Effectiveness evaluation of smart equipment support information system based on Entropy-Revised G1 method

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Abstract. Focusing on the complexity of the structure and the diversification of indicators in the equipment support information system, a combination weighting method was proposed to evaluate the system effectiveness. Firstly, based on the working principle of the equipment support information system, this method constructed its evaluation indicator system; Secondly, based on the subjective and objective characteristics of the indicators, it determined the weight of each indicator by combining the entropy method and the G1 sequence method; Subsequently, through the comparative analysis of the model, the efficiency ranking of the system was carried out. The results of theoretical analysis and simulation verified that this method is an effectively integration of qualitative and quantitative analysis, and is a feasible plan in the effectiveness evaluation of equipment support information system.

Keywords: G1 method, entropy method, index system, information system, effectiveness evaluation.

1. Introduction
With the widespread application of modern high-tech technology, especially information technology in the military field, the type of warfare is gradually changing from the traditional mechanized mode to network information warfare. Internet-centric information warfare will become the main combat mode in the future [1]. Therefore, the support situation of equipment is gradually shifting to an intelligent and networked support model, that is, an equipment support model based on information systems [2]. The equipment support information system mainly collects and processes equipment information data, and generates new data after sorting, and the information does not change the content of the information itself during the transmission process [3]. A reasonable assessment of the equipment support information system [4-5] is conducive to the accuracy of technical personnel support and the correctness of the commander’s decision-making and deployment. Currently, there are many methods for system effectiveness evaluation, and the following three are usually selected: model-based, knowledge-based, and data-driven evaluation methods [6-8]. Aiming at the network and integration characteristics of the equipment support information system, this paper will use the entropy correction G1 weighting method to evaluate the system's effectiveness. The method has a simple operation process and pays more attention to the comprehensiveness of index selection, which is helpful to complete the effectiveness evaluation of the system.
2. Entropy modified G1 method

2.1. Entropy method.
The entropy method is a typical objective weighting method [9-11]. The basic idea [11] is to set the observed value of the k index on the i evaluation objects as $V_{ik}$, and the entropy value of the k index $e_k$ as:

$$e_k = -\frac{1}{\ln n} \sum_{i=1}^{n} \left( \frac{v_{ik}}{\sum_{i=1}^{n} v_{ik}} \right) \ln \left( \frac{v_{ik}}{\sum_{i=1}^{n} v_{ik}} \right)$$  \hspace{1cm} (1)

The smaller the given k, $e_k$, the greater the difference between $V_{ik}$, which can be specifically explained as the greater the difference of each evaluation target on the k-th index, the more obvious the comparison effect of this index on each evaluation target. Conversely, when the value of $e_k$ is larger, the comparative effect of k indicators on each evaluation target is weaker. It can be seen that the weight of the k-th index is:

$$w_k = \frac{(1 - e_k)}{\sum_{i=1}^{m} (1 - e_i)}, k = 1,2, ..., m.$$  \hspace{1cm} (2)

However, when using the entropy method to evaluate, due to the large dependence of sample data, the weights may vary depending on the sample data in the model.

2.2. G1 Empowerment Method.
G1 weighting is a subjective weighting method that optimizes and improves the analytic hierarchy process[12]. The main feature is that only the judgment matrix needs to be constructed, and the consistency test is not necessary. The basic principle is to arrange the evaluation indicators in descending order of $(x_1, x_2, \cdots, x_n)$ according to the expert evaluation experience and the subjective needs of users[13], set it to $x_1 > x_2 > \cdots > x_n$, and then compare the importance of $x_j$ and $x_{j+1}$ with to obtain the scale value of $f_j$. The scale value is defined as shown in the table below[13]:

| Scale value | definition |
|-------------|------------|
| 1           | Two evaluation indicators are of equal importance |
| 1.2         | One indicator is slightly more important than another indicator |
| 1.4         | The importance of one indicator is very important than another indicator |
| 1.6         | One indicator is more important than another indicator |
| 1.8         | One indicator is too important than another |
| 1.1,1.3,1.5,1.7 | The importance is between the above levels |

The indicators are compared in pairs to obtain the judgment matrix $R = \left[ r_{ij} \right]$ constructed by the scale value. The matrix satisfies the following characteristics:

1. $r_{ij}$ is the scale value obtained by comparing the k-th and j-th indicators in pairs, where $k, j = 1,2,\cdots,n$;
2. $r_{ij} = \frac{1}{r_{ji}}$ ;
3. $r_{jj} = 1$ ;
4. $r_{kj} = r_{ki} \cdot r_{ij}$, in $k = 1,2,\cdots,n$.
From the above content, it can be concluded that the judgment matrix $R$ can be regarded as satisfying the principle of consistency, and a reasonable subjective weight can be obtained. The subjective weight of each indicator is $\alpha_j$:

$$\alpha_j = \frac{\prod_{r=1}^{n} r_j^{\gamma_j}}{\sum_{j=1}^{n} \prod_{r=1}^{n} r_j^{\gamma_j}}$$

The $G1$ weighting method can clearly and easily judge the importance of evaluation indicators through expert experience, but there are many evaluation indicators for system performance, so it is difficult to accurately judge the importance of the indicators.

3. Entropy modified $G1$ method.

The specific process is as follows:

1. According to the working principle, divide the system effectiveness into different characteristic indexes, construct its evaluation index system, and then normalize each system index[14];

2. Determine the weight of the indicator layer to the criterion layer: relying on expert opinions to clarify the importance of indicators. The results are shown in Figure 1. Make full use of the key information of the original data and rely on the index level to obtain the corresponding criterion level weight $y_n$.
Assuming that \( e_j \) is the entropy value of the j-th index, the calculation process is as follows:

\[
y_{ij} = \frac{f_{ij}}{\sum_{i=1}^{m} f_{ij}} \quad (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m)
\]

\[
e_j = -\ln m \sum_{i=1}^{m} y_{ij} \ln(y_{ij})
\]

If \( f_{ij} \) is the original value of the j-th index in the i-th evaluation target, \( \sum_{i=1}^{m} f_{ij} \) is the sum of the original value of the j-th index of the m-th evaluation target, and \( y_{ij} \) is the i-th evaluation the j-th feature ratio of the target.

In summary, the greater the gap between \( j \) and \( y_{ij} \), the greater the degree of impact on the evaluation result, and the increase in entropy.

(3) The G1 method is too subjective in determining the importance of adjacent indicators and cannot more accurately reflect the relative importance of the indicators. In view of this drawback, the entropy method is used to compare the importance of weights.

\[
r_k = \begin{cases} 
\frac{e_{k-1}}{e_k}, & e_k < e_{k-1} \\
1, & e_k \geq e_{k-1}
\end{cases}
\]

\( e_k \) is the entropy of the k-th index. According to the value of \( r_k \), the weights of m three-level indicators under the second-level indicators are calculated as:

\[
w_m = \left\{1 + \sum_{k=2}^{m} \prod_{l=k}^{m} r_l \right\}^{-1}
\]

After the weight \( w_m \) is obtained, the index weight of the mth, m-1 is

\[
w_{k-1} = r_k w_k, \quad (k = m, m-1, \ldots, 2)
\]

Through the above formula, the weight of the criterion layer to the target layer \( V^{(j)} \) can be obtained, and then the combined weight of the index layer to the target layer is obtained:

\[
\beta_k = W_k \times V^{(j)}
\]

(4) The evaluation indicators of the equipment support information system use a combination of positive and negative indicators. The larger the positive index data, the more advantageous the evaluation index of the system, such as the type of information acquisition, recognition probability, communication capacity, etc.; the smaller the negative index data, the more advantageous the evaluation index of the system, such as bit error rate, average Queue length, etc.

Suppose, \( x_{ij} \) is the score of the i-th expert on the j-th index of the system, and \( v_{ij} \) is the sample data provided by the i-th expert on the j-th index. The forward scoring formula is as follows:

\[
x_{ij} = \frac{v_{ij} - \min_{1 \leq i \leq m} (v_{ij})}{\max_{1 \leq i \leq m} (v_{ij}) - \min_{1 \leq i \leq m} (v_{ij})}
\]

The scoring formula for negative indicators is:

\[
x_{ij} = \frac{\max_{1 \leq i \leq m} (v_{ij}) - v_{ij}}{\max_{1 \leq i \leq m} (v_{ij}) - \min_{1 \leq i \leq m} (v_{ij})}
\]
Let $P_i$ be the comprehensive evaluation score of the $i$-th system capability, relying on the linear weighted evaluation formula, it is desirable

$$P_i = \sum_{j=1}^{m} x_{ij} \alpha_j (i = 1, 2, ..., m)$$  \hspace{1cm} (13)

As expressed by the above formula, $x_{ij}$ is the result of the evaluation index, and $\alpha_j$ is the $j$th evaluation index using the entropy correction G1 method to calculate the combined weight of the target layer.

In summary, relying on the entropy correction G1 method to determine the weights can exert the maximum information value of the index data, neutralize the subjectivity of the G1 weighting method[15-16], enhance the scientific nature of the evaluation results, and avoid the use of entropy method alone. It is easy to overlook the practicality of the problem and the impact caused by the change of the sample.

4. Equipment Support Information System Evaluation Model

Based on the working principle and operating characteristics of the equipment support information system, this paper divides the system effectiveness into different characteristic indexes, constructs an evaluation index system, and normalizes each index to be tested. Subsequently, the entropy modified G1 weighting method is used to calculate the index weight, and the model is finally used to obtain the system effectiveness evaluation result. The specific evaluation process is as follows:

In accordance with the purpose, science, scope and generality of the evaluation system, comprehensively considering the overall effectiveness of the subsystem and the equipment support information system, according to the equipment comprehensive support standard S5000F, the index system is established as follows:

![Figure 2. Entropy correction G1 evaluation model](image-url)
The information system effectiveness evaluation system has three levels: the first level is called the target level; the second level is called the criterion level, which is divided into three aspects: information acquisition capability, information processing capability, and information protection capability. The specific description and deployment; the third layer is called the indicator layer, this layer is a detailed description of the criteria layer indicators.

Information acquisition capability: the ability of the system to acquire information from the outside world through equipment and numerous information collection methods[17].

Information processing capability: the ability of the system to process information in accordance with certain rules and procedures.

Information protection capability: the ability of the system to attack the enemy and protect itself from information attacks[18].

5. Case simulation and result analysis.

There are currently five types of equipment support information systems A, B, C, D, and E. The sample data is constructed through evaluation indicators, the qualitative indicators adopt a 0-10 scoring method, and the quantitative indicators refer to the measured data of the equipment support information system. The relevant data is shown in Table 2.

| Criterion layer | Index layer | A  | B  | C  | D  | E  |
|-----------------|-------------|----|----|----|----|----|
| Information access $U_1$ | $U_{11}$ Types of information acquisition (a) | 45 | 50 | 66 | 57 | 25 |
|                 | $U_{12}$ Recognition probability (tenth scale) | 7  | 8  | 7  | 6  | 5  |
|                 | $U_{13}$ Transmission rate (decade system) | 7  | 6  | 6  | 7  | 7  |
|                 | $U_{14}$ Transmission distance (km) | 5  | 9  | 6  | 3  | 8  |
|                 | $U_{15}$ Transmission delay (decade system) | 7  | 9  | 8  | 9  | 9  |
|                 | $U_{16}$ Bit error rate (standard rate %) | 75 | 60 | 90 | 80 | 93 |
|                 | $U_{17}$ Communication capacity (ten thousand) | 20 | 30 | 27 | 12 | 13 |
|                 | $U_{18}$ Average response time (seconds) | 8  | 6  | 9  | 7  | 7  |
|                 | $U_{19}$ Average queue length (pieces) | 170 | 130 | 220 | 150 | 160 |
| Information processing capability $U_2$ | $U_{21}$ Throughput (ten thousand) | 11 | 22 | 26 | 30 | 24 |
|                 | $U_{22}$ Failure prediction accuracy (10 points) | 6  | 7  | 8  | 7  | 3  |
|                 | $U_{23}$ Comprehensiveness of failure prediction (10 points system) | 5  | 7  | 6  | 6  | 7  |
|                 | $U_{24}$ Task allocation time efficiency (on-time rate%) | 89 | 87 | 89 | 80 | 73 |
|                 | $U_{25}$ Reasonability of task allocation (10 points) | 7  | 5  | 9  | 6  | 3  |
| Information protection capability $U_3$ | $U_{31}$ Network Security (10% system) | 9  | 8  | 9  | 9  | 8  |
|                 | $U_{32}$ Software security (10 points) | 6  | 9  | 7  | 7  | 7  |

5.1. Index importance ranking.

The relative order of the criterion level and the index level is based on the evaluation experience of experts to rank the importance. The order of importance between the criterion levels is $U_1 > U_2 > U_3$. Taking $U_1$ as an example, the importance ranking of its subordinate indicators is $U_{11} > U_{12} > U_{13} >$
$U_{14} > U_{15} > U_{16} > U_{17} > U_{18} > U_{19}$, The ranking of the importance of indicators under other criterion levels is shown in Figure 2.

5.2. Neighboring index importance ratio.

Calculate the index entropy value according to formula (5) (6). The detailed results are shown in Table 3. Relying on the obtained entropy value and formula (7) to obtain the ratio of the importance of adjacent indicators $r_i$.

By comparing the entropy values of adjacent indicators, the uncertain factors of expert judgment in the G1 method can be effectively avoided, and the entropy value can better reflect the difference between the indicator data and the data.

| Guidelines index | $e_j$ | $r_k$ | $w_k$ | Criterion weight | Combination weight |
|------------------|-------|-------|-------|------------------|-------------------|
| Information access $U_1$ |
| $U_{11}$ | 0.972836 | - | 0.121026 | 0.049631 |
| $U_{12}$ | 0.992417 | 1 | 0.121026 | 0.049631 |
| $U_{13}$ | 0.998269 | 1 | 0.121026 | 0.049631 |
| $U_{14}$ | 0.961054 | 1.038723 | 0.116514 | 0.410085 | 0.047781 |
| $U_{15}$ | 0.997097 | 1 | 0.116514 | 0.410085 | 0.047781 |
| $U_{16}$ | 0.992979 | 1.004147 | 0.116033 | 0.410085 | 0.047781 |
| $U_{17}$ | 0.960303 | 1.034027 | 0.112215 | 0.410085 | 0.047781 |
| $U_{18}$ | 0.994138 | 1 | 0.112215 | 0.410085 | 0.047781 |
| $U_{19}$ | 0.990166 | 1.004011 | 0.111766 | 0.410085 | 0.047781 |
| Information processing capability $U_2$ |
| $U_{21}$ | 0.972116 | - | 0.20362 | 0.075449 |
| $U_{22}$ | 0.972668 | 1 | 0.20362 | 0.075449 |
| $U_{23}$ | 0.99539 | 1 | 0.20362 | 0.075449 |
| $U_{24}$ | 0.99823 | 1 | 0.20362 | 0.075449 |
| $U_{25}$ | 0.964021 | 1.035486 | 0.196642 | 0.075449 |
| Information protection capability $U_3$ |
| $U_{31}$ | 0.998983 | - | 0.501142 | 0.185694 |
| $U_{32}$ | 0.994429 | 1.00458 | 0.498858 | 0.370541 | 0.184847 |

By scoring the index data of the five information security systems in Table 3, and substituting the index scores and the combined weights in Table 3 into formula (13), a comprehensive evaluation result of the system's ability values is obtained.

| Evaluation score | A | B | C | D | E |
|------------------|---|---|---|---|---|
| Information access | 0.257845 | 0.313127 | 0.173173 | 0.189983 | 0.179193 |
| Information processing capability | 0.169295 | 0.269796 | 0.321052 | 0.242974 | 0.127073 |
| Information protection capability | 0.185694 | 0.184847 | 0.247309 | 0.247309 | 0.061616 |
| Comprehensive efficiency | 0.612834 | 0.76777 | 0.741534 | 0.680266 | 0.367882 |
5.3. Evaluation result analysis.

This paper selects the entropy correction G1 weighting method to evaluate the effectiveness of the equipment support information system. This method not only combines the working principle and operating characteristics of the system, but also integrates the objective entropy weighting method and the subjective G1 weighting method to reflect experts' opinions and the degree of change in indicator data, as well as the way to determine the main relationship between indicators, are spiritually integrated. It avoids the shortcomings of G1 weighting method due to human decision-making, and also avoids the contradiction of unsuitable weight distribution due to the lack of neutralization of objective weighting method. Compared with pure subjective and objective weighting method, it is more in line with actual application.

It can be seen from Table 4 and Figure 3 that the comprehensive effectiveness comparison results of the five equipment support information systems are B>C>D>A>E. Therefore, in the process of system design and application, the most suitable system can be selected according to the requirements of equipment support tasks, combined with the system's individual capabilities and comprehensive effectiveness values.

6. Conclusions

Based on the demand of equipment support information system, this paper establishes an equipment support information system effectiveness evaluation index system. Due to the ambiguity and randomness of qualitative data in the evaluation index, an equipment support information system evaluation model based on the entropy modified G1 method is proposed. Experiments show that this research method has good applicability and guidance, and the effectiveness of the evaluation is also demonstrated.

Compared with traditional methods, the method proposed in this paper has the following characteristics: (1) The method has a strict theoretical system, and has excellent small and medium sample data classification and recognition capabilities; (2) This method weakens the artificiality to a certain extent. The influence of factors on the evaluation results ensures the rationality and scientific nature of the evaluation.

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