Research On Evolution Of Quality Chain Network Model Based On Multi-Attribute Weighting Of Complex Network

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Abstract. Using the linear optimal connection mechanism of complex network model, a multi-attribute weighted quality chain network model construction method is proposed. Firstly, the enterprise node in the quality chain is defined to have its own attributes of quality elements and node business relevance. Secondly, the degree and the intermediate number are combined to comprehensively consider the local and global characteristics of the network to express the network attributes of the node, and the multi-attribute weighted quality chain network edge connection strategy algorithm is designed under the combination with the node's own attribute weighting. Finally, the simulation results show that the quality chain network model established by this strategy meets the scale-free characteristics and has higher network efficiency and stronger network invulnerability which proves that the newly established model is reasonable.

Keywords: quality chain network, multi-attribute, edge link strategy.

1. Intriducture

With the development of big data technology, the organizational structure of supply chain enterprises that are multipoint, heterotopia and interconnected has gradually emerged, which accelerate the formation of economic globalization, and also promote the frequent interaction of quality activities among supply chain enterprises. This kind of quality activity runs through the whole supply chain. The quality characteristics, values and business capabilities flow, transfer and transform with the quality activities. The interaction between various elements forms the quality chain. In the supply chain, a series of business activities and quality interactions between enterprise nodes constitute each chain node. Therefore, if a quality defect occurs in a certain link of the quality chain, which will lead to a series of quality problems.

2. Literature Review

Research on node attributes, Jiang Weijin et al. (2022) [1] sort the node importance by processing the local and global topology of the network at the same time, and integrate the network attribute information from multiple angles, and provide a more comprehensive measure of node importance. Feng Fenling et al. (2022)[2] believe that if an important node in the transport network fails, the transport efficiency and cargo flow of the China-EU train will be seriously restricted, and put forward a multi-layer network node importance evaluation method based on the improved TOPSIS (Technology for Order Preference by Similarity to an Ideal Solution) method and grey correlation analysis. Yu Hui et al. (2013)[3] believe that the importance evaluation of nodes in complex networks is of great significance in practical applications. Some existing importance evaluation indicators, such as degree and intermediate number, have shortcomings such as limited scope of application and incomplete evaluation results. Yang Kang et al. (2015)[4] used the multi-attribute index enterprise importance evaluation model and the supply chain network risk comprehensive evaluation model to make more accurate quantitative evaluation of the enterprise comprehensive importance and the supply chain network comprehensive risk. Hu Haiqing et al. (2020)[5] take SMEs in each node of the supply chain network as the researched object, according to the idea of 'resource-structure-behavior-performance', and reveal the mechanism of the relationship capital accumulated by SMEs in the supply chain network to improve their supply chain financing access frequency, and verified the potential regulatory effect of supply chain complexity by constructing a multi-group SEM model. Chi K et al. (2019)[6] studied a supply chain network equilibrium model considering the multi-attribute behavior of decision makers from the perspective of behavioral finance, and constructed an equilibrium model of uncertain SNC. HAM Malik H (2022)[7] propose that it has been an main issue to detect and recognize the influential nodes in any complex network. For controlling over the network, it is an irreplaceable factor. Any information can be spread and stopped in a short span of time by controlling on a network. CC Pan et al. (2022)[8] A quantitative measurement method for the occurrence and potential spread of risks between nodes in petrochemical supply chain enterprise was studied by CC Pan et al. A risk propagation model of the supply chain based on cascading failure process is introduced and carry out simulation experiment of risk propagation to investigate the different model parameters and different risk source enterprises on the communication process by combining with the characteristics of petrochemical supply chain network. Wicaksono T et al. (2022)[9],through knowing customer demand and logical risks in food supply chain, their reseach aims to empolder the application of a quality function deployment methods to increase the ecasticity of the food supply chain. Yuan Y et al. (2022)[10] study proposes a theoretical model, Design/methodology/approach Grounded in the resource-based view (RBV) and signaling theory. Then, use structural equation modeling and interview analysis to test the theoretical model. Zhao Y et al. (2022)[11] develop a game-theoretic model where manufacturers produce goods with a certain level of quality to the retailer at a static or dynamic wholesale prices over two periods. Zeng W (2022)[12] A principal-agent model considering the cost structure between capacity and quality under asymmetric information is proposed by Zen W to solve the supply chain contracting. Fan Jianchang et al.(2023)[13] built a supply chain game model with retailers as the core, and considered the quality cost sharing strategy in advance and the benefit sharing strategy after the event, as well as the corresponding retailer decision-making and Nash bargaining decision-making, and studied the differences of supply chain operation strategies. Campanur A G et al. (2018)[14] analyzes a distribution network design problem for a four-echelon supply chain. Then, proposed a method for linearization of the nonlinear model based on a piecewise linear approximation. The objective function and nonlinear constraints are reexpressed as linear formulations and the original nonlinear problem is transformed into a mixed integer linear programming model. He G et al. (2020)[15] proposed a multicore, correlated, conditional SC model, called a supply chain network (SCN), SCN collaborative evaluation models are discussed including industrial metabolic balance (IMB), enterprise profitability, contract execution ability and information interaction ability, for which IMB is used as the efficiency index of resource coordination of SCN, also as the constraints of the models on system levels. Jiang Y (2019)[16] propose an artificial bee colony algorithm for complex network, which can be processed in parallel to tackle the so-called combinatorial problem.

Therefore, one of the key tasks for enterprise to optimize their quality management system and product quality is to strengthen the management of each node of the enterprise quality chain. Quality chain management is new research filed. Its connotation has become more and more rich with the continuous research of many scholars, but so far there is no clear quality chain network model. Based on this, this research combines the relevant basic theory of quality chain with the complex network model, and proposes a quality chain network model construction method based on multi-attribute weighting. The degree and the intermediate number are combined to comprehensively consider the local and global characteristics of the network to express the network attributes of the node, and then combined with the node's own attribute weighting to represent the connection characteristics of the network. A quality chain network model construction method based on multi-attribute weighting is proposed.

3. Quality chain network characteristics analysis

1) Hierarchy of network

The nodes in the quality chain network have an obvious hierarchical relationship. Based on the supply chain link, the enterprise node quality interaction among five levels of suppliers, manufacturing processors, transportation centers, distributors, and retailers and customers are implemented. The quality of enterprise nodes among the levels interacts with each other. The business relevance level makes decisions according to their actual conditions, and the decisions are adjusted at any time according to the conditions of the upper and lower enterprise nodes.

2) Hierarchy of node attributes

The higher the hierarchical levels of node attributes, the more attribute weights of nodes, which shows that nodes are more important in the network. In the quality chain network, the node attribute represents the network attribute of the quality chain node, and the network attribute represents the position of the node in the network. The physical meaning of the node network attribute can be represented by the degree of the node.

3) Hierarchy of load distribution

In the quality chain network, node loads are different due to different levels of nodes and different organizational positions and performance requirements. In complex networks, node load can be characterized by node intermediate. The node intermediary reflects the importance of the global node of the network. If only the node intermediary is taken as the network attribute of the node, it can only consider the factor that the node has an impact on the network connectivity, but it is difficult to reflect the local characteristics of the network. Therefore, the intermediate number of the node reflects the network attribute of the node, which also has certain shortcomings.

4) Synergy of quality information

In the quality chain network, there are business relationships and quality interactions between the upper and lower levels. There is coordination or synergy between the same level.

4. Quality chain network model based on multi-attribute weighting

4.1 Description of quality chain network model

The use of complex network theory to describe the quality chain network is mainly reflected in the business communication relationship between the various quality chain levels, as well as the interaction between quality elements. Therefore, In the topology of the quality chain network, the business relationship and quality interaction relationship of enterprise nodes at all levels are abstracted and described. In this paper, undirected connected graph is used to represent.

Define node collections in the abstract: $V = \{v_1, v_2, v_3, \ldots, v_n\}$. Node v_i ($i = 1,2,3, \ldots, n$) represents the abstraction of enterprise nodes at all levels in the quality chain network. Abstract edge aggregate (aggregate of abstract edge): $E = \{e_1, e_2, e_3, \ldots, e_n\}$, edge e_i ($i = 1,2,3, \ldots, n$) represents the business and information interaction connection relationship between nodes, which compose network diagram: $G = \{V, E\}$.

The model constructed in this paper is to divide the quality chain nodes into different levels according to the hierarchical characteristics of the quality chain network. For nodes on the same layer, if there is information transfer and business volume transfer between two business nodes, it is considered that these two nodes have a collaborative relationship. For nodes at different levels, if there is information transfer and actual business relationship between two nodes, there is a parent-child relationship between two enterprise nodes. By adding attributes to entities in the quality chain network, the specific information of the relationship between entities can be represented and the collaboration relationship can be depicted. This paper defines the node's own attributes and node network attributes for nodes.

4.1.1 Node's own attributes

The node's own attributes include quality elements and node business related attributes. Their definitions are as follows:

1) Quality elements

The quality element represents the quality element of the node. The quality element represents a measure of the node in the global or local nodes of the quality chain network. The quality element mainly includes five elements of the worker, machine, material, method, environment (4M1E), which forms a five-order weight matrix of the quality element, $QE_i \in [0,1]$, which represents the control ability of the global and local quality nodes.

2) Node business relevance

The premise of collaborative interaction between nodes in the quality chain network is that node businesses are related. The degree of node business relevance is expressed in forming a node business relevance weight matrix. $BR_{ij} \in [0,1]$. The degree of relevance is proportional to the size of the connection probability value, indicating that the business relationship between enterprise entities is irrelevant, $BR_{ij} = 1$ indicating that the degree of relevance is the highest. In the quality chain network, the correlation degree of business transfer belonging to the same level and different enterprise nodes is also between [0,1], and the weight value is related to the level of enterprise nodes in the quality chain network and the internal structure of the quality chain network.

4.1.2 Network attributes of nodes

The quality chain network edge connection is closely related to the node's own attributes and network attributes. Among them, the physical definition of network attribute is the richness of combat resources, which represents the role of nodes in the network. In modeling, the network attribute of nodes is usually measured by the connectivity of nodes in the network.

$$a_{ij} = \frac{K_i}{\sum K_i} \quad (1)$$

1) Node degree

The degree of a node is equal to the total number of connected edges of nodes in the network graph, which is recorded as. The heterogeneity of the quality chain network will inevitably lead to uneven distribution of node degrees. To some extent, the node degree can be used as the basis for its importance in the network.

$$a_{ij} = \begin{cases} = 1, \text{Node i and j are connected} \\ = 0, \text{Node i and j are not connected} \end{cases} \quad (2)$$

2) Intermediate number

The intermediate number is an indicator that describes the important of a node based on the number of shortest paths through a node. The intermediate number of nodes in the quality chain network can reflect the quality information flow ability between nodes, reflect the role of nodes in the whole network, and is an indicator to depict the influence of nodes in the network as a whole. The larger the intermediate number of nodes, the more quality information flows through the node, that is, the greater the influence of nodes in the network.

$$B_j = \sum_{i \neq j \neq l} \frac{N_{il}^j}{N_{il}} \quad (3)$$

Where N_{il} represents the number of shortest paths from node v_i to node v_l, and N_{il}^j represents the number of shortest paths passing through the node v_j among the shortest paths from node v_i to node v_l.

3) Network Attribute Combining Node Degree and Intermediate Number

The understanding of the network should not only focus on the overall situation, find the overall law, but also pay attention to the local characteristics, both of which are important for the construction of the quality chain network model. Node degree can only reflect the importance of local network node. If only the node degree is used as the edge connection strategy, the nodes in the quality chain network with low degree but great impact on the whole network will be ignored. The node intermediate number reflects the importance of the global network node. It can only consider the impact of the node on the network connectivity, and it is difficult to reflect the local characteristics of the network. Therefore, when modeling the network, this paper considers both local and global aspects of the network, and comprehensively considers the two indicators of node degree and intermediate number, and proposes a quality chain network edge connection method based on the combination of node degree and intermediate number. The node importance is defined as follows:

$$DB_j = \partial \frac{K_j}{\sum K} + (1-\partial) B_j \quad (4)$$

Wherein, K_j represents the degree of nodes j in the quality chain network, $\sum K$ represents the sum of degrees of all nodes, B_j represents the intermediate number of nodes j, ∂ is an adjustable parameter, and the value range is $0 \leq \partial \leq 1$. Node degree can be seen as the business interaction relationship between other nodes. The higher the node degree, the more important the node is in the local network. For a node with a higher intermediate number, the number of times the shortest path in the network passes through this node is more, which means that it is easier to reach other nodes from this node. It can be seen that this node has relatively high significance and value for the network as a whole. The local and global characteristics of nodes in the network are comprehensively considered, and two important indicators, node degree and intermediate number, are used as the basis for modeling node network attributes in the quality chain network.

4.2 Evolution of quality chain network model based on multi-attribute weighting

Considering the multi-attribute characteristics of the nodes in the quality chain network. This paper proposes a multi-attribute weighted edge connection strategy. The attributes of the nodes comprehensively consider the impact of their attributes such as quality elements and business relevance on the generation of dynamic connections. (In the edge connection strategy, the impact of node attributes such as quality elements and business relevance on the generation of dynamic connections is comprehensively considered.) The probability of node v_i to node v_j connection is P_1, and its expression is.

$$P_1 = \frac{QE_i \cdot BR_{ij}}{\sum QE_i \cdot BR_{ij}} \quad (5)$$

In the edge connection strategy, the network attribute of the node comprehensively considers the degree and intermediary of the node. The connection probability P_2 represents the influence of the network attribute of the node on the generation of dynamic connection, and its expression is.

$$P_2 = \frac{DB_j}{\sum DB_j} \quad (6)$$

Wherein, DB_j is the node importance of nodes in the quality chain network, which $\sum DB_j$ is the sum of the node importance.

To sum up, the expression of side connection strategy method of quality chain network model based on multi-attribute weighting is P_2.

$$P = \beta_1 P_1 + \beta_2 P_2 \quad (7)$$

Wherein, β_1 represents the weight parameters of node attributes, β_2 represents the weight parameters of node network attributes, and $\beta_1 + \beta_2 = 1$

4.3 Quality chain network generation algorithm

In this paper, the BA network structure is taken as the initial network, and the multi-attribute characteristics of nodes in the network are considered. Based on the multi-attribute weighting method, the quality chain network model is constructed. The construction steps are as follows:

1) Initial time: Set m_0 nodes in the network, and the connection mode of points is complete graph.

2) Network growth: Add m nodes and n edges each time, and the final network node size is N.

3) Preferred growth: The increase of connectivity in the network is not necessarily random. It is necessarily to follow the principle of optimization, generate the quality element matrix and node business correlation matrix according to the node's own attributes, and generate the edge connection relationship of nodes.

4) Connection mechanism: Select a node randomly from all nodes except the end node, and the node dynamically connects to another node; The adjacency matrix of the quality chain network is updated after dynamic connection.

The method to judge whether the dynamic connection is possible is P: ① Calculate the probability of the side connection strategy, ② A connection probability is defined to determine whether a node can be connected to other nodes. If the edge connection strategy probability of the node to be connected is less than the connection probability, it can be connected. Otherwise, it cannot be connected.

The dynamic connection process is divided into two steps:

①Judge whether it is connected with nodes at the same level.

②Judge whether it is connected with nodes at the upper and lower levels.

⑸Cycle ⑶-⑷ steps to generate the quality chain network node model.

5. Simulation analysis

In this paper, the software Matlab and Gephi are used to simulate the experiment. Initialize network parameters: the initial number of nodes is $m_0 = 3$, and the connection mode of these three points is complete graph connection. The number of nodes added each time is $m = 2$, the number of edges added each time is $n = 2$. Finally, the total number of nodes in the network is $N = 100$. Based on the BA network connection and dynamically generate the interaction between nodes in quality chain network according to the edge connection probability. As show in Figure 1 Quality chain network topology. For the convenience of simulation and analysis, the relevant parameters of the node's own properties are given in advance: the general damping coefficient in the algorithm is 0.85, so the value in this paper are $\partial = 0.15$, $\beta_1 = 0.3$, $\beta_2 = 0.7$, which is reasonable according to the experiment.

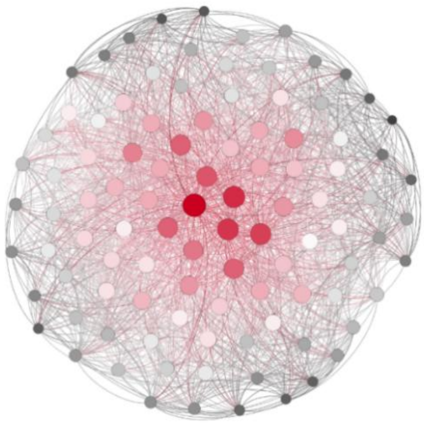

Figure 1. Quality chain network topology

5.1 Scale-free analysis

The node degree distribution obtained from the quality chain network model of the edge connection strategy proposed in this paper is shown in Figure 2, and the node degree probability distribution diagram is shown in Figure 3 From Figure 2, it can be seen that the node degree distribution will deviate from the power-law distribution at the low end and lead to a low-end phenomenon, while at the high end, it can still maintain the consistent with analysis, which is consistent with the empirical data of the quality chain network, indicating that the quality chain network is scale-free network.

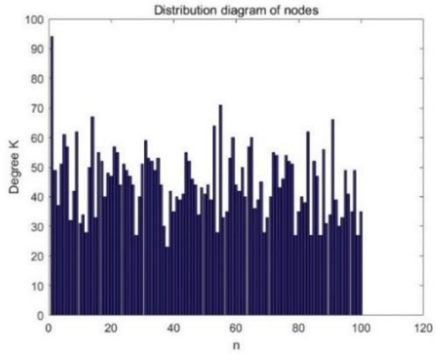

Figure 2. Node degree distribution diagram

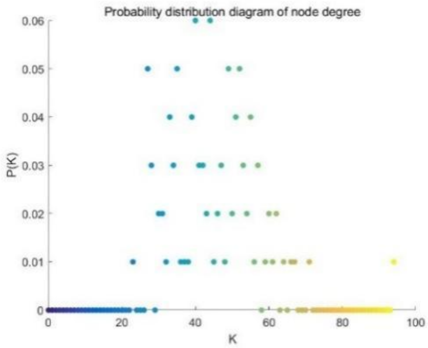

Figure 3. Node degree probability distribution diagram

5.2 Analysis of network node characteristics

When the initial network parameters of the quality chain network are the same and the final network size is the same, and calculate the average path length L and aggregation coefficient C of the network structure generated by different side connection strategies, as shown in Table 1. The network model of random generated priority is shown in Figure 4, the network model of medium priority is shown in Figure 5, and the average path length and aggregation coefficient of the two models are shown in Table 1.

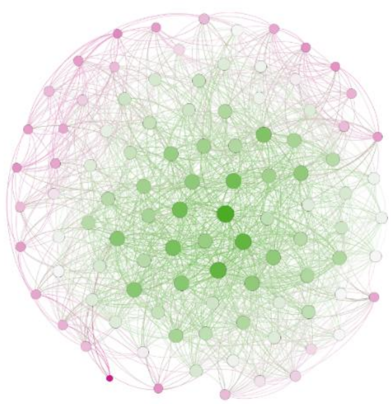

Figure 4. The network model of random generated priority

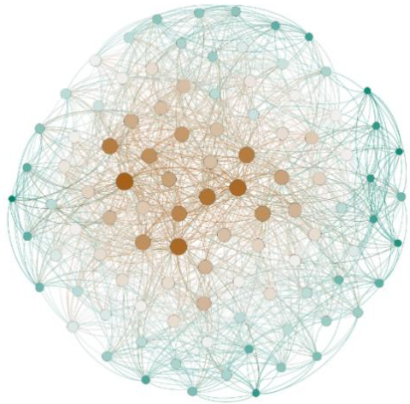

Figure 5. The network model of medium priority

It can be seen from Table 1 that the quality chain network model in this paper is slightly better than the degree-connected network model and the medium network model in the average path length L, but better than the degree-connected network model and the medium network model in the clustering coefficient C. This shows that it is unreasonable to use degree or intermediate number alone to represent network attributes in the quality chain network edge connection strategy, and the evaluation based on degree cannot reflect the difference of node importance. In this paper, the network attribute of the quality chain network model in the edge connection method takes into account the advantages of degree and medium, and takes into account the local and global characteristics of nodes in the network, so it is more reasonable to build the model.

Table 1. Compare L and C of different edge connection strategies

Characteristic Parameter	L	C
Degree-first connection network model	1.750	0.518
Intermediate-first connection network model	1.741	0.521
Quality chain network model	1.548	0.629

5.3 Survivability analysis

When conducting topological analysis of the multi-attribute weighted quality chain network model built in this paper, the survivability analysis is E carried out from the index of network efficiency, whose expression is

$$E = \frac{1}{n(n-1)} \sum_{i,j \in V, i \neq j} \frac{1}{d_{ij}} \quad (8)$$

Wherein $E \in [0,1]$, d_{ij} represents the shortest path between node i and node j. In the simulation experiment under random attack and deliberate attack strategy, the attack intensity is expressed by the number of nodes N in the deleted network. Compared with the network models generated by different side connection strategies, the first connection method is the degree-first connection network model, the second connection method is the betweenness-first network model, and the third connection method is the quality chain network model in this paper.

Where conducting random attacks respectively, the network efficiency E changes with the number of deleted nodes, as shown in Figure 6. It can be seen from the Figure that the network efficiency of the three models decreases slowly from 0 to 80, and it can be seen that the network efficiency is higher than the other two models. There is a significant difference when the number of attacks is 80-90. The survivability of the quality chain network model in in this paper is better than that of the betweenness priority network model. It shows that the modeling method in this paper has good survivability against random attacks and conforms to the scale-free characteristics of the actual quality chain network.

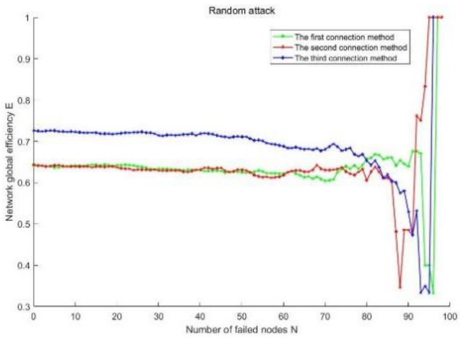

Figure 6. Comparison of three connection strategies under random attack strategies

There are two strategies for deliberate attacks. The ID strategy means to remove nodes in the order of node degree, as shown in Figure 7 IB strategy means that nodes are removed according to the size of the intermediate number of nodes, as shown in Figure 8.

As shown in Figure 7, from a macro perspective, the three network models under deliberate attack is basically the same. When the number of attacks is 0-70 under the ID strategy, this paper shows better survivability than the other two models. When the number of attacks is 70-100, the survivability of the quality chain network model in this paper is between the survivability of the other two models. Under the IB strategy, As shown in Figure 8, when the number of attacks is 0-90, the quality chain network model in this paper shows better survivability than the other two models. When the number of attacks is 90-100, the quality chain network model in this paper shows poor survivability. The reason is that the multi-attribute characteristics of the network itself and its dynamic optimization method are considered in the modeling algorithm in this paper, so that three is good network survivability and cooperation between nodes. From the microscopic point of view, the quality chain network model in this paper suffers from deliberate attack ID strategy and IB strategy, and performs well in the stage of survivability.

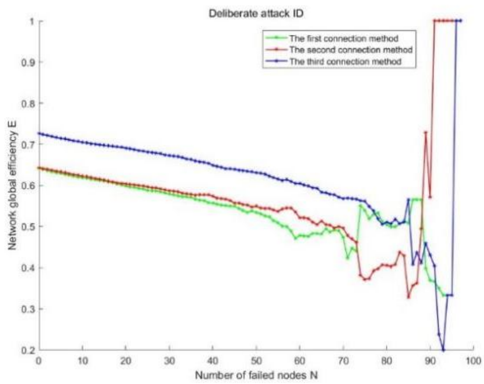

Figure 7. Comparison of three connection strategies under ID attack strategy

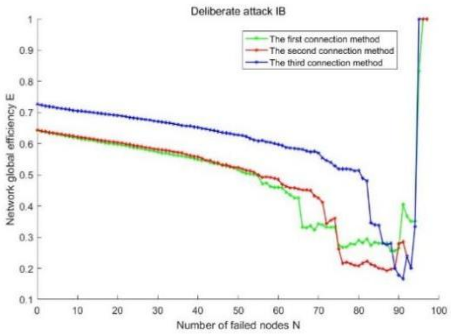

Figure 8. Comparison of three connection strategies under IB attack strategy

6. Conclusion

The quality chain network modeling method based on multi-attribute weighting proposed in this paper comprehensively considers the local and global characteristics of the network, and designs the multi-attribute weighted quality chain network edge connection strategy algorithm by combining the node network attributes with its own attribute weighting, which can be effectively applied to the quality chain network modeling. On the premise of ensuring the feasibility of the algorithm, the model conforms to the practical characteristics of the quality chain network, and has strong survivability, which can provide a reference for the construction of the quality chain network. There are still many deficiencies in the work of this paper. The identification and control of key quality element nodes in the quality chain network model is the focus of the next step, which will be further studied later.

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