Research on Equipment Importance Evaluation for Battlefield Maintenance

Hanqiang Deng, Jianguo Hao, Liang Gong, and Jiangtao Kong

***Abstract*—The evaluation of the importance of equipment is an important basis for decision-making on maintenance. To solve the problem that the indicators in the current assessment method are irrational and the fusion method is not objective enough, the evaluation method for the equipment importance of battlefield maintenance is proposed. According to the basic principles of logistical support, an indicator system was established from the perspectives of command and control relationships, operational capabilities, and combat space. Indicator importance is calculated respectively and integrated using evidence fusion methods to obtain the importance of equipment. Finally, an example is given to verify the rationality and effectiveness of the method.**

***Index Terms*—Importance evaluation, operational mission, complex network, evidence fusion, multi-indicator**

I. Introduction

The importance of equipment is an important factor for task scheduling in battlefield repair. Battlefield emergency repair is one of the most effective methods to restore the combat effectiveness of the troops in the modern battlefield. Different types of equipment play different roles in the combat system. To reasonably schedule maintenance tasks and maximize the combat effectiveness of the troops, it is necessary to determine the importance of the equipment reasonably according to the function and role of the equipment in the battle before dispatching the maintenance tasks.

Various equipment interact in battlefield environment to form a complex system and complex network theory is a powerful tool for modeling and analyzing complex systems. At present, there are many researches and applications in military field [1]. Zhang Yong [2] takes the Army Division as the research object, uses the topological structure of the system and the repair capability of the equipment itself as the indicators, applies the complex network to model, and the method of equipment importance evaluation is designed. An equipment often has many attributes. In order to solve the problem that evaluation is not objective enough from a single view, Jiang Zhipeng [3] studied the importance evaluation method of command nodes from four dimensions: topological structure, combat missions, command types and attributes of nodes. Chen Chunliang [4] uses complex networks to analyze the importance of equipment under different indicators from the perspectives of command-control relationship, collaborative relationship and other indicators, and weights and fuses the indicators to determine the final importance.

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Through the analysis of the research status of equipment importance evaluation methods, we can find that the current research still has the following shortcomings:

1) The indicators were not reasonably selected when evaluating with multi-indicators, such as the coupling relationship between command-control relationship and coordination relationship.
2) The fusion algorithm for multiple indicators is not objective enough. The reliability of the evaluation results of different indicators differ when different evaluation methods were applied, making the weighted summation method incomplete.

The basic principles of battlefield repair and support are: ensuring key equipment and taking into account general equipment. That is to say, in terms of supporting objects, command and main battle equipment are the main ones, followed by other equipment; in terms of operational space, the main direction is first and the secondary direction is second [5].

In view of the shortcomings of the existing evaluation methods and the basic principles of battlefield emergency repair, this paper puts forward a three-indicator system of command-and-control relationship, combat capability and combat space, and chooses the corresponding evaluation methods according to the characteristics of each indicator to evaluate (The importance of command and control relation is analyzed by complex network, the importance of combat capability is analyzed by judgment matrix according to combat mission, and the importance of combat space is obtained by expert scoring method). In order to evaluate the importance of each equipment under the current combat mission, the importance of the three indicators are fused by the evidence fusion algorithm. Finally, an example is given to illustrate the feasibility and effectiveness of the method.

II. Analysis of Equipment Importance Evaluation

A. Basic Concepts

Indicator importance: refers to the importance of each equipment in a combat system. This paper includes the importance of command-control relationship $\boldsymbol{I}^1$, the importance of operational capability $\boldsymbol{I}^2$ and the importance of combat space $\boldsymbol{I}^3$.

B. Analysis of Importance of Command and Control Relationship

The command and control node plays an important role in

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the combat system. The command and control ability and combat effectiveness of the system can be effectively improved by evaluating the importance of the command and control relationship in the combat system and giving priority to the equipment with high importance.

Most of the existing research considers command-control relationship and coordination relationship separately, but in fact, coordination relationship can affect the action of the same level equipment, and has a high similarity with the command-control relationship network. Therefore, this paper combines the command and control relationship network with the cooperative relationship network, and describes them with one directed weighted network. Directed links are used to represent the flow of information, including top-down command information flow, bottom-up information flow, and collaborative information flow between peers, and the importance of the flow of information to enhance combat effectiveness is expressed by edge weight.

Complex network is an important method to analyze problems with network topology. The complex network theory can be used to evaluate the command-and-control relationship network and get the importance of the command-and-control relationship.

C. Analysis of Importance Degree of Operational Capability

Combat capability is the basis for achieving operational objectives, and equipment with strong operational capability should be given priority.

Usually a type of combat equipment has a variety of capabilities, and the size of each capability in the equipment design stage has been determined. And under different combat tasks, the demand for various combat capabilities is also different. For example, in the execution of maneuvering tasks, the demand for maneuvering capabilities is higher than the demand for striking capabilities, and in the execution of striking tasks, the demand for striking capabilities is higher than the demand for maneuvering capabilities.

Therefore, the importance of operational capability of equipment can be expressed as the weighted sum of each capability and the requirement degree of each capability, and the key is how to get the objective and reasonable requirement degree from the combat mission.

D. Analysis of the Importance of Operational Space

Usually a war can be divided into several operational directions, the main direction of action directly affects the overall situation of the battlefield, and the minor direction of action has an important impact on the main direction. Therefore, the equipment of different operational directions has different importance to the whole battlefield, and the equipment of the same operational direction has higher similarity in the operational space, which can be considered as having the same operational space importance.

E. Analysis of Importance Integration

Independent multi-indicator importance cannot provide a good basis for equipment support decision-making in practice, therefore, integrate them into comprehensive importance $\boldsymbol{S}$ can effectively improve the operability in use. Most of the existing research uses simple weighting method to fuse, and the simple weighting weight is scored by experts, which has higher subjective factors. Moreover, this method does not consider the relationship between the importance of indicators, and cannot completely consider the information contained in them.

DST (Dempster-Shafer theory) [6]-[8] can fuse multiple sets of evidences without prior knowledge. It has been widely studied and applied in multi-sensor data fusion. Li Bicheng [9] improved DST in order to solve the problem of evidence fusion with high conflict and get reasonable and reliable results.

In the evaluation of equipment importance, the indicator importance describes the equipment from different angles, which is similar to the multi-sensor system. Using the improved D-S evidence theory [9] to fuse the indicator importance, the fusion result $\boldsymbol{S}^{DS}$ can be obtained, and the weighted average value can be calculated with the weighted fusion result $\boldsymbol{S}^{WA}$, and the comprehensive importance $\boldsymbol{S}$ can be obtained. This method can improve the objectivity of the evaluation method, and ensure the stability and reliability of the result.

III. Equipment Importance Evaluation Algorithm

A. Equipment Importance Evaluation Model

For easy description, the parameters in the evaluation model are defined as follows:

1) There are *n* equipment in the operation system.

2) The command and control relationship between equipment is represented by directed weighted network $G=\{V,E,\boldsymbol{W}\}$. Among them, $V=\{v_1,v_2,\cdots,v_n\}$ is a set of nodes, representing all the equipment in the system; $E=\{e_1,e_2,\cdots\}$ is a set of edges between nodes; $(v_i,v_j)\in E$ indicates that there is a directed link between nodes v_i to v_j, indicating the existence of command and control information flow; $\boldsymbol{W}=[w_{ij}]_{i,j=1}^{n}$ is the weighted matrix of the linked edges. w_{ij} is the weight of the edge from v_i to v_j, and $w_{ij}\geq 0$.

3) The combat system has *m* capability types, and the capability matrix of the equipment is expressed as $\boldsymbol{C}=[c_{ij}]_{n\times m}$. Among them, c_{ij} is the *j*th capacity of the equipment v_i, with $c_{ij}\geq 0$.

4) $\boldsymbol{F}=(f_1,f_2,\cdots,f_m)$ is the requirement vector for each combat capability of a combat mission, in which $f_j(j=1,2,\cdots,m)$ is the degree the *j*th capacity is required by the combat mission, has $\sum_{j=1}^{m} f_j=1$ and $f_j\geq 0$.

5) $\boldsymbol{I}^b(b=1,2,3)$ represents the importance vector of command and control relation, combat capability and combat space respectively, with $\sum_{i=1}^{n}\boldsymbol{I}_i^b=1$ and $\boldsymbol{I}_i^b\geq 0$.

6) There are *q* operational directions in the battlefield. The operational direction importance vector $\boldsymbol{D}=(d_1,d_2,\cdots,d_q)$, in which $d_r(r=1,2,\cdots,q)$ is the importance of operational direction *r*, has $\sum_{r=1}^{q} d_r=1$ and $d_r>0$.

7) When the indicator importance is fused by static weight, the expert weights are $\boldsymbol{\omega}_b(b=1,2,3)$, where $\sum_{b=1}^{3}\boldsymbol{\omega}_b=1$ and

$\omega_b \geq 0$.

8) $\boldsymbol{S}$ indicates the integrated and final importance of equipment.

B. Importance Evaluation of Command and Control Relationships

At present, there are few researches on the importance evaluation of directed weighted network nodes, such as the multiple impact matrix evaluation method proposed by Wang Yu[10], and eigenvector method proposed by Bonacich [11], etc.

In order to evaluate the importance of the alleged network nodes under the offensive combat mission, Chen Weilong[12] proposed using the network efficiency method for analysis. The command and control network is regarded as a directed weighted network, and the degree of influence of the removal of an equipment node on the efficiency of the entire network is calculated to judge the importance of the allegation relationship of the equipment.

Defining a path from any node to a node in a weighted network sequentially passes through an intermediate node, the path length can be expressed as

$$d_{ij} = \frac{w_{ij_1} + w_{j_1 j_2} + \cdots + w_{j_{r-1} j_r} + w_{j_r j}}{w_{ij_1} \times w_{j_1 j_2} \times \cdots \times w_{j_{r-1} j_r} \times w_{j_r j}} \tag{1}$$

where $w_{ij_1}, w_{j_1 j_2}, \cdots, w_{j_{r-1} j_r}, w_{j_r j}$ is the edge weight of each directed edge in the path, and when a weight w=0, the path length tends to infinity.

Obviously, the path length should increase monotonically as the path increases through the nodes, as demonstrated below.

***Proof*:** Let the path length of v_i to v_j be $d_{ij} = \dfrac{A}{B}$, where $A = w_{ij_1} + w_{j_1 j_2} + \cdots + w_{j_{r-1} j_r} + w_{j_r j}$ and $B = w_{ij_1} \times w_{j_1 j_2} \times \cdots \times w_{j_{r-1} j_r} \times w_{j_r j}$, then add node v_k after the path, and the length of which becomes

$$\begin{aligned} d_{ik} &= \frac{A + w_{jk}}{B \times w_{jk}} = \frac{1}{B}\frac{A + w_{jk}}{w_{jk}} \\ &= \frac{1}{B}(\frac{A}{w_{jk}} + 1) \end{aligned}$$

Since the weight of any directed edge satisfies $1 \geq w_{jk} \geq 0$, there is

$$\begin{aligned} d_{ik} &= \frac{1}{B}(\frac{A}{w_{jk}} + 1) \geq \frac{1}{B}(A+1) \\ &> \frac{A}{B} = d_{ij} \end{aligned}$$

So the monotony of this problem is proved.

Let node efficiency e_{ij} denote the influence of the allegation information sent by node v_i on node v_j. Then, as the path increases, the node efficiency should decrease, and the higher the information weight issued by v_i, the node efficiency should increase, so the node efficiency e_{ij} can be expressed as

$$e_{ij} = \frac{w_{ij_1}}{\min d_{ij}} \tag{2}$$

where $\min d_{ij}$ is the shortest path from v_i to v_j, and w_{ij_1} is the weight of the directed edge from v_i on the shortest path.

Comparing the definition of network efficiency in this paper with the definition in [12], it can be found that when two nodes are adjacent, the node efficiency calculated with the method defined in [12] has the result of $e_{ij} \equiv 1$, which cannot reflect the difference of w_{ij}. And using equation (2), node efficiency is proportional to the edge weight, which is more reasonable.

Network efficiency E can be expressed as

$$E = \sum_{i \neq j} e_{ij} \tag{3}$$

When a certain equipment node v_f fails, the network efficiency becomes E_f, and greater the network efficiency decline rate $\eta_f = 1 - E_f / E$ is, the more important the node is in this network. Therefore, the importance of the command and control relationship can be expressed as

$$\boldsymbol{I}^1 = \begin{pmatrix} \dfrac{\eta_1}{\sum_{f=1}^{n} \eta_f} & \dfrac{\eta_2}{\sum_{f=1}^{n} \eta_f} & \cdots & \dfrac{\eta_n}{\sum_{f=1}^{n} \eta_f} \end{pmatrix} \tag{4}$$

C. Operational Capability Importance Assessment

When the capability matrix $\boldsymbol{C}$ of the combat system is known, the operational capability importance of the equipment can be obtained by weighting the capability matrix $\boldsymbol{C}$ with the capability requirement $\boldsymbol{F}$, then the operational capability importance $\boldsymbol{I}_i^2$ of the equipment v_i is expressed as

$$\boldsymbol{I}_i^2 = \sum_{j=1}^{m} c_{ij} f_j \tag{5}$$

Expert scoring is a common method to determine the ability requirement vector, but this method has high subjectivity. Judgment matrix ranking method[13] is the key method of importance calculation in AHP. It has been widely used in military, economic and other fields. Compared with expert scoring method, this method is more objective and stable. Through the comparison of two capabilities, the relative importance between them is expressed by 1-9 scale method, and the judgment matrix is constructed. Then the importance of each capability is obtained by using NHM or ANC or other method. Eigenvector method (EM) is one of the best methods in ranking calculation.

Under a given combat task, the judgement matrix is scored by experts' pairwise comparison. Let the domain be m-type ability to be evaluated, the requirement degree of class j ability in the task be $f_j(j=1,2,\cdots,m)$, the judgment matrix $\boldsymbol{P}=[p_{ij}]_{m\times m}$. According to the definition of judgment matrix, the theoretical importance of the i^{th} kind of ability relative to the j^{th} kind is defined as

$$p_{ij}=\frac{f_i}{f_j},(i,j=1,2,\cdots,m) \tag{6}$$

By using the 1-9 scale method, we can get the judgement matrix $\boldsymbol{P}$. In this paper, the eigenvector method is used to calculate the ranking. Assuming that the maximum eigenvalue of matrix $\boldsymbol{P}$ is λ_{max}, the corresponding eigenvector is the ranking vector $\boldsymbol{F}$ of degree of demand. The eigenvector equation can be expressed as

$$\boldsymbol{PF}=\lambda_{max}\boldsymbol{F} \tag{7}$$

Eigenvectors $\boldsymbol{F}$ can be obtained from the characteristic equation.

According to the capacity demand vector $\boldsymbol{F}$ and the capacity matrix $\boldsymbol{C}$, the importance of combat capability can be obtained from equation (5).

D. Operational Space Importance Assessment

Make the operational space importance $\boldsymbol{I}_i^3$ of the equipment equal to the importance d_r of its operational direction (combat echelon), d_r can be obtained by the judgment matrix method described in subsection C. In order to avoid miscellaneous, this paper gives the importance of combat echelon directly and takes it as the importance of combat space.

E. Important Degree Fusion Based on D-S Evidence Theory

Evidence fusion and simple weighting method are used to fuse the importance of indicators. The improved evidence fusion method [9] is used to get the fusion result $\boldsymbol{S}^{DS}$ and weighted average with the result $\boldsymbol{S}^{WA}$ of simple weighting fusion in order to evaluate the importance of equipment more objectively.

1) Evidence fusion method

Evidence fusion is based on a set of primitive attributes (i.e. identification framework) $\Theta=\{H_i\}$ $(i=1,2,\cdots,n)$, where H_i is called primitive and in this paper, the proposition "equipment v_i is important" is expressed. The indicator importance $\boldsymbol{I}^b$ is the evidence participating in information fusion. Its focal attribute set is the same as that of the basic attribute set. The probability that the evidence $\boldsymbol{I}^b$ supports proposition H_i is true is represented by $\boldsymbol{I}^b(H_i)=\boldsymbol{I}_i^b$.

The fusion method proposed in [10] can solve the conflict problem of evidence. Using this method for reference, the average support degree of evidence to proposition H_i is defined as

$$q(H_i)=\frac{1}{3}\sum_{b=1}^{3}\boldsymbol{I}^b(H_i) \tag{8}$$

The synthetic formula of evidence is

$$\begin{aligned}\boldsymbol{S}_i^{DS}&=\prod_{b=1}^{3}\boldsymbol{I}^b(H_i)+k\cdot q(H_i)\\&=\prod_{b=1}^{3}\boldsymbol{I}_i^b+k\cdot q(H_i)\end{aligned} \tag{9}$$

Among them, k is the conflict coefficient between evidence and is defined as:

$$\begin{aligned}k&=1-\sum_{i=1}^{n}\boldsymbol{I}^1(H_i)\cdot\boldsymbol{I}^2(H_i)\cdot\boldsymbol{I}^3(H_i)\\&=1-\sum_{i=1}^{n}\boldsymbol{I}_i^1\cdot\boldsymbol{I}_i^2\cdot\boldsymbol{I}_i^3\end{aligned} \tag{10}$$

The result of evidence fusion $\boldsymbol{S}^{DS}$ can be obtained by using this method.

2) Weighted fusion method

Through expert scoring or judgment matrix method, the expert weight $\boldsymbol{\omega}$ of each indicator importance degree is obtained. The weighted fusion result of equipment v_i importance is expressed as

$$\boldsymbol{S}_i^{WA}=\sum_{b=1}^{3}\boldsymbol{I}_i^b\boldsymbol{\omega}_b \tag{11}$$

3) Weighted average of $\boldsymbol{S}^{DS}$ and $\boldsymbol{S}^{WA}$

Define $\tau\in[0,1]$ as the degree of confidence in the results of weighted fusion method. Thus, the composite importance of equipment v_i can be the weighted average of weighted fusion results and evidence fusion results, and is expressed as

$$\boldsymbol{S}_i=\tau\boldsymbol{S}_i^{WA}+(1-\tau)\boldsymbol{S}_i^{DS} \tag{12}$$

IV. Example Analysis

A. Example Background

To verify the rationality of the above method, the following example is constructed: A command and control relationship network of a combat unit is established as shown in Fig. 1. Among them, there is a command information flow with a weight of 0.1 between the command equipment, and the direction and weight of the other information flow are marked out in the network.

The operational capability of each equipment is shown in Table I; the judgment matrix of the capability requirement is shown in Table II, assuming that the real value is in brackets and the expert scoring value is outside brackets; the expert weights of the three indicators in weighted fusion are shown in Table III; and the importance of each combat echelon in this task is shown in Table IV.

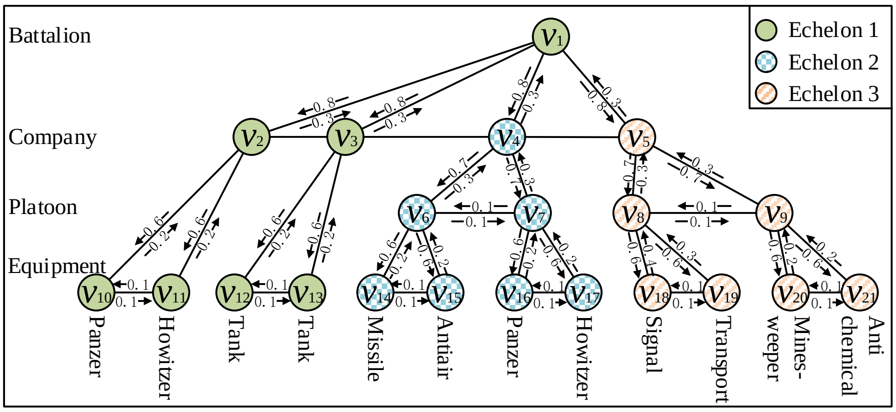

Fig. 1. Command and control networks of combat unit

TABLE I: COMBAT CAPABILITY OF EQUIPMENT

ID	Strike	Antiair	Support	Maneuver
1	0.3	0	0	1
2	0.4	0	0	1
3	0.6	0	0	1
4	0.5	0	0	1
5	0.1	0	0.4	1
6	0.6	0.4	0	1
7	0.5	0	0.2	1
8	0	0	0.4	1
9	0	0	0	1
10	0	0	0.7	1
11	0.7	0	0	1
12	0.9	0	0	1
13	0.9	0	0	1
14	0.1	0.9	0	1
15	0.1	0.9	0	1
16	0	0	0.7	1
17	0.7	0	0	1
18	0	0	0.8	1
19	0	0	0.7	1
20	0	0	0	1
21	0	0	0	1

TABLE II: COMPARISON MATRIX OF CAPABILITY REQUIREMENT DEGREE

	Strike	Antiair	Support	Maneuver
Strike	1	9(8)	3(4)	2
Antiair	1/9(1/8)	1	1/5	1/7(1/6)
Support	1/3(1/4)	5	1	2/1
Maneuver	1/2	7(6)	2	1

TABLE III: EXPERT WEIGHT FOR INDICATOR IMPORTANCE

	Cmd&Ctrl	Capability	Space
Weight	0.5	0.3	0.2

TABLE IV: THE IMPORTANCE OF EACH ECHELON

	Echelon 1	Echelon 2	Echelon 3
Importance	0.9	0.8	0.6

TABLE V: THE REQUIREMENT DEGREE OF CAPABILITY

	Strike	Antiair	Support	Maneuver
Capacity demanded level	0.447 (0.477)	0.038 (0.040)	0.244 (0.227)	0.271 (0.256)

S^{DS} and S^{WA} are combined with τ=0.5 . Matlab R2016a is used to calculate.

B. Example Result

By analyzing the judgment matrix with eigenvector method, the requirement degree of combat capability can be obtained, as shown in Table V.

The importance degree of each node can be obtained from the index importance assessment method, as shown in Fig. 2.

Using evidence theory and weighted fusion method, we can get two kinds of fusion results shown in Fig. 3 respectively. The weighted average of the results of evidence theory and weighted fusion is used to obtain the combined equipment importance, and the ranking results are shown in Fig. 4.

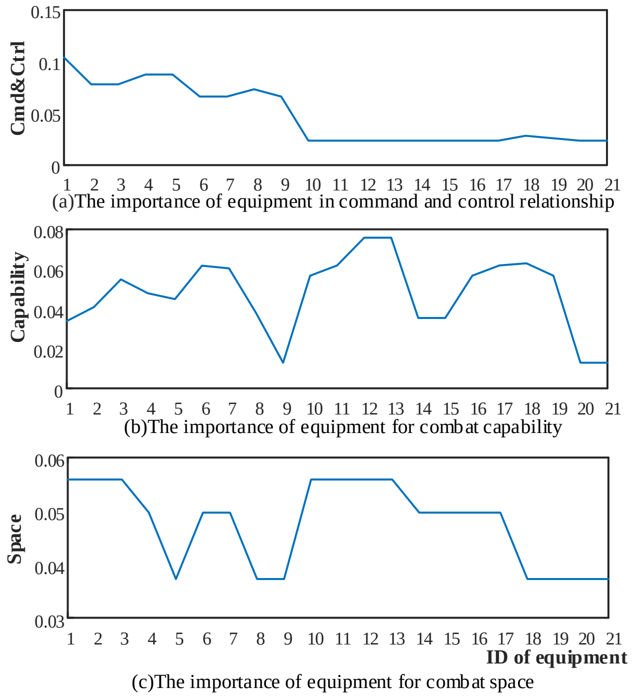

Fig. 2. The importance of indicator

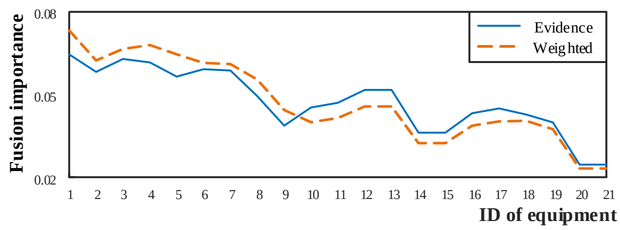

Fig. 3. Comparison of evidence fusion and weighted fusion

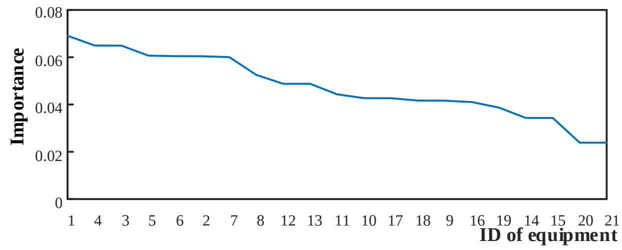

Fig. 4. Ranking of equipment importance

C. Result Analysis

1) The calculation method of the importance degree of the accusation relationship based on the network efficiency method can objectively and reasonably evaluate the importance of the accusation relationship of the equipment according to the network topology information. For example, the battalion v_1 is in the network center, which has the highest importance, while the company equipment v_4 and v_5 has the second highest importance. v_2 and v_3 also of high importance because it is directly linked to the battalion and combat equipment.
2) Using eigenvector method to rank judgment matrix can reasonably judge the requirement of tasks for various abilities, and compared with the real value, it can be found that even if there are some differences in the score, the evaluation results are basically the same, which shows that the method is stable and reliable.
3) Comparing the results of evidence fusion and weighted fusion, we can find that they are highly consistent, which shows that it is reasonable to use evidence fusion in importance evaluation. Compared with the weighted fusion results, the evidence fusion results show that the importance of command equipment should be reduced, and the importance of the underlying equipment should be increased, which is consistent with the current idea of flat combat development of our army.
4) From the results of equipment importance evaluation shown in Fig. 4, it can be seen that the combination of evidence fusion and weighted fusion can accurately identify the key equipment in the system and effectively distinguish the importance between equipment. If equipment v_1 is the supreme command equipment in this combat mission, it should be the most priority to support to ensure the completion of the combat intent, and equipment v_{20}, v_{21} combat capability does not conform to the current mission, its support cannot effectively enhance the operational capability of the system.

V. Conclusion

In this paper, a method of equipment importance evaluation based on multi-index fusion is proposed. The three indexes of command-and-control relationship, combat capability and combat space are analyzed as index system. Based on network efficiency method, the importance of command and control relationship is calculated, the operational capability requirement is calculated with judgment matrix, and the operational space importance is obtained by expert scoring method. Finally, the D-S evidence fusion and weighted fusion method are used to fuse the importance of the three indicators. The analysis of an example shows that the calculation results of the importance of the command relationship based on network efficiency conform to the logic of the command relationship, the calculation results of the importance of the combat capability are objective and stable, and the results of evidence fusion and weighted fusion are highly consistent. The method proposed in this paper can reduce the dependence on expert experience and make the calculation results more objective. It proves that the method proposed in this paper is objective and effective, and can provide decision-making basis for battlefield support.

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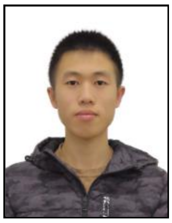

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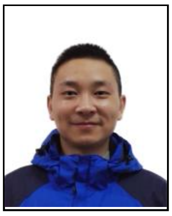

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