute $D$ is $sig(c_i)$.

$$pos_c(D) = \{Y \in U / C | Y \subseteq D\}$$

(1)
The weight of each index can be obtained by normalizing the importance of each attribute:

\[ W_{RS}(c_i) = \frac{\text{sig}(c_i)}{\sum_{i=1}^{n} \text{sig}(c_i)} \tag{3} \]

Thus, the greater the attribute important \( \text{sig}(c_i) \) of an index \( c_i \) is, the greater its weight \( W \) will be. However, when the importance degree of an attribute is calculated by formula (2), the importance degree of an individual attribute may be zero, resulting in the weight value of this index being zero. Each index in the index system has its own significance. If the weight value of the index is zero, it is not in line with the actual situation. It can be seen that this method has shortcomings.

In order to ensure that the weight value of each index is greater than zero, it is necessary to ensure that the attribute importance of this index is greater than zero. Here, the concept of conditional entropy is introduced:

Definition 3 [10]: In the decision table \( S = \{ U, R, V, f \} \), the conditional entropy of decision attribute \( D = \{ D_1, D_2, \cdots, D_k \} \) relative to the conditional attribute \( C = \{ c_1, c_2, \cdots, c_n \} \) is:

\[ I(D|C) = \sum_{i=1}^{n} \left| \frac{\sum_{j=1}^{k} D_j \cap c_i}{|c_i|} \right| \left( 1 - \frac{\sum_{j=1}^{k} D_j \cap c_i}{|c_i|} \right) \tag{4} \]

The improved attribute importance is:

\[ \text{sig}'(c_i) = I(D|C - \{c_i\}) - I(D|C) + \frac{\sum_{a \in C} |a(x)| - \sum_{a \in C - \{c_i\}} |a(x)|}{\sum_{a \in C} |a(x)|} \tag{5} \]

Then the improved weight of index \( c_i \) is:

\[ W_{RS}'(c_i) = \frac{\text{sig}'(c_i) + I(D|\{c_i\})}{\sum_{a \in C} \{\text{sig}'(a) + I(D|\{a\})\}} \tag{6} \]

The attribute importance calculated by formula (5) is always greater than zero, so that the weight value of the index is always greater than zero. Therefore, by introducing the concept of conditional entropy, the problem of index weight value being zero in the original rough set weighting method can be avoided.

3.1.2 The G1 weighting method. In this paper, the order relation analysis method [11] is used to calculate the subjective weight of each index.

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 \( \{ x_i \} \) is sorted in order relationship "\( \succ \)".

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

\[ r_k = w_{k-1}/w_k, k = n, n-1, \cdots, 3, 2 \tag{7} \]

If \( r_k \) given by the experts meets the following conditions:
Then the weight $W_{G1}$ is:

$$W_{G1} = \left( 1 + \sum_{k=2}^{n} \prod_{i=k}^{n} r_{i} \right)^{-1}$$ \hspace{1cm} (9)

$$w_{k-1} = w_{k} r_{k}, k = n, n-1, \cdots, 3, 2$$ \hspace{1cm} (10)

### 3.1.3 The comprehensive weight.

By using the method of multiplication synthesis normalization, the comprehensive weighting model is constructed as follows:

$$W_i = \frac{W_{G1} W_{G1}'}{\sum_{j=1}^{n} W_{G1} W_{G1}'}$$ \hspace{1cm} (11)

### 3.2 The supportability cloud evaluation of radar equipment

The cloud model [12] is a transformation model between qualitative linguistic values and quantitative numerical domains, which can better describe the correlation between linguistic randomness and fuzziness.

The cloud model is determined by three numerical characteristics: expectation (Ex), entropy (En) and hyperentropy (He), denoted as $C(Ex, En, He)$. The cloud model is generated by forward cloud or reverse cloud generator algorithm. The forward cloud generator generates cloud droplets satisfying the normal cloud distribution rule according to the known digital characteristics $C(Ex, En, He)$. The generated cloud droplets constitute the whole cloud, thus the qualitative concept is expressed quantitatively. The reverse cloud generator, on the contrary, generates the corresponding digital characteristics through a given set of cloud droplets conforming to a normal cloud distribution rule as samples.

If the rating of radar equipment supportability is divided into five grades: excellent, good, average, poor and extremely poor, then the evaluation set is $V = \{ \text{excellent, good, average, poor, extremely poor} \}$. Since it is a qualitative concept, a one-dimensional normal cloud can be used to describe each comment. For a comment with a bilateral constraint $[\lambda_{\min}, \lambda_{\max}]$, the expectation can be taken as the median of the constraint condition and the comment can be approximated by the cloud in the bilateral constraint region. The digital characteristics are calculated by the following formula:

$$\begin{align*}
    Ex &= (\lambda_{\min} + \lambda_{\max})/2 \\
    En &= (\lambda_{\max} - \lambda_{\min})/6 \\
    He &= k
\end{align*}$$ \hspace{1cm} (12)

In the supportability evaluation index system of radar equipment, the $m$ indexes are evaluated by $n$ experts, and the matrix $S = (s_{ij})_{n \times m}$ is obtained. Then, the cloud model of the $j$ index is as follows:
According to formulas (13), the numerical characteristics of a certain level of indexes are obtained, and then the cloud model of the upper level indexes is calculated. Assuming that a certain upper level index includes $n_k$ subordinate indexes, the cloud model of the upper level index is:

\[
\begin{align*}
Ex_j &= \frac{1}{n} \sum_{i=1}^{n} s_{ij} \\
En_j &= \left(\frac{\pi}{2}\right)^{1/2} \frac{1}{n-1} \sum_{i=1}^{n} [s_{ij} - Ex_j] \\
Sx_j^2 &= \frac{1}{n-1} \sum_{i=1}^{n} (s_{ij} - Ex_j)^2 \\
He_j &= (Sx_j^2 - En_j^2)^{1/2}
\end{align*}
\]  \tag{13}

Calculate the membership of the topmost cloud droplet $x_j$ according to the following formula:

\[
\xi_j = \exp\left(-\frac{(x_j - Ex_j)^2}{2En_j^2}\right)
\]  \tag{15}

Following the principle of maximum membership, the comprehensive evaluation level is the interval of the evaluation cloud corresponding to $\xi_j$ with the largest membership degree.

4. Example analysis
Take a certain type of radar equipment as an example to evaluate its supportability. The grade of supportability evaluation of radar equipment is divided into five levels of I-V. According to the rating scale standard in literature [7], the scores of each level are: level I (0.8,1] is excellent, level II (0.6,0.8] is good, level III (0.4,0.6] is average, level IV (0.2,0.4] is poor, level V [0,0.2] is extremely poor. According to the radar equipment supportability evaluation index system and the cloud evaluation model based on the improved RS-G1, the following calculation and analysis were performed.

4.1 Improved RS method to determine the objective weight
Under the improved RS weighting method, the weight of each evaluation index in the supportability evaluation index system of radar equipment is:

\[
W_{RS} = (0.0709,0.0837,0.0558,0.1007,0.0516,0.0965,0.0324,0.1157,0.0773,0.0901,0.0965,0.0580,0.0709)
\]
4.2 G1 method to determine the subjective weight
Under the G1 weighting method, the weight of each evaluation index in the supportability evaluation index system of radar equipment is:

\[ W_{G1} = (0.0954, 0.0682, 0.0682, 0.0524, 0.0885, 0.0804, 0.0665, 0.0731, 0.0665, 0.0978, 0.0808, 0.0735, 0.0889) \]

4.3 Determine the comprehensive weight
After the objective weight is calculated according to the improved RS method and the subjective weight is calculated by the G1 method, the comprehensive weight can be calculated.

\[ W = (0.0881, 0.0743, 0.0495, 0.0687, 0.0595, 0.1010, 0.0281, 0.1101, 0.0669, 0.1147, 0.1015, 0.0555, 0.0821) \]

4.4 Supportability evaluation of radar equipment based on cloud model
According to the grade standard of supportability evaluation of radar equipment and formula (12), the digital characteristics of the standard evaluation of radar equipment supportability based on cloud model can be obtained, see table 1.

| Standard reviews   | (Ex, En, He)         |
|--------------------|----------------------|
| Excellent          | (0.9, 0.0333, 0.013) |
| Good               | (0.7, 0.0333, 0.008) |
| Average            | (0.5, 0.0333, 0.005) |
| Poor               | (0.3, 0.0333, 0.008) |
| Extremely poor     | (0.1, 0.0333, 0.013) |

Seven experts including radar manufacturers, research institution and using units are invited to score each evaluation index system according to the evaluation criteria.

The numerical characteristics of each index corresponding to the cloud model are calculated according to formulas (13). According to the weight values of all levels of indexes and formulas (14), the digital characteristics of the comprehensive evaluation cloud model of the type of radar equipment supportability is (0.7376, 0.0350, 0.0207). The generated comprehensive evaluation cloud is compared with the standard evaluation cloud, as shown in figure 1.

![Figure 1. Comprehensive evaluation of radar equipment supportability cloud drop diagram](image_url)
As can be seen from figure 1, most of the cloud droplets in the comprehensive supportability evaluation of radar equipment are in a "good" position, while the rest are in an "excellent" position. According to formula (15), the membership of evaluation are $\xi_I = 6.85 \times 10^{-6}$, $\xi_{II} = 0.53$, $\xi_{III} = 8.81 \times 10^{-12}$, $\xi_{IV} = 3.17 \times 10^{-38}$, $\xi_V = 2.46 \times 10^{-80}$. Following the principle of maximum membership, the supportability evaluation of radar equipment level for II "good", which is consistent with the conclusion of cloud droplets diagram.

5. Conclusion
In this paper, according to the requirements of the definition of radar equipment supportability, the supportability evaluation index system of radar equipment is established. By improving the RS-G1 comprehensive weighting method, the deficiency of the single weighting method is made up, so that the calculation of index weight is more reasonable. According to the evaluation criteria of the supportability evaluation of radar equipment, the evaluation criteria are converted into the digital characteristics of the cloud model to better express the fuzziness and randomness in the evaluation process, and the evaluation process is more scientific. The example shows that the supportability evaluation method of radar equipment based on the cloud theory is feasible, which provides a new method for the supportability evaluation of radar equipment, and provides a basis for the manufacturers and users to promote the supportability of radar.

However, the supportability level of radar in this paper depends on the comparative analysis between the evaluation index cloud model and the evaluation index standard comments, and this comparative analysis relies on the knowledge and experience of experts, which is a problem worth studying in the next step.

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