Experimental research on mechanical performance of the lightweight composite slabs

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Abstract. Aimed at reliability model in the satellite communication system, the index weight of subjective problem, this paper proposes a method based on entropy weight - the combination of cloud model method, combining the expert's subjective analysis in the process of modelling and model their own objective data to get a more complete set of index weight, and USES the fuzzy quantitative evaluation method for satellite communication system reliability model of the final evaluation results. The validity and feasibility of the algorithm are verified by an example, and the application of entropy weight-cloud model realizes the uncertain evaluation between the evaluation index and the evaluation level, which provides a new idea and method for the evaluation of the reliability model of satellite communication system.

1. Introduction

The fuzzy quantitative evaluation method is to evaluate the reliability model with multiple attributes according to different business needs. It is closely related to the attribute weight. Because the reasonableness of the weight directly affects the accuracy of the fuzzy quantitative evaluation value EVA, it is in the quantitative evaluation method, the research on the weight problem occupies an important position.

At present, there are many methods to determine the weight coefficient [1], which can be roughly divided into two categories: subjective weighting method and objective weighting method. The subjective weighting method is based on the subjective preference information given by evaluation experts or directly based on experience to give attribute weights. For example, expert direct evaluation method and analytic hierarchy process [2]. The objective weighting method is based on the information of the decision matrix, and the weight coefficient is calculated by establishing a certain mathematical model. For example, entropy method and principal component analysis method [3]. The two weighting methods have different characteristics: the subjective weighting method can directly reflect the empirical judgment of the evaluation expert, and the relative importance of attributes generally does not violate people's attempts, but the accuracy and reliability of decision-making are slightly less objective [4]; the weighting method has objective criteria for weighting, and certain mathematical models can be used to calculate the weight coefficient of the attribute [5]. Its disadvantage is that it ignores subjective preference information, and the weight coefficient is unreasonable.
In order to make the fuzzy quantitative evaluation value more scientific, this paper combines the two weighting methods and proposes a fuzzy quantitative evaluation method based on combined weighting. The cloud model algorithm is used to combine subjective weighting method and entropy weighting method to make the evaluation the result can reflect both subjective information and objective information.

2. Basic principles of combinatorial weighting method

At present, there are many methods to determine the weight coefficient, which can be roughly divided into two categories: subjective weighting method and objective weighting method [6]. Subjective weighting method is based on the subjective preference information given by evaluation experts or directly according to experience to give attribute weight. For example, direct expert assessment and analytic hierarchy process. Objective weighting method is based on the decision matrix information, through the establishment of a certain mathematical model to calculate the weight coefficient. For example, entropy weight method and principal component analysis method [7]. The two weighting methods have different characteristics: subjective weighting method can directly reflect the experience judgment of evaluation experts, and the relative importance of attributes generally does not violate people’s attempts, but the accuracy and reliability of decision-making are slightly poor; the objective weighting method has objective criteria for weighting, and can use a certain mathematical model to calculate the weight coefficient of attributes. Its disadvantage is that the subjective preference information is ignored, and the weight coefficient is unreasonable.

Because the index weights determined by different methods have certain differences, but different methods have their own rationality, therefore, this paper adopts the combination weighting method to synthesize the weights determined by different methods through certain mathematical and statistical methods to get the final index weight [8].

2.1. Objective weighting method

Entropy weight method belongs to objective weighting method, which defines the weight of each index by the amount of information provided by the entropy value under objective conditions. In the calculation process, the deviation caused by human subjective factors can be avoided as far as possible, so as to get the index weight which can better reflect the data information.

① Construction of judgment matrix. Set \( m \) evaluation objects and \( n \) evaluation indicators to establish a comparison matrix \( R = \left[ r_{ij} \right]_{mn} \), where \( r_{ij} \) represents the value of the \( i \) item evaluation index of the \( j \) evaluation object.

② Standard normalization correction. Since different attributes often have different dimensions and dimensionless units, in order to eliminate the incommensurability brought by them, attribute indexes should be dimensionless before making decisions. However, the dimensionless processing methods will be different for different types of decision attributes. The larger the attribute, the better the indicator, generally can make \( r_{ij}' = r_{ij} - r_{\min}(i)/r_{\max}(i) - r_{\min}(i) \); the smaller the attribute, the better the index, generally make \( r_{ij}' = r_{\max}(i) - r_{ij} / r_{\max}(i) - r_{\min}(i) \). After standardization, the data is normalized, namely

\[
r_{ij}'' = r_{ij}' / \sum_{i=1}^{n} r_{ij}' .
\]

③ Calculate the entropy value of each index. Let the entropy value of the \( j \) index be, namely:

\[
en_j = -\frac{1}{\ln m} \sum_{i=1}^{n} r_{ij}'' \ln r_{ij}'' , \quad j = 1, 2, \cdots, n
\]

④ The coefficient of variation was calculated. The greater the variation coefficient \( d_j \) is, the greater the effect of this index on the research object, and the better this index is, that is:

\[
d_j = 1 - en_j , \quad j = 1, 2, \cdots, n
\]
⑤ Calculate entropy weight.

\[
\omega_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad j = 1, 2, \ldots, n
\]  

(3)

2.2. **Subjective weighting**
At present, the commonly used evaluation methods, such as expert meeting method and Delphi method, rely too much on experts, and cannot get real results when the number of people is small, and the evaluation results are difficult to converge when the number of people is large. Clustering analysis method is to calculate the distance or similarity coefficient between the indicators to carry out systematic clustering, which requires a lot of statistical data, which is difficult in the development stage of satellite communication network reliability model; fuzzy comprehensive evaluation cannot solve the problems caused by the correlation between the various links in the process of reliability modeling comprehensive comparison, the analytic hierarchy process is more suitable to obtain the subjective weight of evaluation index of satellite communication network reliability model. The specific steps to calculate the weight \( w_j \) will not be described in this paper.

2.3. **Calculate the composite weight**
After the subjective weight and objective weight are obtained, the comprehensive weight \( w_{ij} = p\omega_i + qw_j \) of the \( j \) index of the \( i \) link is finally obtained, where \( p \) and \( q \) reflect the degree of difference between the subjective and objective weights, which can be calculated by the Euclidean distance function \( \rho(\omega_i, w_j) \), namely:

\[
\rho(\omega_i, w_j) = \sqrt{\sum_{i=1}^{n} (\omega_i - w_j)^2} \\
\rho(\omega_i, w_j) = (p - q)^2 \\
p + q = 1
\]  

(4)

3. **Fuzzy quantitative evaluation method based on combination weighting method**
When evaluating the reliability model of satellite communication system, the fuzzy quantitative evaluation considers each stage of the whole process from the establishment to the use and optimization of the model, as shown in the figure, and evaluates the three links in the whole process, that is, defining the system definition, determining the mathematical model and reliability calculation [9].

![Diagram](image-url)

Fig 1 The reliability model of satellite communication system is established and optimized

3.1. **Satellite communication system reliability model evaluation system**
The establishment of the index system of model evaluation mainly includes subjective scoring, literature review, hierarchical analysis, expert analysis and other methods. In the evaluation of satellite
communication network reliability model, it is necessary to establish the index system by combining various methods according to the actual situation of satellite communication network background. Combined with the national military standard GJB813-1990 "Reliability Model Establishment and Reliability Prediction", this paper summarizes the design process of satellite communication network reliability model, as shown in the figure 2:

![Evaluation index system of satellite communication system reliability model](image)

**Fig 2 Evaluation index system of satellite communication system reliability model**

**3.2. The combined weighting method is represented with the cloud model**

In the evaluation of a single link, each data factor set is independent of each other, while the three links in the object set are interrelated. Moreover, the evaluation results of each link have different influences on the final evaluation result EVA of the satellite communication system reliability model. In this paper, combined weighting method is adopted to make the final evaluation result EVA more accurate.

1. Generate the evaluation cloud model. In fuzzy quantitative evaluation, there is a certain fuzziness among the elements of the evaluation set \( V \) of each indicator factor, and an evaluation set \( V \) containing \( n \) evaluation levels is set, namely \( V = \{v_1, v_2, \ldots, v_n\} \). According to the lower limit \( v^- \) and upper limit \( v^+ \) of each evaluation interval, the digital feature \((Ex, En, He)\) of the cloud model can be calculated, as shown in the formula:

\[
\begin{align*}
Ex_k &= \frac{v^- + v^+}{2} \\
En_k &= \frac{(Ex_k - Ex_{k-1})}{(n + 1)}, \quad k = 1, 2, \ldots, n \\
He &= 0.1
\end{align*}
\]

Where, for the hyper entropy \( He \), represents the dispersion degree of entropy. Due to the stability of evaluation experts, the dispersion degree is basically the same. Here, it is generally obtained based on experience, so \( He = 0.1 \).

3.3. Generate the comprehensive cloud and get the evaluation result

Calculate the cloud digital characteristics of each index, and then according to the cloud digital characteristics, combined with the comprehensive weight obtained in Chapter 2, get the digital characteristics of the comprehensive cloud and generate the comprehensive cloud. Finally, through the formula (4), the parameters of the comprehensive cloud model are compared with those of the judgment set cloud model, and the similarity degree \( \sin(i, j) \) between the comprehensive cloud model and the "very consistent" cloud model is calculated as the final evaluation value. That is:
\( \sin(i, j) = \cos(\vec{V}_i, \vec{V}_j) = \frac{\vec{V}_i \cdot \vec{V}_j}{\|\vec{V}_i\| \|\vec{V}_j\|} \) \tag{6}

Where, \( \vec{V}_i = (E_{x_i}, E_{n_i}, H_{e_i}) \) represents the cloud vector of the integrated cloud model, and \( \vec{V}_j = (E_{x_j}, E_{n_j}, H_{e_j}) \) represents the cloud vector "very consistent" with the cloud model.

4. Algorithm simulation and analysis

4.1. Find the data factor set

The model to be evaluated in this paper is the QoS reliability model under multiple states. For three different services, namely bandwidth polymorphism reliability, time delay polymorphism reliability and node network packet loss rate polymorphism reliability, the data factor values of three links in the reliability model modeling process are obtained, as shown in Table 1:

| QoS reliability model | UD_{SD} | UD_{DM} | UD_{RC} |
|-----------------------|---------|---------|---------|
| ud_{SD1}              | ud_{SD2} | ud_{SD3} | ud_{DM1} | ud_{DM2} | ud_{DM3} | ud_{RC1} | ud_{RC2} |
| 2                     | 3       | 2       | a       | b       | 1       | O(N)     | S(N)     |

The data factor values of the SD link need to be carefully considered for the model. The model can complete two tasks, namely, calculating the single-path reliability of polymorphic arc network and the single-path reliability of multi-node network. There are three functions that can be completed, namely, the reliability calculation of bandwidth sensitive service, delay sensitive service and reliability sensitive service. As shown in Equation (7), reliability calculation depends on two performance parameters, namely link reliability and node reliability, so the number of performance parameters is 2.

\[
\begin{cases}
R(L) = a \prod_{i=1}^{j} P_{L_i} + b \prod_{i=1}^{K_j} P(i) \\
\sum_{i=1}^{L} T_i \leq T_{\text{max}}
\end{cases} \tag{7}
\]

The data factor values of DM link need to obtain the sensitivity of each performance parameter index of the model, and local sensitivity analysis method is adopted. Only one of the parameters is set as a variable, and the other parameters are taken as the central value. The sensitivity of the reliability model with respect to this parameter is the change amount of this parameter when it changes each time.

In the QoS reliability model, the comprehensive performance reliability \( R(L) = f(P_{L'}, P(i)) \) is determined by the probability \( P_{L'} \) of normal communication of the link and the probability \( P(i) \) of meeting the maximum packet loss rate under a certain state (0/1/2 state). Therefore, the sensitivity of \( P_{L'} \) is taken as the \( ud_{MD1} \) of DM link and the sensitivity of \( P(i) \) is taken as the \( ud_{MD3} \) of DM link. In different businesses, the sensitivity will also change.

The robustness of the model means that if the accuracy of the model hypothesis relative to the actual situation has little influence on the solution of the model, the mathematical model is said to be robust. On the other hand, a mathematical model is said to be fragile if its solution depends heavily on the accuracy of an assumption relative to the actual situation. The error value between the actual situation and the ideal situation of the QoS reliability model designed in this project is less than 10%, which meets the requirements of the project. Therefore, this model is robust and is represented by the reliability error.

The time complexity and space complexity of RC link are calculated as \( O(N) \) and \( S(N) \).
4.2. Generate cloud model evaluation set

The evaluation set containing 5 evaluation levels is set as \( V = \{ v_1, v_2, v_3, v_4, v_5 \} = \{ \text{very disagrees, relatively disagrees, generally agrees, relatively agrees, very agrees} \} \), and experts have a higher degree of discrimination for "very disagrees", "generally agrees" and "very agrees" than for "relatively disagrees" and "relatively agrees". Therefore, the golden section method is used here to set the entropy and hypermetropy of adjacent cloud models, in which the smaller \( \alpha \) is 0.618 times of the larger. The research domain \([0,10]\) is divided into five rating intervals. The center point is used as the expected value of "general agreement", and 0 and 10 are the expected value of "very disagreement" and "very agreement", respectively. Based on the principle of being close to the "medium" grade, the expected values of "relatively inconsistent" and "relatively consistent" can be calculated as 6.91 and 3.09. In this study, \( \alpha = 0.1 \) was set. Using the properties of normal clouds, the EN value of each evaluation grade can be obtained, and its calculation formula is as follows: \( EN \alpha = (E_x \alpha - E_x) / 3 \).

The comment set cloud model calculated according to the formula is expressed as follows: very consistent \((10,1.1031,0.1)\), relatively consistent \((6.91,0.636,0.1)\), generally consistent \((5,0.39,0.1)\), relatively inconsistent \((3.09,0.636,0.1)\), and very inconsistent \((0,1.1031,0.1)\).

4.3. Calculation of index weights

According to the subjective decisions of 50 experts, the weight \( w_\beta \) of each index was calculated by fuzzy interval hierarchy analysis. The actual situation of QoS reliability model was obtained by referring to the self-developed software, and the weight \( w_\alpha \) of each index was calculated by using entropy weight method. Finally, the comprehensive weight \( w_i \) is calculated, and the weight \( w_i \) of the link to be evaluated is calculated.

| Table 2 Data factor index comprehensive weight |
|-----------------------------------------------|
| Section to be evaluated | Data elements | Subjective weight \( w_\beta \) | Objective weight \( w_\alpha \) | The comprehensive weight \( w_i \) | Weight of the link to be evaluated \( w_i \) |
|-------------------------|---------------|------------------|------------------|-----------------|-----------------|
| The system definition   | Number of tasks and functions that can be done | 0.13719 | 0.091956 | 0.121908 | 0.38914 |
|                         | Define the number of performance parameters \( n \) for the fault | 0.12029 | 0.149425 | 0.130133 | 0.38914 |
|                         | Number of performance parameters for fault definition | 0.16013 | 0.091956 | 0.137097 | 0.38914 |
| Quality of mathematical model | Bandwidth sensitivity | 0.11369 | 0.149425 | 0.125763 | 0.39826 |
|                         | Packet loss rate sensitivity | 0.15543 | 0.137935 | 0.149519 | 0.39826 |
|                         | Whether the model is robust | 0.10949 | 0.149425 | 0.122982 | 0.39826 |
| The complexity of reliability calculations | Computational complexity | 0.10189 | 0.114938 | 0.106298 | 0.21260 |
|                         | Spatial complexity | 0.10189 | 0.114938 | 0.106298 | 0.21260 |
4.4. Indicator cloud model and evaluation cloud map

If \( m \) experts participate in the evaluation, then \( m \) cloud models will appear, which are respectively:

\[ C_1 = \left( \bar{E}_x, \bar{E}_n, \bar{H}_e \right), \quad C_2 = \left( \bar{E}_x, \bar{E}_n, \bar{H}_e \right), \quad \ldots \quad C_m = \left( \bar{E}_x, \bar{E}_n, \bar{H}_e \right). \]

In order to make use of the relevant information of each expert, a new integrated cloud decision cloud \( C \) is obtained by using the floating clustering method. The results are shown in Table 3.

| Section to be evaluated | Data elements                                      | Each data factor cloud model parameters | Cloud model parameters of each link |
|-------------------------|---------------------------------------------------|----------------------------------------|-----------------------------------|
| The system definition   | Number of tasks and functions that can be done    | (8.4930,0.3220,0.1553)                 |                                   |
|                         | Define the number of performance parameters \( n \) for the fault | (8.9705,0.1862,0.1855)                 | (9.0491,0.2300,0.1772)            |
|                         | Number of performance parameters for fault definition | (9.6183,0.1967,0.1871)                 |                                   |
| Quality of mathematical model | Bandwidth sensitivity                          | (9.1958,0.2092,0.1882)                 |                                   |
|                         | Packet loss rate sensitivity                      | (8.4578,0.2489,0.1858)                 | (8.6908,0.1986,0.1775)            |
|                         | Whether the model is robust                       | (8.4368,0.1131,0.1540)                 |                                   |
| The complexity of reliability calculations | Computational complexity | (8.4933,0.2384,0.1873)                 | (8.9497,0.1653,0.1617)            |
|                         | Spatial complexity                                | (9.4061,0.0922,0.1361)                 |                                   |

Data factors are independent of each other, and the correlation between indicators is small, so the cloud model parameters of each link can be calculated by formula (8).

\[
\begin{align*}
\bar{E}_x &= \frac{\bar{E}_x w_1 + \bar{E}_x w_2 + \cdots + \bar{E}_x w_n}{w_1 + w_2 + \cdots + w_n} \\
\bar{E}_n &= \frac{\bar{E}_n w_1 + \bar{E}_n w_2 + \cdots + \bar{E}_n w_n}{w_1 + w_2 + \cdots + w_n} \\
\bar{H}_e &= \frac{\bar{H}_e w_1 + \bar{H}_e w_2 + \cdots + \bar{H}_e w_n}{w_1 + w_2 + \cdots + w_n}
\end{align*}
\]

(8)

The three links in the modeling process are interrelated, such as the mathematical model will directly affect the calculation of reliability, so the comprehensive evaluation value of QoS reliability model cloud map parameters can be calculated by formula (9), the results are (8.8929, 0.2037, 0.1746).

\[
\begin{align*}
\bar{E}_x &= \frac{\bar{E}_x \bar{E}_n w_1 + \bar{E}_x \bar{E}_n w_2 + \cdots + \bar{E}_x \bar{E}_n w_n}{\bar{E}_n w_1 + \bar{E}_n w_2 + \cdots + \bar{E}_n w_n} \\
\bar{E}_n &= \frac{\bar{E}_n w_1 + \bar{E}_n w_2 + \cdots + \bar{E}_n w_n}{\bar{E}_n w_1 + \bar{E}_n w_2 + \cdots + \bar{E}_n w_n} \\
\bar{H}_e &= \frac{\bar{H}_e \bar{E}_n w_1 + \bar{H}_e \bar{E}_n w_2 + \cdots + \bar{H}_e \bar{E}_n w_n}{\bar{E}_n w_1 + \bar{E}_n w_2 + \cdots + \bar{E}_n w_n}
\end{align*}
\]

(9)

The comprehensive evaluation value cloud model and the judgment set cloud model are represented in the same figure by MATLAB, as shown in Figure 3. It can be seen from the figure that the cloud model of comprehensive evaluation value is between "very consistent" and "relatively consistent", but
closer to the cloud model of "very consistent". Therefore, we believe that the evaluation result of this QoS reliability model is "very consistent" with the project requirements.

Fig 3 Comparison diagram of comprehensive evaluation cloud model and evaluation set cloud model

4.5. Comparison and analysis

In order to verify the reliability of the cloud model calculation results and evaluation conclusions, this paper uses fuzzy evaluation method and analytic hierarchy process to verify the above evaluation results. The specific steps will not be described in detail. The evaluation results are shown in Table 4. The final calculation result of the cloud model is represented by the similarity between the cloud model and the "very consistent" cloud model.

Table 4 The fuzzy quantitative evaluation value and the final evaluation value EVA of each link of modeling

| Evaluation methods | Fuzzy evaluation method | Analytic hierarchy process | Evaluation value in this paper | Actual estimated value |
|--------------------|-------------------------|----------------------------|-------------------------------|------------------------|
| QoS reliability model | 0.941                 | 0.954                     | 0.996                        | 0.983                  |

Therefore, it can be seen that the evaluation results in this paper are closer to the actual evaluation values of QoS reliability model, and the method adopted in this paper can reflect the evaluation results more intuitively.

5. Conclusion

Reliability model is the key of reliability analysis of satellite communication system. Reliability model evaluation is one of the key points of reliability model development and reliability analysis research. Based on the theory of combination weighting and cloud model, this paper establishes a comprehensive evaluation index system and applies it to the evaluation of QoS reliability model. The method combines objective data and subjective analysis to evaluate the reliability model, and the result is complete. As for the determination of index weight, although the organic combination of subjective calculation and objective calculation has been considered and the defects of a single method have been avoided to a certain extent, the research on the selection method of unified overall index system and the calculation of index system weight can be further improved according to the actual situation.

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