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Evaluation of Equipment Node Importance based on Bi-Layer Coupling Complex Networks

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Abstract

Considering the complex multi-dimensional relationship of equipment in the equipment system, this paper constructs a spatial structure network that reflects the spatial relationship between equipment and a functional structure network that reflects the command and control and collaboration of equipment. Based on this, a bi-layer coupled complex network model is put forward. Combined with the relevant characteristics of equipment architecture, the structural characteristics of each network and evaluation parameters of the node importance are determined, and coupled intensity is confirmed by the improved group analytic hierarchy process. The evaluation method of equipment node importance is determined. Finally, the rationality and effectuality of this method are validated through the example analysis of a synthetic battalion executing offensive operation tasks.

Keywords: complex networks; bi-layer coupling; equipment system; node importance; evaluation method

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1. Introduction

System operation under the condition of information has gradually become the main style of future wars, and exerting the overall combat effectiveness of the equipment system is the core factor that restricts the battlefield situation. The equipment system is a complex system in which the equipment cooperates with each other to enhance combat capability. As a sub-body of the equipment system, equipment not only cooperates with each other but also plays different roles, resulting in differences in the importance of the equipment system.

Equipment importance reflects the extent to which equipment plays a role in the equipment system. Scientific evaluation of the equipment importance can reasonably measure the contribution of equipment to the equipment system. This not only lays the foundation for improving the combat effectiveness of the equipment system, but also provides a basis for battlefield repair decision-making. At present, there is not much research on the evaluation of the importance degree of equipment. Literature [1] established the evaluation model from the perspective of the system by using the combat ring and system operational capability as the evaluation index. Literature [2] introduced the complex network theory, abstracted equipment as nodes in complex networks, obtained equipment importance through the improved node importance evaluation method, and provided a good idea for equipment importance evaluation.

By mapping the equipment architecture into a complex network, the evaluation of the equipment importance and the evaluation of the importance of complex network nodes have become a main trend in current research. Node importance evaluation can be divided into two categories: one expresses node importance by node significance [3], such as the common node importance evaluation index, and the other characterizes node importance through the degree of influence on the network by node destruction [4], such as the node contraction method [5] and node deletion method. With the deepening of research, some new methods of node importance evaluation, such as the domain similarity method [6], PageRank algorithm

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based on eigenvector [7], and Leader-Rank algorithm [8], are constantly emerging. On the basis of traditional undirected and unauthorized networks, research on directed networks [9] and weighted networks [10] has gradually emerged, but it is still not sufficient. The evaluation of equipment node importance has not yet been adequately addressed.

The evaluation of equipment importance at this stage has encountered the following two issues:

(1) When evaluating equipment node importance by constructing a complex network, the core of the research is limited to the importance of node topology. The space structure of the equipment system is considered in more depth. However, the command and control relationship and coordination relationship between equipment are not reflected well. The multi-dimensional complex network should be constructed considering all aspects of equipment node importance to fully evaluate the importance of equipment nodes.

(2) The existing research only analyzes the structural characteristics of the equipment system and ignores the functional characteristics of the equipment system, which makes it difficult to truly reflect the importance of equipment. For example, for damaged equipment in the equipment system, the communication function is impaired, but they still have the functions of firepower and maneuver. The traditional research directly removes the corresponding damaged nodes of equipment, considers that the importance is reduced to zero, and calculates the change in the importance of other nodes; it obviously does not reflect the true situation of equipment importance. Therefore, the description of the functional structure should be introduced based on the characterization of the equipment spatial structural so that the model construction more closely complies with the actual situation of the equipment system.

To address the above problems, based on the construction of the spatial structure network of the equipment system, this paper introduces the functional structure network and proposes the bi-layer complex network structure model of the equipment system to make up for the deficiencies of the traditional single-layer complex network structure model. The node importance evaluation methods are determined by combining the characteristics of different networks. The equipment node importance evaluation model is constructed and verified through an example.

2. Equipment Architecture Modeling based on Bi-layer Coupling Complex Networks

2.1. Model Building

For the equipment system, due to the combat formation between equipment, the location of the equipment and their contributions may vary. They constitute the equipment spatial structure network layer of the equipment system [11], with nodes from the equipment abstraction known as the equipment nodes, and the connection between nodes represents the weight relationship between nodes. Equipment coordination between the equipment is realized through functions such as command and control and fire coordination. According to the functional nodes (communication, firepower, motor function) and their interrelationships, the functional network layer of the equipment system is built. Each equipment node has one or more functions and can be coupled as a “one-to-one” or “one-to-many” function as a function node. Each function node uniquely corresponds to one equipment node. Therefore, equipment nodes of the spatial structure layer and function nodes of the functional layer have a coupling relationship.

It can be seen that the complicated network structure of the equipment system is a bi-layer complex network that is formed by the coupling of the spatial structure network and the functional structure network. The two networks interact and are coupled by the mapping between the equipment node and the function node. The equipment spatial structure network is the carrier of the functional structure network and also the constraint the functional structure network. The two are combined to form the multi-dimensional complex network structure of the equipment system.

2.1.1. Spatial Structure Network

The complex spatial relationship between equipment constitutes a complex network of equipment spatial structure and can be expressed as $G_T=(V_T,E_T,W_T)$, where V_T represents a set of nodes in the spatial network G_T, and if the number of equipment in the equipment system is n, then the number of nodes in G_T is also n, and assume the node set is $V_T=\{v_{T1},v_{T2},\cdots,v_{Tn}\}$; E_T represents the edge set between nodes, and $E_T=\{e_{Tij}\,|\,e_{Tij}=(v_{Ti},v_{Tj}),v_{Ti},v_{Tj}\in V_T\}$; and W_T represents the set of edge weights. d_{ij}^t represents the spatial distance between node v_{Tj} and node v_{Tj}, and w_{ij}^t represents the spatial relationship weight between node v_{Tj} and node v_{Tj}, which is determined by the spatial distance between nodes and is inversely proportional to the distance.

2.1.2. Functional Structure Network

The functional network is a directed complex network, which can be expressed as $G_F = (V_F, E_F, W_F)$, where V_F denotes the node set G_F. Suppose that the number of nodes in G_F is m and the nodes set is $V_F = \{v_{F1}, v_{F2}, \cdots, v_{Fm}\}$. The functional nodes communicate information between functions interacting with each other, the edge set of information exchange between functional nodes is denoted as E_F, and W_T represents the set of edge weights. Functional structure networks have both command and control relationships and cooperative relationships, so we can construct command and control networks and cooperative networks respectively.

① The command and control relationship between functional nodes is denoted as C, d_{ij}^c is the shortest path between node v_{Fi} and node v_{Fj} in the command and control relation dimension, w_{ij}^c is the command and control relationship weight between node v_{Fi} and node v_{Fj}, and $w_{ij}^c \in [0,1]$.

② The cooperative relationship between functional nodes is denoted as S, d_{ij}^s is the shortest path between node v_{Fi} and node v_{Fj} in the cooperative relation dimension, w_{ij}^s is the cooperative relationship weight between node v_{Fi} and node v_{Fj}, and $w_{ij}^s = \{0,1\}$.

2.1.3. Coupling Network

The bi-layer coupled network of the equipment system structure is G_{T-F}. It is formed by the coupling of spatial structure network G_T and functional structure network G_F and is denoted by $G_{T-F} = (G_T, G_F, R_{T-F})$. R_{T-F} denotes the coupling relationship between the equipment space structure network and the functional network. When the equipment node is mapped into a single functional node, R_{T-F} is a "one-to-one" coupling, and R_{T-F} is a "one-to-many" coupling when the equipment node is mapped to multiple functional nodes.

The coupling intensity of the bi-layer coupled network in equipment architecture is determined by the importance of the corresponding functions of equipment. The more important the function nodes mapped by equipment nodes, the higher the coupling intensity of the bi-layer network.

Based on the above analysis, an equipment architecture model based on a bi-layer coupled multidimensional complex network can be expressed as $\Theta = (G_T, G_F, G_{T-F})$.

2.2. Complex Network Characteristics Analysis

The equipment architecture model is a bi-layer coupled complex network structure. For the structural layer of the equipment system, it is a complex network formed by the spatial relationship between equipment nodes. For the functional layer of the equipment system, it is a complex network formed by the functional nodes mapped by equipment nodes and their command and control and cooperative relationship. The structural layer and the functional layer are coupled with each other to form an equipment architecture model, as shown in Figure 1.

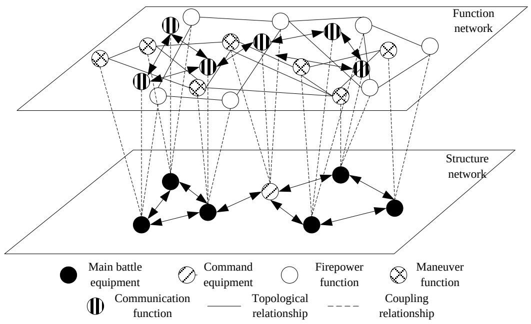

Figure 1. Bi-layer coupled complex networks model of equipment architecture

(1) For the network layer of equipment spatial structure, the spatial relationship between equipment nodes reflects the position and the distribution of the equipment in the equipment system. For different combat missions and formation deployment, the importance of equipment performance depends on the location. Therefore, the spatial structure network is an undirected weighted network.

(2) The functional structure network of the equipment reflects the relationship between the equipment functions. The command and control between equipment is realized through the information upload and release of the command and control relation between the function nodes, and there is a difference in direction and intensity between them. Therefore, the command and control relational network is a directed weighted network. The collaborative relationship between function nodes reflects the mutual collaborative support between the equipment and the functions in the equipment system, and directionality exists. Therefore, the coordination relationship network is an undirected un-weighted network.

2.3. Parameter Analysis

As the equipment structure network is a complex network, when analysing the importance of nodes, the related parameters are analysed first. For complex networks $G(V,E,W)$, $V=\{v_1,v_2,\cdots,v_n\}$ is the node set, $E=\{e_{ij}\,|\,e_{ij}=(v_i,v_j),v_i,v_j\in V\}$ is the edge set, and $W=(w_1,w_2,\cdots,w_n)$ is the set of edge weights, which has the following characteristic parameters:

Node degree. The degree k_i of a node is the number of edges directly connected to the node.

Node distance. The node distance d_{ij} is the shortest path from node v_i to node v_j. For an un-weighted network, d_{ij} is the number of edges on the shortest path from node v_i to node v_j. For weighted networks, weights need to be taken into account, and the expression is

$$d_{ij}=\frac{w_{ik_1}+w_{k_1k_2}+\ldots+w_{k_{l-1}k_l}+w_{k_l j}}{w_{ik_1}w_{k_1k_2}\cdots w_{k_{l-1}k_l}w_{k_l j}}$$

In the formula, $w_{ik_1},w_{k_1k_2},\cdots,w_{k_{l-1}k_l},w_{k_l j}$ represent the weights of each side on the shortest path from node v_i to node v_j.

Length between nodes. The length of the inter-node f_{ij} is the shortest number of edges between node v_i to node v_j.

Node proximity degree. Node proximity degree C_i is the reciprocal of the sum of the distances from node v_i to all other nodes.

Node efficiency. Node efficiency η_i reflects the average ease of the node to other nodes in the network, and it can be expressed as

$$\eta_i=\frac{1}{n-1}\sum_{j=1,i\neq j}^{n}\frac{1}{d_{ij}}$$

Node intensity. Node intensity S_i represents the sum of the weights of the edges directly connected to node v_i, and it promotes the degree of un-weighted nodes in the weighted network.

3. Equipment Node Importance Evaluation

The node importance reflects the extent to which equipment plays a role in the equipment system and is an important indicator of the importance of equipment. As a complex network, equipment structure needs to consider the node importance in the local network and its importance in the global network according to the structural characteristics of complex networks in solving the node importance. Based on this, the node importance of structural networks and functional networks and the coupling intensity should be considered comprehensively to weigh the equipment node importance.

3.1. Node Importance Evaluation of Spatial Structure Network

The spatial structure network is an undirected weighted network. Since the node intensity takes into account both the adjacent nodes and the weights of the adjacent nodes, it is the embodiment of the local information of the nodes. Therefore, the local importance of nodes in the spatial network can be expressed by the node intensity. The node proximity degree reflects the degree of the node distance from the entire network center. It is the overall embodiment of the node global information. Therefore, the global importance of nodes in the spatial network can be expressed by the node's proximity degree.

The node local importance of the spatial structure network of v_{Ti} is

$$E_T(i)_1 = S_i^t = \sum_{j \in N_i} w_{ij}^t \tag{1}$$

In the formula, N_i represents the node set directly connected with node v_{Ti}. w_{ij}^t represents the weight from node v_{Ti} to node v_{Tj}.

The node global importance of the spatial structure network of v_{Ti} is

$$E_T(i)_2 = C_i^t = \frac{1}{\sum_{j=1, j \neq i}^{n} d_{ij}^t} \tag{2}$$

The fusion of the local importance and the global importance of nodes in the space structure is

$$E_T{}'(i) = E_T(i)_1 E_T(i)_2 = S_i^t \cdot C_i^t = \frac{\sum_{j \in N_i} w_{ij}^t}{\sum_{j=1, j \neq i}^{n} d_{ij}^t} \tag{3}$$

The node importance of v_{Ti} can be obtained after normalization.

3.2. Node Importance Evaluation of Functional Structure Network

Functional nodes in functional networks include communication function nodes, firepower function nodes, and motor function nodes. The relationship between nodes is relatively complicated. There exist not only command and control but also synergies, such as command and control between communication nodes, as well as the coordination between motor function nodes. There are differences in the nature of complex networks corresponding to the two relations. Therefore, it is necessary to project the functional network to the command network and the collaborative network for solving the node importance of the functional network, and the projection diagram is shown in Figure 2.

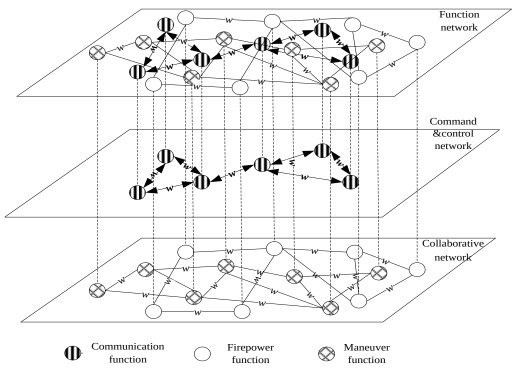

Figure 2. Structure chart of equipment function network decompose projection

3.2.1. Calculation of Command and Control Relationship Function Node Importance

3.2.1.1. Node Local Importance Calculation of Command and Control Relationship

The partial information of the command and control relational nodes can be characterized by the mutual influence among the nodes, while the command and control relational networks are directed weighted networks. The mutual influence among the nodes can be reflected by the connection and intensity of the adjacent nodes. For the command and control relational network, the greater the intensity, the larger the local importance of the node. Therefore, the local importance of a node can be characterized by the node intensity S_i^c and the contribution $1/w_{ij}^c S_i^c$ of the node local importance to the neighboring node v_{Cj}. Then, the contribution proportion of their adjacent nodes can be reflected by the node's importance contribution matrix [12]. Its expression is

$$H_{IC} = \begin{bmatrix} 1 & \frac{\delta_{12}^c w_{12}^c}{S_2^c} & \cdots & \frac{\delta_{1m}^c w_{1m}^c}{S_m^c} \\ \frac{\delta_{21}^c w_{21}^c}{S_1^c} & 1 & \cdots & \frac{\delta_{2m}^c w_{2m}^c}{S_m^c} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\delta_{m1}^c w_{m1}^c}{S_1^c} & \frac{\delta_{m2}^c w_{m2}^c}{S_2^c} & \cdots & 1 \end{bmatrix} \tag{4}$$

In the formula, m is the number of command and control function nodes, S_i^c is the node intensity of the command and control network, w_{ij}^c is the weight of the command and control relation between node v_{Ci} and node v_{Cj} in the command and control network, and δ_{ij}^c is the contribution parameter of the command and control network. When v_{Ci} and v_{Cj} are adjacent, $\delta_{ij}^c = 1$; otherwise, $\delta_{ij}^c = 0$.

It should be noted that since the command and control network is a directed weighted network, in contrast to literature [3, 13], considering the influence of the side rights on the node importance, the weight of the command and control and the intensity of the node are introduced into the node important contribution matrix.

3.2.1.2. Node Global Importance Calculation of Command and Control Relationship

The global importance of the command and control relation node can be reflected by the location information of the node. The node efficiency in the network can represent the role of node in the network information transmission. The higher the node efficiency, the easier it is to transmit the node information and the closer the network is to the center. Therefore, node efficiency can be used to characterize the global importance of the node.

Therefore, the node global importance of the command and control network is

$$\mu_i^c = \eta_i^c = \frac{1}{m-1} \sum_{j=1, i \neq j}^{m} \frac{1}{d_{ij}^c} \tag{5}$$

3.2.1.3. Command and Control Node Comprehensive Importance Calculation

Comprehensively considering the local importance and global importance of the nodes, the node efficiency that characterizes the node global importance is integrated into the node local importance evaluation matrix, and the comprehensive importance evaluation matrix of the command and control nodes is

$$G_{EC} = \begin{bmatrix} \mu_1^c & \frac{\mu_2^c \delta_{12}^c w_{12}^c}{S_2^c} & \cdots & \frac{\mu_m^c \delta_{1m}^c w_{1m}^c}{S_n^c} \\ \frac{\mu_1^c \delta_{21}^c w_{21}^c}{S_1^c} & \mu_2^c & \cdots & \frac{\mu_m^c \delta_{2m}^c w_{2m}^c}{S_n^c} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\mu_1^c \delta_{m1}^c w_{m1}^c}{S_1^c} & \frac{\mu_2^c \delta_{m2}^c w_{m2}^c}{S_1^c} & \cdots & \mu_m^c \end{bmatrix} \tag{6}$$

According to the node comprehensive importance evaluation matrix H_{EC}, the comprehensive node importance $E_C{}'$ can be derived as

$$E_C{}'(i) = \mu_i^c \cdot \sum_{j=1, j\neq i}^{m} \frac{\mu_j^c \delta_{ij}^c w_{ij}^c}{S_j^c} \tag{7}$$

The node importance of v_{Ci} can be obtained after normalization.

3.2.2. Calculation of Collaborative Relationship Node Importance

Since the collaborative network is an undirected network, the calculation of the coordinated relationship node importance of the firepower function node is the same as that of the motorized function. Therefore, the calculation of the node importance of the firepower function is taken as an example. The node local importance can be characterized by the contribution matrix; in reference [13], node global importance is characterized by the node proximity degree.

3.2.2.1. Local Importance Calculation of Collaborative Nodes

The contribution matrix of the collaborative node importance is

$$H_{IS} = \begin{bmatrix} 1 & \frac{\delta_{12}^s k_2^s}{(\bar{k}^s)^2} & \cdots & \frac{\delta_{1p}^s k_p^s}{(\bar{k}^s)^2} \\ \frac{\delta_{21}^s k_1^s}{(\bar{k}^s)^2} & 1 & \cdots & \frac{\delta_{2n}^s k_p^s}{(\bar{k}^s)^2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\delta_{p1}^s k_1^s}{(\bar{k}^s)^2} & \frac{\delta_{p2}^s k_2^s}{(\bar{k}^s)^2} & \cdots & 1 \end{bmatrix} \tag{8}$$

In the formula, p is the number of collaborative network nodes, k_i^s is the degree of node v_{Si} in the collaborative network, and $\bar{k}^s$ is the average degree of nodes in the collaborative network, the formula of which is

$$\bar{k}^s = \frac{1}{p}\sum_{i=1}^{p} k_i^s \tag{9}$$

δ_{ij}^s contributes to allocation parameters for the cooperative network. When node v_{Si} is adjacent to node v_{Sj}, $\delta_{ij}^s = 1$; otherwise $\delta_{ij}^s = 0$.

3.2.2.2. Global Importance Calculation of Collaborative Nodes

The global importance of nodes in a collaborative relationship is characterized by the node proximity degree, which is calculated as follows:

$$C_i^s = \frac{1}{\sum_{j=1, j \neq i}^{p} d_{ij}^s} \tag{10}$$

In the formula, d_{ij}^s is the distance between node v_{Si} and node v_{Sj} in the collaborative relation network.

3.2.2.3. Comprehensive Importance Calculation of Collaborative Relation Nodes

Integrating the node's degree of proximateness that represents the global importance of a node into A, we can obtain the comprehensive importance degree of the collaborative node as

$$H_{SE} = \begin{bmatrix} C_1^s & \frac{k_2^s C_2^s}{(\bar{k}^s)^2} & \cdots & \frac{k_p^s C_p^s}{(\bar{k}^s)^2} \\ \frac{k_1^s C_1^s}{(\bar{k}^s)^2} & C_2^s & \cdots & \frac{k_p^s C_p^s}{(\bar{k}^s)^2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{k_1^s C_1^s}{(\bar{k}^s)^2} & \frac{k_2^s C_2^s}{(\bar{k}^s)^2} & \cdots & C_p^s \end{bmatrix} \tag{11}$$

According to the node comprehensive importance evaluation matrix H_{EC}, the formula for node comprehensive importance $E_S{}'$ can be derived as

$$E_S{}' = C_i^s \cdot \sum_{j=1, j \neq 1}^{p} \frac{\delta_{ij}^s k_j^s C_j^s}{(\bar{k}^s)^2} \tag{12}$$

The node importance of v_{Si} can be obtained after normalization.

3.3. Coupling Intensity Evaluation

Coupling intensity reflects the intensity of the coupling relationship between different layers of networks. For equipment architecture, the coupling intensity between equipment and each function reflects the importance of each function to equipment. Therefore, it can be expressed as a weight of each function, which can be evaluated by IGAHP [14] based on factors such as equipment type and operational mission.

Taking battalion command equipment as an example, a number of experts in relevant neighborhoods were invited to give scores according to the importance of battalion command equipment for communication functions, firepower functions, and maneuver functions according to the characteristics of combat missions and equipment types. According to the AHP method, the function importance of battalion command equipment is given by experts. According to the IGAHP method from literature [14], the weight of each expert can be obtained. Thus, the function importance vector of battalion command equipment can be obtained, which is the coupling intensity ϕ^a.

$$\phi^a = \sum_{i=1}^{q} \mu_i \times \gamma_i = (\phi_1^a, \phi_2^a, \phi_3^a) \tag{13}$$

In the formula, q is the number of experts, γ_i is the functional importance weight vector given by expert i, and μ_i is the weight of expert i. Similarly, the coupling intensity of company command equipment and the main battle equipment ϕ^b and ϕ^c can be obtained.

3.4. Node Comprehensive Importance Evaluation

For equipment nodes in the equipment architecture network, the importance of the equipment node depends on the node importance in the spatial structure and the node importance of the corresponding functional network. While the equipment function node is derived from the equipment node mapping, the contribution rate of each function node to the corresponding equipment node importance is represented by the coupling intensity. Therefore, the equipment node importance $E_1(i)$ corresponding to the node v_{Ti} can be calculated as

$$E_1(i) = \begin{cases} \beta E_T(i) + \phi_1^a E_C(\tilde{i}) + \phi_2^a E_S(\hat{i}) + \phi_3^a E_S(\breve{i}),\ \Gamma_1 \\ \beta E_T(i) + \phi_1^b E_C(\tilde{i}) + \phi_2^b E_S(\hat{i}) + \phi_3^b E_S(\breve{i}),\ \Gamma_2 \\ \beta E_T(i) + \phi_1^c E_C(\tilde{i}) + \phi_2^c E_S(\hat{i}) + \phi_3^c E_S(\breve{i}),\ \Gamma_3 \end{cases} \tag{14}$$

In the formula, Γ_1 means battalion command equipment, Γ_2 means company command equipment, and Γ_3 means main battle equipment. β is the spatial relation conversion coefficient, which represents the degree of the spatial relationship's contribution to the node comprehensive importance. $E_C(\tilde{i})$ is the node importance of the command and control relationship that is mapped by the node v_{Ti} , $E_S(\hat{i})$ is the collaborative relationship node importance of the firepower function node that is mapped by the node v_{Ti} , and $E_S(\breve{i})$ is the collaborative relationship node importance of the maneuver function node that is mapped by the node v_{Ti} .

4. Analysis of Example

4.1. Example Construction

4.1.1. Analysis of Equipment Architecture

Directed by superiors, our synthetic brigade performs manoeuvring offensive missions aimed at capturing some key points and annihilating the enemy forces. Under the direction and coordination of the Synthetic Brigade Command and Information System, each synthetic battalion independently performs mission-by-item combat operations. Spatial relationships, command and control relationships, and collaborative relationships between the equipment exist in the synthetic battalion. Therefore, in this paper, each synthetic battalion will be regarded as an equipment system for calculation and analysis.

Each synthetic battalion has five main battle companies. Each company has one company command equipment and nine main battle equipment. Companies within the offensive formation, the battalion of the company's attack formation, and equipment topological relations are shown in Figure 3.

Equipment numbers are denoted as *i-j*, which means the company number - equipment number. Designated number 1-1 represents the battalion command equipment; equipment 2-1, 3-1, 4-1, and 5-1 represent the company command equipment; and equipment 3-3 represents the main battle equipment of the 3rd Synthetic Battalion 3rd Company.

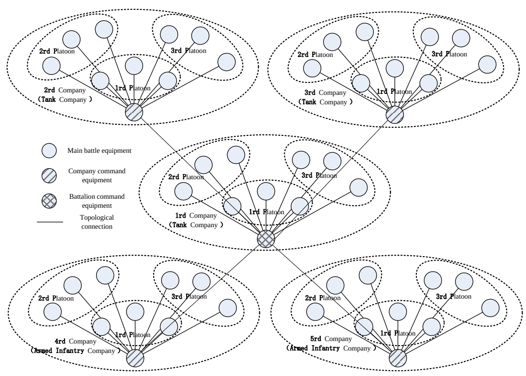

Figure 3. Topological structure and subordination relationship of equipment

4.1.2. Analysis of Spatial Relationship Structure Network

According to the characteristics of the composite battalion, part of the spatial relationship can be simplified, as shown in Figure 4.

It should be noted that: ① the spatial relationship weight between the equipment node of the spatial relationship is related to the distance, because the synthetic battalion attack front and attack depth is about 2-3km, so take the reciprocal of 100 meters distance between the equipment as the weight of the spatial relationship edge; ② because the distance between equipment in the same platoon is relatively short, this equipment can be reduced to the same node; ③ as the distance between companies is greater than the distance between platoons, any equipment within the company and any other equipment within any other company can be considered as the same, and the distance between command equipment is considered as the distance between the equipment of one company and other equipment of another company.

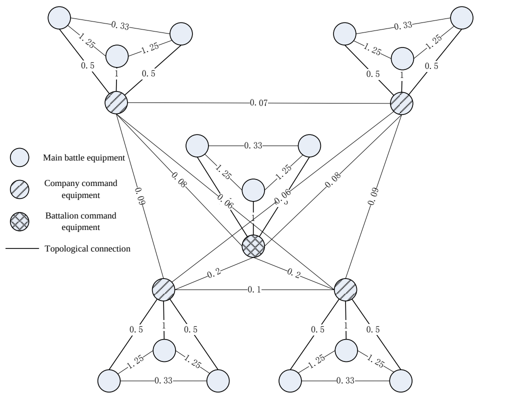

Figure 4. Simplified topological sketch of spatial relationship networks structure

4.1.3. Analysis of Command and Control Relationship Structure Network

The command and control relationship network is a directed weighted network composed of communication function nodes of each equipment. When the communication function node of the command equipment is damaged, the function node is removed and the command and control task is temporarily assumed by the communication function node of affiliated main battle equipment. The communication intensity connected with the impaired communication function node is affected. In this paper, the weight of the affected side is reduced to 70% of the original. In order to facilitate the display of the network of command and control, the nodes with the same command and control are merged. The simplified structure of the network of command and control is shown in Figure 5.

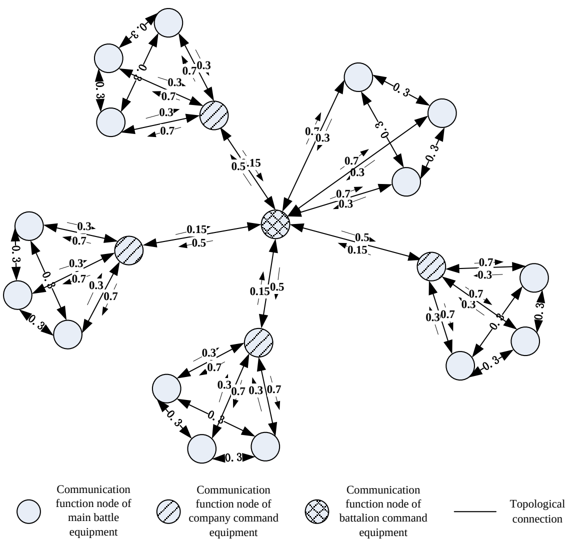

Figure 5. Simplified topological sketch of command and control relationship networks structure

4.1.4. Analysis of Collaborative Relationship Network

The collaborative relationship network is a directed network that exists between equipment function nodes. The synergic relationship between the equipment exists mainly between the equipment in the same company. Therefore, in this paper, the equipment that function between different companies do not have direct synergies, and the indirect synergy relationship with the company is embodied by the function node of command equipment. In order to concisely show the synergistic relationship between functions, some of the same synergistic relationship nodes are merged. The firepower function synergetic relationship network structure diagram is shown in Figure 6. The motor synergy relationship is similar.

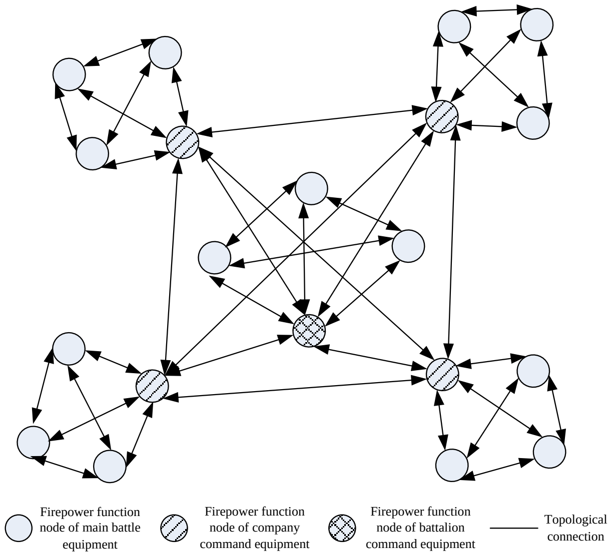

Figure 6. Simplified topological sketch of firepower function collaborative relationship networks structure

4.2. Equipment Node Importance Calculation

By IGAHP, we can get the weights of experts and further obtain the coupling intensity, as shown in Table 1.

Table 1. Results of coupled intensity

Equipment type	Φ
Battalion command equipment	（0.53,0.21,0.26）
Company command equipment	（0.41,0.27,0.32）
Main battle equipment	（0.12,0.57,0.31）

Setting the adjustment parameters as α=0.5 and β=0.6, the node importance of the corresponding equipment spatial structure, the node importance of the command and control relationship, and the node importance of the collaborative relationship are obtained. Due to the large amount of equipment involved in the example and limited article length, only some of the equipment node importance results are shown in Table 2.

Table 2. Evaluation results of equipment node importance

Equipment number	Equipment type	E_T	E_C	E_S	E
1-1	Battalion command equipment	1.497	9.527	2.693	5.408
1-3	Main battle equipment	1.783	0.726	1.209	1.825
1-8	Main battle equipment	0.946	0.726	1.209	1.470
2-1	Company command equipment	0.807	2.121	1.850	1.980
2-3	Main battle equipment	1.194	0.707	0.806	1.317
2-8	Main battle equipment	0.656	0.707	0.806	1.091
4-1	Company command equipment	1.115	2.121	1.850	2.101
4-3	Main battle equipment	1.491	0.707	0.806	1.428
4-8	Main battle equipment	0.805	0.707	0.806	1.128

For any of them, taking equipment 1-3 as an example, when the function is impaired, the equipment node importance is calculated as shown in Table 3.

Table 3. Evaluation result of node importance of equipment 1-3

Impaired function	E_T	E_C	E_{S1}	E_{S2}	E
None	1.783	0.726	1.209	1.209	1.825
1	1.783	0	1.209	1.209	1.744
2	1.783	0.726	0	1.209	1.257
3	1.783	0.726	1.209	0	1.460
1,2	1.783	0	0	1.209	1.147
1,3	1.783	0	1.209	0	1.370
2,3	1.783	0.726	0	0	0.877
1,2,3	0	0	0	0	0

1- Communication function; 2- Firepower function; 3- Motor function.

4.3. Evaluation Results Analysis

(1) In the same synthetic battalion, there is a comparative criterion for the equipment node importance, that is, the command equipment is more important than the main battle equipment, and the battalion command equipment is more important than the company command equipment. For example, in the synthetic battalion in terms of equipment importance, equipment 1-1 is higher than equipment 2-1 and equipment 2-1 is higher than equipment 2-3, which is consistent with the basic principles of comparative importance of the actual battlefield equipment.

(2) The spatial, command and control, and collaborative relationships within the equipment system will have an impact on the importance of equipment. For example, main battle equipment 1-3 and 1-8 belong to the same company, both of which have the same importance of command and control and collaborative relationships. However, due to the difference in location between the two, the importance of the spatial relationship is different. Thus, the importance of the two nodes in the equipment system is different, leading to differences in equipment importance.

(3) For battlefield damage equipment, the equipment importance is not all down to zero, but it also relates to its impaired function. For example, for the main battle equipment 1-3, as its function is damaged, the importance of the equipment will decrease, and the importance of the equipment changes due to the damage of different functions varies. For the main battle equipment, when the single function is damaged, the damage of the firepower function has the greatest influence on the equipment importance, and the damage of the communication function has the least influence on the equipment importance. When the communication, firepower, and maneuvering function are all impaired, the equipment is useless to this task and can be regarded as removed, so the equipment importance drops to zero.

5. Conclusions

The evaluation of the importance of equipment nodes in the equipment system can not only clarify the extent to which the equipment plays a role in the equipment system and provide a basis for improving the combat effectiveness of the equipment system, but also provide support for repair task scheduling in battlefield repair and help develop programs to provide reliable data support. Based on the interrelationship of equipment in the equipment system, this paper constructs the equipment network and the functional structure network. Based on this, a two-layer coupled complex network model is constructed and the parameters and methods for solving the node importance in each network relationship are designed. The importance of equipment nodes is evaluated, and the rationality of the model and method is verified through examples. The next step is to consider the evaluation of the importance of equipment under dynamic conditions.

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